Coordination of Mobile Devices: Technology and Standards Scan

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16. Abstract

This document presents the technology scan and standards assessment performed for the U.S. DOT project, *Coordination of Mobile Devices for Connected Vehicle Applications*. This project seeks to develop personal safety and personal mobility messages that complement the existing basic safety and vehicle situation data messages exchanged in the connected vehicle environment by utilizing mobile devices as a message-capable medium, enabling individual users to participate as a connected "person."

This document presents the terminology and scenario development process used to identify and describe the use case scenarios that will be utilized in the concept and design phases of the project; example scenarios are provided to illustrate the range of characteristics each scenario is intended to demonstrate. An overview of relevant communication and connected vehicle technology is then presented to identify which technologies are most capable of supporting these use cases. Finally, a summary of domestic and international industry standards are used to identify which standards are most applicable to incorporating mobile devices into the connected vehicle environment.

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Executive Summary

The connected vehicle environment was envisioned as a means of exchanging messages through a connected vehicle fleet. The majority of the current connected vehicle environment focuses on the *vehicle*, by supporting the exchange of messages from vehicle-to-vehicle (V2V), from vehicle-to-infrastructure (V2I), and from infrastructure-to-vehicle (I2V). These messages are exchanged to communicate safety and mobility-related messages, as a basic safety message (BSM) or a vehicle situation data message (VSM).

This *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.

Specific to this report, the authors present the preliminary results of the structured technology scan and standards assessment in support of the project. This document details the approach used to identify and evaluate the relevant review material, characterize current technologies and relevant solutions in the mobile device market, and identify and summarize relevant domestic and international vehicular and mobile-device messaging standards. Further, this project aims to build a foundation for that research by establishing a baseline understanding of how these protocols might coexist, what challenges in technology and/or standards must be addressed, where gaps in current standards and protocols might delay practical incorporation, and what issues would a dense concentration of these devices incur.

The breadth of potential uses of mobile devices in the connected vehicle environment is vast. To provide the context and focus to the research, a scenario framework, based on real-world use of transportation systems, was developed. This scenario helped describe various travel states an individual traveler would encounter on a typical trip, as well as describing various transitions between coordination points.

The team conducted an extensive literature review, including relevant U.S. DOT research as well as a scan of industry practices and specifications in the mobile device environment. Of particular interest, technologies that supported the wireless communication of information, as well as the ability of the devices to ascertain data and the current travel state of the user (i.e. walking, on a bus, in a bus terminal, etc.). Finally, the team identified and assessed specific relevant work being performed domestically or internationally as it relates to personal safety and mobility messages.

The research conducted in this task, revealed the following:

- Specific personal safety and mobility messages do not presently exist in any robust, industry-wide formats or specifications, neither domestically nor internationally.
- 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.
- 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 SAE J2735:2009 Message Set Standard.
    - Message content should utilize, to the extent possible, the data elements included in the current BSM and the emerging VSM message and others as appropriate, but be tailored to meet the needs of the personal safety and mobility messages
- Device sensors and communication technologies, to include GPS, accelerometers, gyroscopes, proximity sensors, NFC, Wi-Fi, 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.

Chapter 1 Introduction

The connected vehicle environment was envisioned as a means of exchanging messages through a connected vehicle fleet. The majority of the current connected vehicle environment focuses on the *vehicle*, by supporting the exchange of messages from vehicle-to-vehicle (V2V), from vehicle-to-infrastructure (V2I), and from infrastructure-to-vehicle (I2V). These messages are exchanged to communicate safety and mobility-related messages, as a basic safety message (BSM) or a vehicle situation data message (VSM). This project seeks to develop personal safety and personal mobility messages that complement the existing basic safety and vehicle situation data messages exchanged in the connected vehicle environment by utilizing mobile devices as a message-capable medium, enabling individual users to participate as a connected "person." The mobile device, as defined by the U.S. DOT, includes smartphones, tablets, and other hand-held devices that have *their own power source* and are capable of hosting one or more applications.[1] Chapter 3 identifies other devices and technologies considered, such a 'wearable' biometric sensors, carry-in and integrated DSRC devices, Smart Watches, and the Internet of Things, all of which are outside of the scope of this research. Likewise, messages and the corresponding data elements associated with 'environmental' messages, while not explicitly excluded, are also not within the scope of this research.

The U.S. Department of Transportation (U.S. DOT) has conducted significant research on the use of Dedicated Short Range Communications (DSRC) to transmit low-latency information between vehicles and infrastructure. Additionally, and more recently, the communication technologies considered to support in-vehicle and infrastructure systems has expanded to include wireless mobile communication technologies such as 3G and LTE, and to a limited degree, wireless fidelity (Wi-Fi) and Bluetooth technologies. While the research and testing continues in these areas, the general interactions and coordination of these systems is generally understood and functions as expected. What has not yet been explored in earnest are the benefits and impacts of expanding this connected vehicle network to include interactions with individually-carried personal mobile devices. This project aims to build a foundation for that research by establishing a baseline understanding of how these protocols might coexist, what challenges in technology and/or standards must be addressed, where gaps in current standards and protocols might delay practical incorporation, and what issues would a dense concentration of these devices incur.

The purpose of this document is to present the preliminary results of the structured technology scan and standards assessment in support of the *Coordination for Mobile Devices for Connected Vehicle Applications* project. This document details the approach used to identify and evaluate the relevant review material, characterize current technologies and relevant solutions in the mobile device market, and identify and summarize relevant domestic and international vehicular and mobile-device messaging standards.

[1] From U.S. DOT Final Report "*AMS Testbed Requirements for DMA and ATDM Programs*", produced by Noblis, dated April 5, 2013

Assessment of the current state of the technologies, standards, and communication mechanisms was completed through a number of different activities including:

- Stakeholder Engagement (Chapter 2)
- Technology Scan/Literature Review, including discussion on ‘other’ technologies considered (Chapter 3)
- Review of Relevant Connected Vehicle Program Research (Chapter 3)
- Review of Relevant Standards (Chapter 4).

The following sections summarize the research of each of these activities.

Chapter 2 Stakeholder Engagement

One important resource for gathering information on the current state of technology, communications protocols, and standards, is to identify and solicit information from key stakeholders that are engaged in activities related to mobile devices. As summarized in a separate report,[2] the engagement of these stakeholders was intended to be conducted as part of a technology scan to ensure that technologies, standards, and other relevant materials were not inadvertently excluded from the findings. As such, the focus of the engagement of these subject matter experts was to obtain feedback on current technologies and standards relevant to the coordinated and uncoordinated use of mobile devices in the connected vehicle environment.

One of the early findings that became apparent fairly quickly in the engagement process was a general confusion and lack of clarity as to the nature of “coordinated” and “uncoordinated” use of mobile devices in the connected vehicle environment and the nature and points in time throughout a typical trip where such coordination between devices would (or could) occur. Also, there were significant barriers and challenges associated with differences in terminology that could create additional confusion among stakeholders. To overcome these challenges and to provide perspective to stakeholders so that feedback for the project team could be obtained, it was determined that a framework that placed the type of information needed into a context of a “typical trip” or a “workday travel scenario,” where a traveler made a multi-modal trip into work from their home. Along with this scenario, a common glossary of terms was developed to present this and future scenarios in a consistent fashion. This framework and glossary of terms was developed by the project team in coordination with the U.S. DOT staff and a limited set of subject matter experts. The following summarizes the developed framework that will be used in subsequent research activities to solicit feedback from a larger Stakeholder group.

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 all three have mobile devices that are broadcasting a “personal probe” message. Without coordination, this would result in duplication of messages potentially overtaxing the communications system. Alternatively, under a coordinated perspective, these three travelers and the vehicle would synchronize or coordinate the release of information from these different sources into a single message. In abstraction, the concept of real-time interaction and coordination between devices to streamline the information flow proved to be a challenging concept to understand and convey. As a result, a travel scenario framework was developed so that the instances where these coordination activities would be conducted by various devices could be highlighted and considered. This framework provides a summary of major activities/actions that occur with a specific travel state/mode of travel (rows of Figure 2-1) at three phases of the trip segment; the “Beginning,” “En Route,” and at the “End” of the segment (as denoted by the columns of Figure 2-1). Activities/actions where some type of coordination of mobile devices would or could occur are indicated by a gold-colored box. A description of the specific type or nature

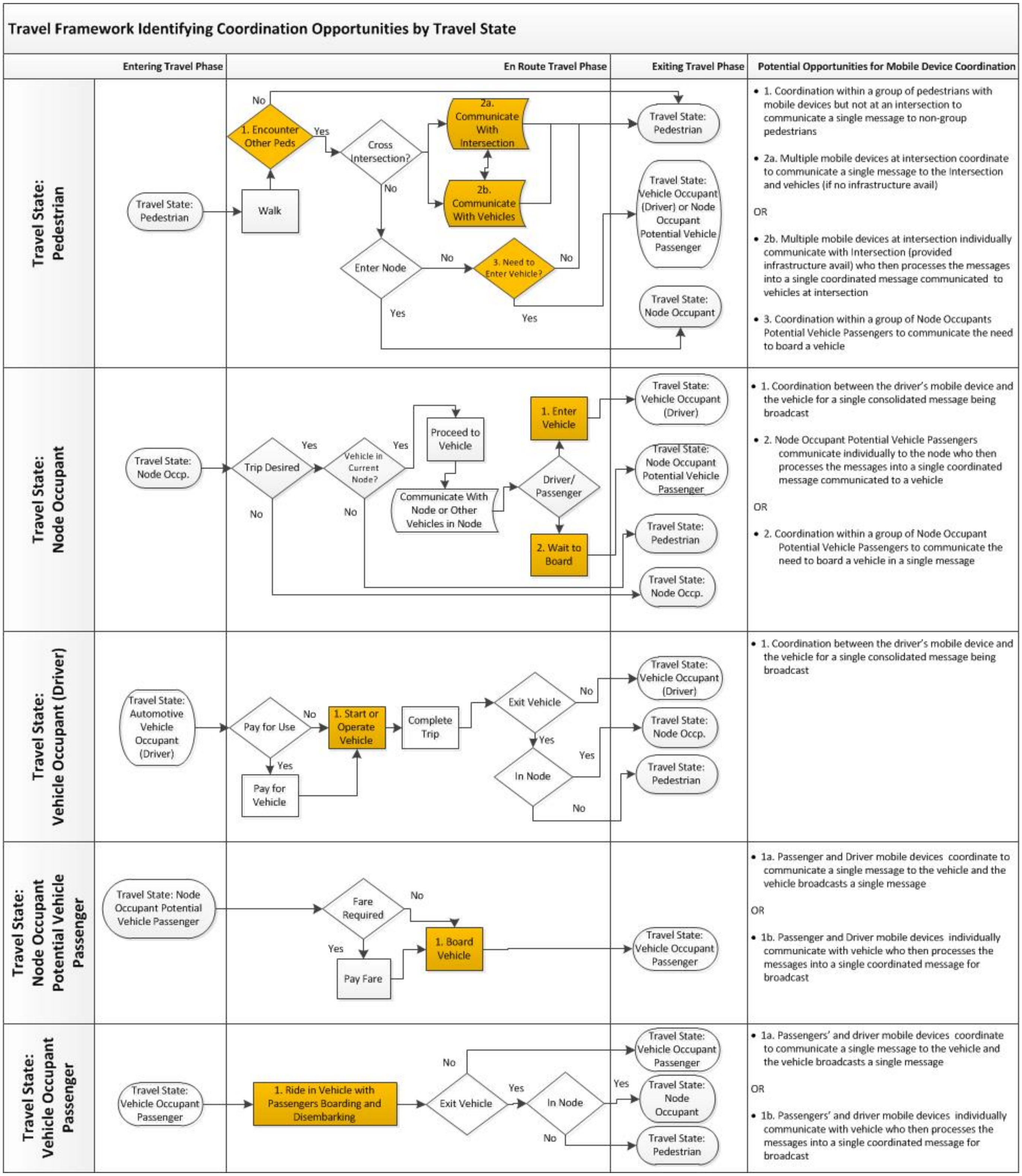
[2] *Stakeholder List, Outreach and Engagement Plan*, December 17, 2014. Produced for U.S. DOT by Battelle Memorial Institute.

of the coordination that would occur at each instantiation of a gold-box is summarized in the final column. In turn, the type, nature, and implementation methodology for the coordination provides a connection to the types of technologies, standards, and communication protocols that need to be examined to determine if they can act harmoniously or if there are inconsistencies that would prevent such coordination of communication.

The travel framework (Figure 2-1) provides a context to understand the potential coordination opportunities for mobile devices and can be used to generate (by combining multiple rows) specific trip scenarios to provide an end-to-end perspective for all of the various potential coordination points in a given trip. For example, the following scenario can be expressed (see Figure 2-2) by combining rows and elements presented in Figure 2-1:

- Two persons living together leave their house and walk to a community bus stop at the end of their street.
- At the bus stop, they meet another neighbor who is waiting for the bus.
- When the bus arrives, they all board the bus and ride it to the central bus station.

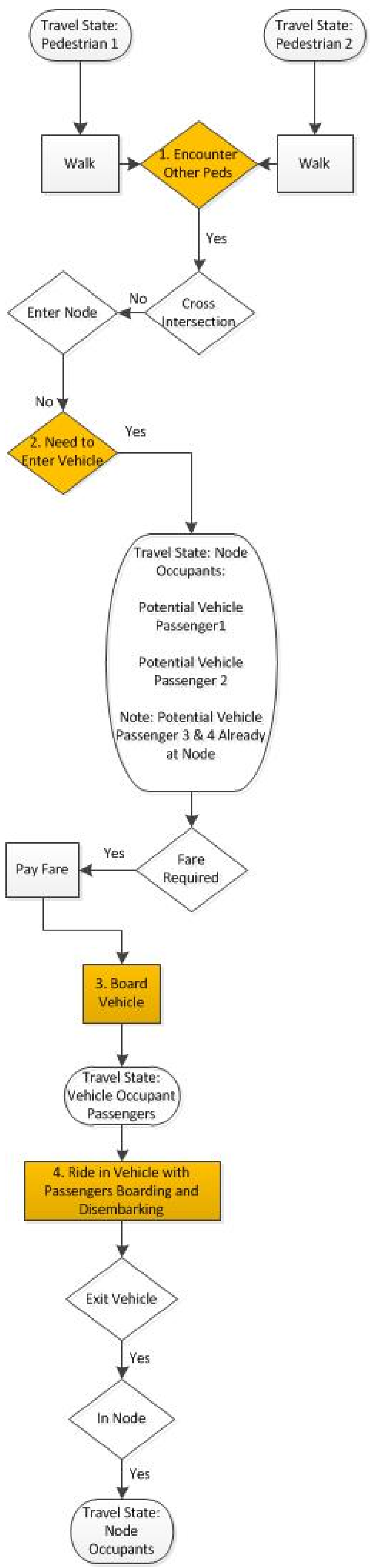
Definitions for the terms used in this diagram can be found later in Chapter 2.



Source: Battelle

Figure 2-1. Travel Framework Identifying Coordination Opportunities by Travel State.

As illustrated in Figure 2-2, in this simple scenario, there would be four opportunities for mobile devices to be coordinated:



1. When the two people leave their house, they are in a "Travel State: Pedestrian." They would immediately "encounter" each other, which would serve as the first opportunity for their mobile devices to coordinate. In this case, the two person's mobile devices could exchange information and determine that since they meet a predefined criteria such as both belonging to family members, only one of the two mobile devices need to broadcast a personal safety message (PSM) or a personal mobility message (PMM). These two mobile devices will have "coordinated" their information and begin to broadcast as a unit rather than as two separate mobile devices. The 'size' of the region protected will be expanded, and as long as the pedestrian remain coordinated and within the radius of the protected region, they will broadcast as one.
2. When the two persons arrive at the bus stop, they encounter the other two potential vehicle passengers. As they all have a need for the bus service, and they are located at a known bus stop, their four mobile devices coordinate information between them and begin to broadcast a single message informing the bus that there are four passengers awaiting pickup (or other message). Alternatively, if the bus stop is a "connected stop" with an inherent communications connection, the four mobile devices could all broadcast individual messages to the bus stop, which then combines these individual messages into a single message to the on-coming bus or on-coming vehicles.
3. After the bus arrives and the four individuals pay the fare and board the bus, their mobile devices could coordinate with the other passengers' devices, the transit operator, and the transit vehicle itself. This could occur through each mobile device coordinating among themselves and determining that only one device would communicate to the transit vehicle that would then send BSM and Probe Messages to other vehicles, infrastructure components, and pedestrians. Alternatively, each of the mobile devices could communicate individually with the transit vehicle that then assimilates the information into a single message for broadcast to other vehicles, infrastructure, and pedestrians.
4. As the passengers continue to ride the bus, they need to coordinate (and cease to coordinate) with passengers and the transit vehicle.

Source: Battelle

Figure 2-2. Example of Using the Travel Framework to Express a Two-Person Transit Trip

It needs to be recognized that travelers have to make many decisions about their travel including mode, time of day, etc. As such, the trip segment chains that can be formed by combining the elements of the Travel Framework can quickly grow to a nearly infinite number of potential travel combinations when multiple travelers are considered. Generally, we have identified a set of other characteristics of a trip that impact these travel choices, which in turn, influences the number and nature of the potential instances when mobile devices could be coordinated. These characteristics can be separated into five primary groupings consisting of travel state, traveler mobility, traveler safety, transportation system, and message type characteristics (see Figure 2-3). These terms are further defined on the following pages.

Travel State

Vehicle Occupant	Node Occupant	Pedestrian

Traveler Mobility Characteristics

Schedule Type	Mobility Level	
• Schedule Restricted • Unscheduled	• Mobility Impaired • No Mobility Restrictions	
• Schedule Restricted • Unscheduled	• Mobility Impaired • No Mobility Restrictions	

Traveler Safety Characteristics

Physical Location Relative to a Conflict Zone	Level of Personal Protection	Situational Urgency
• Within a Conflict Zone • Outside a Conflict Zone	• Traveler Protected • Traveler Unprotected	• Safety • Mobility

Node/Link Characteristics

Mode Ownership	Schedule Type	Occupancy
• Private Personal Vehicle • Public Vehicle • Shared Personal Vehicle	• Scheduled • Unscheduled	• Vehicle Capacity • Number of Travelers • Storage Availability
Fare Payment	**Mobility Access**	
• None • Ticket • Tap-On/Tap-Off	• Accessible for Travelers with Disabilities • Non-accessible	

Message Characteristics

Message Type	Technology Type	
• Safety Message • Mobility Message	• DSRC • Mobile Network (cellular)	• Bluetooth/Wi-Fi

Source: Battelle

Figure 2-3. Summary of Characteristics Related to Travel Choices That Can Be Used to Define Scenarios Where Coordination of Mobile Devices may be needed.

The following provides additional information on each of the five groups of characteristics.

Travel State

Travel state describes the orientation of a traveler with respect to both vehicles and structure types. A specific designation applies to each phase of the trip chain (node or link) from origin to destination. A link is a phase in which the traveler is in transit. A node is a phase in which the traveler is located at a transition point, such as a bus stop or train station. The following travel states have been identified:

Vehicle Occupant	The state of traveling within any mode (with the exception of pedestrian).
Node Occupant	The state in which a traveler is enclosed within a structure and protected from vehicular travel. This includes an origin, destination, or transfer point between any two vehicle types within a trip chain (such as a train station or bus stop).
Pedestrian	The state in which a traveler is traveling by foot, contained by neither a vehicle nor a structure.

Traveler Mobility Characteristics

Traveler mobility characteristics describe mobility restrictions unique to a traveler that are typically unchanged throughout an entire trip chain. They do not vary with time, mode, or location. For example, a weekday commuter who requires a wheelchair will experience the same limitations throughout an entire trip. Traveler mobility attributes do, however, impact traveler decisions within a trip by determining mode and time choices. Traveler mobility attributes include the following:

Schedule Type	*Schedule Restricted*	A traveler with a schedule-restricted trip is dependent upon an on-time arrival, such as a commute; travel time reliability plays a key role in departure time and mode choice.
	Unscheduled	A traveler with a non-schedule restricted trip, such as a recreational trip; such a traveler is not dependent upon an on-time arrival, allowing for a greater range of travel choices and a more flexible departure time.
Mobility Level	*Requires additional disability services*	A traveler with mobility restrictions, such limited motor function or vision impairment, will be limited to modes of travel and transfer points that can accommodate his or her disability(ies).
	Does not require additional disability services	A traveler without mobility restrictions can make trip decisions without this consideration.

Traveler Safety Characteristics

Traveler safety characteristics describe the safety characteristics experienced by a traveler at each moment in time during a trip. These characteristics can vary both between nodes/links and within them. For example, a traveler on foot might experience varying levels of exposure to vehicles (i.e. in a crosswalk vs. on a sidewalk), even though the traveler remains a pedestrian for the duration of the trip. Traveler safety attributes include the following:

Physical Location Relative to a Conflict Zone	*Within a Conflict Zone*	A traveler is located within the zone of vehicular travel where a vehicle-pedestrian collision could occur, such as a crosswalk or parking lot.
	Outside a Conflict Zone	A traveler is located outside of a vehicular travel zone where vehicle-pedestrian collisions are extremely unlikely, such as an office building or sidewalk.
Level of Personal Protection	*Traveler Protected*	A traveler is contained within a building or vehicle, which offers protection from a potential vehicle collection.
	Traveler Unprotected	A traveler is unprotected from potential of a vehicle collision.
Situational Urgency	*Safety*	Safety concerns are considered to be an urgent priority necessitating immediate action. Transmittal by means of a low latency message is required to ensure adequate reaction time.
	Mobility	Mobility concerns are less urgent in nature, allowing for transmittal by any available means of communication.

Transportation System Characteristics

Transportation System characteristics describe the characteristics that pertain to each "node" (a phase in which the traveler is located at a transition point) and "link" (a phase in which the traveler is in transit) within a trip chain. These attributes can vary both between nodes/links and within them. For example, a traveler by bus may experience varying degrees of bus occupancy between trip links. Node/link attributes include the following:

Mode Ownership	*Private Personal Vehicle*	A privately owned vehicle, such as a personal automobile or bicycle, which affords its user the flexibility to start and end trips whenever it is convenient and wherever there is capacity for the vehicle type.
	Public Vehicle	A public agency owned vehicle, such as a transit bus or commuter rail, which runs on a set schedule, restricting user flexibility and node location.
	Shared Personal Vehicle	A publicly or privately owned vehicle, such as a car share or bike share that is rented for a designated time period. While users have additional flexibility in schedule and route, node location and capacity is limited at certain times.
Schedule Type	*Scheduled*	A mode that runs on a set schedule or timetable, restricting the flexibility of users dependent upon an on-time arrival.
	Unscheduled	A demand-responsive mode that operates based on the needs of an individual user.
Occupancy	*Vehicle Capacity*	The total number of travelers a specific vehicle can carry.
	Number of Travelers	The current number of travelers a vehicle is carrying.
	Storage Availability	The capacity for a vehicle to accommodate ancillary travel devices, such as bicycles or wheelchairs.
Fare Payment	*None*	A mode that is designated as free or does not require fare payment, such as a personal vehicle.
	Ticket	A mode that requires the purchase of a fare (either before or after boarding the vehicle), such as a bus or commuter rail.
	Tap-On/Tap-Off	A mode that requires the purchase of a fare prior to entering the station or boarding the vehicle, and a second time in order to exit the vehicle or station.
Mobility Access	*Accessible for Travelers with Disabilities*	A mode that provides facilities for people with disabilities, such as wheelchair lifts and priority seating.
	Non-accessible	A mode that does not accommodate use by disabled travelers.

Message Characteristics

Traveler mobility, traveler safety, and node/link characteristics combine to inform the considerations that will determine the message type appropriate for a given scenario. Like traveler safety and node/link characteristics, message characteristics are unique to a moment in the trip chain and will vary by needs and conditions.

Message Type	*Safety Message*	Safety messages are considered to be high priority. The speed with which safety messages are transmitted necessitates a low latency level, thus limiting the technology that can be used for transmission.
	Mobility Message	Mobility messages are considered to be lower in priority, allowing transmission by a range of technologies from low to high latency.
Communication Technology Type	*Dedicated Short-Range Communications (DSRC)*	DSRC has a short range and low latency, making it the only method currently used to exchange safety messages; DSRC can also be used to exchange mobility messages.
	Mobile Network	Mobile network messages have a wide range and high latency, making the technology ideal for exchanging mobility messages across a wide area such as a metropolitan area.
	Near Field Communication (NFC)	NFC has a very short range (1-2 inches), making it ideal for facilitating payments via a tap-on/tap-off system identified through an NFC tag read for public transportation facilities such as a transit station.
	Bluetooth	Bluetooth has a local range and high latency, making the technology ideal for exchanging mobility messages across a localized area such as a transit station.
	Wi-Fi	Wi-Fi has a short range and high latency, making the technology ideal for exchanging mobility messages across a localized area such as a transit station.

As these characteristics change for each traveler and potentially for each trip, so too will the choices of travel modes and resulting opportunities for coordination of mobile devices. In particular, each gold-colored box in Figure 2-2 is expected to result in at least one type of message, and potentially more as the contextual nature of the characteristics defined above are considered. For example, consider the gold-box in the "Travel State: Node Occupant" row labeled "2. Wait to Board." As described in the figure, there is a coordination opportunity for the mobile devices of the persons waiting to board to coordinate either among themselves or with the node (i.e., bus stop). However, in terms of messages being distributed, this could result in several different types of messages 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.
- 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.

Chapter 3 Technology Scan

This Chapter presents the findings of the technology scan and presents possible sources and mediums for safety and mobility message exchange utilizing mobile devices. Additionally, these same devices will be assessed for their ability to exhibit specific characteristics about their current use state as it supports the identification of a traveler's current state and/or mode. While these findings are extensive, they are not exhaustive of every possible technology that exists today. Each subsection addresses assumptions and boundaries of the research.

There are many components within mobile devices, vehicles, and infrastructure that allow user data to be captured, processed, and communicated. As was discussed in Chapter 2 of this report, a traveler is considered to be in one of three mutually exclusive states: a vehicle, a node, or as a pedestrian. The ability to differentiate between these states is important in the context of coordinating and broadcasting messages. Sensor data and communication device connection data being captured can be used to infer the current travel state, when state transitions occur, and to communicate this information among other devices, vehicles, and infrastructure.

Mobile Device Communication and Sensor Technologies

Mobile Devices of Interest	
Google (Android)	**Apple (iOS)**
• Samsung Galaxy SIII • Samsung Galaxy S4 • Samsung Galaxy S5	• iPhone 5 • iPhone 5s • iPhone 6/6 Plus

Given the nature of this project, it is important to assess the characteristics of communications technologies and sensors that currently exist in mobile devices. Because it would be impractical to list out specifications for every manufacturer and associated model, it is assumed that mobile devices that currently possess the greatest market share will continue to reflect the communications technologies and sensors that are or can be utilized by a large portion of device users. The Apple iPhone (iOS-based) and devices based on Google's Android operating system made up over 95 percent of the domestic mobile device market share as of the end of 2014 (iOS: 20 percent, Android, 77 percent).[3] While Apple manufactures all mobile devices running on iOS, Samsung manufactures the majority of devices running on Android. Data shows that the most popular Apple-manufactured devices since 2012 include: the iPhone 5; the iPhone 5s; and the iPhone 6/6 Plus. (Note: At the time the cited article was published, the iPhone 6 / 6 Plus was rapidly gaining device-share among iOS devices. Although not in the top three iOS devices as of October 2014, given its adoption rate, it will likely eventually outpace use of other iOS devices).[4] The most popular mobile devices manufactured by Samsung include: the Samsung Galaxy SIII, the Samsung Galaxy S4, and the Samsung Galaxy S5.[5] While there is no certainty regarding which communications components and sensors will be included

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

[4] "More iPhone 6's being sold, but iPhone 6 Plus shows stronger user engagement." Localytics. October 20, 2014. http://info.localytics.com/blog/more-iphone-6%E2%80%99s-being-sold-but-iphone-6-shows-stronger-user-engagement

[5] http://www.appbrain.com/stats/top-android-phones

in future mobile devices, these representative devices should provide a starting point from which assumptions can be made regarding the capabilities of current mobile devices.

As will be detailed in the following subsections, components from these six mobile devices are assessed showing which communications technologies and sensors are available to be utilized to establish the personal mobility state, determine appropriate times for coordination, and to transmit and receive mobility and safety-related messages tailored for the specific, current state.

Mobile Device Communications Technologies

Of the mobile devices researched, the communications devices that could be leveraged include Bluetooth, Wi-Fi, NFC, DSRC, and the mobile device cellular network. These communications technologies can be leveraged in two different ways. First, communications technologies can be used to send raw sensor data or processed sensor data to operators or other users of the network. Second, the ability for devices to communicate allows a device to recognize when it is in the presence of another device – which can be utilized (in addition to sensor data) to infer travel state. While these communications by themselves can provide a great deal of information, additional benefit is derived from the fact that they are all contained within a single mobile device and can be attributed to a single user of the transportation system. Table 3-1 provides a high-level overview of key components of each technology.

Table 3-1. Mobile Device Communication Technology Overview.

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) 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
Wi-Fi	• Supports Infrastructure and Ad-Hoc Modes • Unique device identifiers may be obtained without a Wi-Fi 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.
DSRC	• Low-latency, high-reliability • Specifically designed for vehicular environment • Not currently available on mobile devices.
Mobile Network	• Providers have network API features that may be used to obtain location information; terminal status; and service provider.

Source: Battelle

While the protocols and use cases of Bluetooth and Wi-Fi are very distinct, they could be leveraged in similar ways. Both Bluetooth and Wi-Fi can be used to send data, either collected from the device's sensors, or from user input, to transportation operators and other users. Furthermore, unique device identifiers, such as a media access control (MAC) address or service set identifier (SSID) can be obtained even if there is not an active Wi-Fi or Bluetooth connection. Bluetooth beacons and Wi-Fi devices on vehicles such as a car or bus is one consideration that may facilitate the identification of a traveler carrying a mobile device within the confines of the vehicle. The mobile device's Bluetooth or Wi-Fi device; however, must be enabled for detection. All of the assessed devices utilize Bluetooth Version 4.0. Bluetooth is further divided up into three classes. Class 1 devices use the most power, and can transmit a signal up to 100 meters. Class 2 devices use less power and transmit a signal up to 30 meters, and Class 3 devices can transmit signals around a few meters.[6] Bluetooth transmitters in mobile devices tend to be Class 2 devices.

[6] "Top Android Phones." AppBrain. Stats. Updated April 2, 2015. http://www.appbrain.com/stats/top-android-phones

One of the more recent advances in Bluetooth is Bluetooth Low Energy (BLE), which uses an extremely small amount of energy in order to broadcast a short-range (typically a few meters) Bluetooth signal. Standard coin cell batteries are able power BLE devices for years. This allows the technology to be applied in small devices such as pedometers, glucose monitors, and beacons.[7] Currently, beacons are predominately used to interact with or advertise to Bluetooth-enabled mobile device users (who opt in).[8] However, a device could potentially be used to detect when a beacon (or another Bluetooth device) is within its range, and the relative strength of the signal could be assessed to estimate the distance between the mobile device and the beacon. Such a capability could be utilized to gauge whether a traveler is inside of a public transit vehicle or has left the vehicle, or to assess a traveler's location in an urban environment where GPS signal may not be as reliable.

Wi-Fi, which for purposes of this analysis, refers to the IEEE 802.11 set of standards, can communicate at distances reaching over 1500 ft. and at speed approach 54 Mbps. A recent enhancement to Wi-Fi is MIMO. MIMO (or multiple input, multiple output) is a Wi-Fi and mobile signal antenna technology where multiple antennas are used to transmit data to a device. Advantages include the ability to transmit data more rapidly, and reduce the likelihood of impacts due to obstructions, which result in signal fading, cut-out, and intermittent reception.[9] While multipath interference typically reduces wireless data transfer speeds, MIMO takes advantage of this effect by combining data streams from different paths at different times to increase the ability of the receiver to capture the signal. MIMO is included in all wireless communication technologies defined by IEEE 802.11n and newer, which indicates the technology is present on all Wi-Fi chips in the mobile devices evaluated.[10]

One of the emerging uses of Wi-Fi is to establish "ad-hoc" communications or networks to exchange information and or provide connectivity to the Internet or other networks. One common usage of this technology is to use a Wi-Fi direct connection for streaming of video and/or audio dynamically from a mobile device to a display screen (e.g., television), which is generally characterized as "Miracasting." Other usages include dynamic discovery of Wi-Fi availability or "Wi-Fi Aware" and providing bridging for Wi-Fi networks (i.e., "Wi-Fi Passpoint").

Near Field Communication (NFC) is a short-range communications technology (typically 1-2 inches), when combined with an electronic payment system, is becoming an increasingly accepted method for making payments via mobile devices. NFC technology has only recently become widely available across both Android and iOS smartphones with the release of the iPhone 6 / 6 Plus. However, NFC technology is expected to remain a prevalent component of future mobile devices as significant investments by mobile device providers in applications such as Google Wallet and Apple Pay (with Passbook), which are designed to facilitate mobile device-based payments continue to occur. Several transit systems had or are currently testing pilot projects to test the feasibility of mobile device-based payments.[11] While there are no examples of a full-scale implementation of an NFC mobile payment solution within the transit community, there is movement and research projects that suggest that this transition will eventually occur. Washington DC's Metro Payment Pilot program is an

[7] "Bluetooth Smart (Low Energy) Technology." Bluetooth® Developer Portal. https://developer.bluetooth.org/TechnologyOverview/Pages/BLE.aspx

[8] "Bluetooth Beacons." http://bluetoothbeacons.com/

[9] "MIMO (multiple input, multiple output). TechTarget. http://searchmobilecomputing.techtarget.com/definition/MIMO

[10] "Wireless Networking: What is Multiple-Input, Multiple-Output (MIMO)?" Intel. http://www.intel.com/support/wireless/sb/cs-025345.htm

[11] "Payment Pilot" WMATA Metro. http://paymentpilot.wmata.com/about/ and "Tap Ride." NJ Transit. http://www.njtransit.com/var/var_servlet.srv?hdnPageAction=TapRideTo

example of an NFC payment system that is expected to eventually replace the current SmartCard system.[12] An individual's transition onto or off of a transit vehicle (for a tap-on/tap-off system) can be identified through an NFC tag read embedded in their mobile device.

Dedicated Short Range Communications (DSRC) is a low-latency, high-reliability, two-way wireless communications tool specifically architected for exchanging messages in a vehicular environment (e.g. when vehicle approaching one-another or approaching a fixed access point at a high rate of speed and having only a limited period of optimal information exchange). Operating in the dedicated 5.9 GHz band, the messages are transmitted vehicle-to-vehicle (V2V) and between vehicles and the infrastructure (V2I). While not a component of today's mobile devices, DSRC has previously been tested in mobile devices from 2007 to 2009 by OKI. OKI integrated DSRC devices into mobile phones to increase safety between DSRC-equipped vehicles and pedestrians carrying DSRC-equipped mobile devices. A DSRC attachment was also developed for non-DSRC phones.[13] The device would alert both pedestrians and drivers of a potentially impending collision.[14] The DSRC radio used consumed 10 mW of power and could send and receive signals up to several hundred meters.[15] In 2013, Honda was able to use a DSRC-enabled mobile device in a similar fashion. A warning was displayed to the driver, and an alert sent to the pedestrian's mobile device when a collision was impending.[16] Device makers are also beginning to support the IEEE 802.11p specification, referred to as Wireless Access in Vehicular Environments (WAVE), alone or in combination with other Wi-Fi and wireless specification. Redpine Signal's pLink module support 802.11p along with 802.11abgn, Bluetooth 4.0 and Zigbee®.[17] Arada Systems is also making an add-on 'backpack' that contains a separate battery-powered DSRC radio that can pair with existing mobile device.[18]

With respect to personal mobility messages, the integration of a DSRC radio into a mobile device would greatly enhance the communications capabilities of mobile devices. With the many benefits that it could provide, as evidenced by the OKI and Honda projects, and the commercial offerings from Redpine Signal and Arada Systems, the inclusion of DSRC in future mobile devices is a plausible scenario that should be given consideration.

There may also be potential for utilizing DSRC for the communication of mobility messages that are generated by a mobile device. This would require information to be transmitted between the mobile device and the DSRC radio installed in a vehicle. In-vehicle DSRC radios are discussed later in this chapter.

[12] "Pay for Metro with your smartphone or watch? Testing starts soon." Metro Payment Pilot. October 14, 2014. http://paymentpilot.wmata.com/pay-for-metro-with-your-smartphone-or-watch-testing-starts-soon/

[13] "World's First DSRC Inter-vehicle Communication Attachment for Mobile Phones. January 8, 2009. http://www.3g.co.uk/PR/Jan2009/Worlds_First_DSRC_Inter-vehicle_Communication_Attachment_for_Mobile_Phones_3G.htm

[14] "DSRC on mobile devices!" Road Talk. July 23, 2008. https://roadtalk.wordpress.com/2008/07/23/dsrc-on-mobile-devices/

[15] "Oki Exhibits DSRC-based Human-vehicle Communication Device." Nikkei Technology. July 23, 2008. http://techon.nikkeibp.co.jp/english/NEWS_EN/20080723/155249/

[16] "Honda Demonstrates Advanced Vehicle-to-Pedestrian and Vehicle-to-Motorcycle Safety Technologies. Honda. August 28, 2013. http://www.honda.com/newsandviews/article.aspx?id=7352-en

[17] RS9113 p-Link Module Family. April 10, 2015. http://www.redpinesignals.us/Modules/Internet_of_Things/p-Link_Family/RS9113-NBZ-D2P.php

[18] Locomate ME (Portable DSRC Unit), April 10, 2015. http://www.aradasystems.com/locomate-me/

Mobile Device Cellular Network (3G, 4G, LTE) can be leveraged to transmit data between the mobile device and other users and transportation service providers. For the purpose of this project, only 3G communications technologies and newer will be considered. It is also common knowledge that different carriers utilize different technology on their mobile networks. When multiple cell towers are visible from a single device, it is possible to triangulate (multilateration) the device's location based on the signal strength from each of the towers. Using this technique may be useful when GPS signal is not available or reliable, and when other communications technologies cannot be established to estimate position. Additionally, mobile network providers, such as Verizon, provide a network API. If the user grants consent, these APIs can be leveraged to perform tasks such as sending text and multi-media messages, and obtaining information about an individual mobile device's location, terminal status (reachable/unreachable), and service provider/carrier.[19] The device's location is either reported as coarse (indicating the location estimate is based off of cell tower triangulation), or precision (GPS trace). The Verizon Location Agent must be installed on the device for precision information to be obtained.[20]

Summary of Communications Devices

Table 3-2 provides a summary of the above discussed communication technology characteristics, and includes some specificity not discussed above, such as the frequency, power consumption, transfer rate and range. This table lists associated standards, frequencies, and maximum data transfer rates for each communication technology. While the majority of these communication technologies could serve as a medium for message dissemination, a trade-off analysis still needs to be performed. This analysis of the benefits and issues of each, including down select will be completed in future tasks associated with this project.

[19] "Supported Verizon Network APIs." Verizon Developer Community http://developer.verizon.com/content/vdc/en/verizon-tools-apis/verizon_apis/network-api/napi_supported_api.html\

[20] "Precision Location Fix Requirements." Verizon Developer Community. http://developer.verizon.com/content/vdc/en/verizon-tools-apis/verizon_apis/network-api-direct-development/napi_technical_resources/napi_techresources_agps_fix.html

Table 3-2. Characteristics of Communication Technologies – Means of Transmission.

Hardware	Latency	Network Standard	Frequency (US)	Power Cons'ption (max)	Max Data Transfer Rate**	Range (unobstructed) ***
Bluetooth						
Bluetooth 4.0	6ms (unconn) 3ms (minimum)	IEEE 802.15.1	2.4-2.485 GHz	~36mA	1 Mbps	100m
Wi-Fi						
Wi-Fi 802.11ac	Unavail.	IEEE 802.11ac	5GHz	~36mA	1300 Mbps	
Wi-Fi 802.11n	Unavail.	IEEE 802.11n	2.412-2.472GHz 5.180-5.825GHz	Unavail.	600 Mbps	820
Wi-Fi 802.11g	Unavail.	IEEE 802.11g	2.412-2.472GHz	Unavail.	54 Mbps	330
Wi-Fi 802.11b	Unavail.	IEEE 802.11b	2.412-2.472GHz	Unavail.	11 Mbps	330
Wi-Fi 802.11a	Unavail.	IEEE 802.11a	5.180-5.825GHz	Unavail.	54 Mbps	100
NFC						
NFC	Low	ISO 13157 ISO 14443	13.56MHz	Unavail.	424kbps	1-2 in.
DSRC						
DSRC*	Very Low	IEEE 1609 IEEE 802.11p	5.85-5.925 GHz	750mW (28.8 dBm)	Unavail.	Unavail.
Mobile Network						
CDMA2000 1xEV-DO (3G)	Unavail.	C.S0024-0 C.S0024-100 C.S0024-200 C.S0024-300 C.S0024-400 C.S0024-500 C.S0024-A C.S0024-B	800/850/1700/1900 MHz	Unavail.	2.5 Mbps (d) 153 kbps (u)	Unavail.
CDMA2000 1xEV-DO Rev-A (3G)	Unavail.			Unavail.	3.1 Mbps (d) 1.8 Mbps (u)	Unavail.
CDMA2000 1xEV-DO Rev-B (3G)	Unavail.			Unavail.	9.3 Mbps (d) 5.4 Mbps (u)	Unavail.
UMTS (WCDMA) (3G)	Unavail.	3GPP – 25 series 3GPP TS 25.101 3GPP TS 25.102	1710-1755 MHz 2110-2155 MHz	Unavail.	384 kbps	Unavail.
HSPA (3G)	Unavail.			Unavail.	14 Mbps (d) 5 Mbps (u)	Unavail.
HSPA+ (3G)	Unavail.			Unavail.	84 Mbps (d) 10.8 Mbps(u)	Unavail.
LTE (3G)	Unavail.	3GPP – 36 series	700,750,800, 850,1700/2100, 1900, 2500, 2600 MHz	Unavail.	300 Mbps (d) 75 Mbps (u)	Unavail.
LTE Advanced* (4G)	Unavail.			Unavail.	1 Gbps	Unavail.

*Not available in current mobile devices

**Typical speeds are much lower, particularly for mobile network communications

***Range varies as a function of the strength of the signal source.

Source: Battelle

Mobile Device Sensor Technologies

A key tenant of being able to successfully coordinate messages and transition between travel states is the belief that each state of travel exhibits a unique set of characteristics. In addition to the various communication technologies available and previously discussed, mobile devices also possess sensors that have the ability to measure a whole host of data, which may be subsequently used to quantify these characteristics and support the identification of the current travel state as well as transitions between states. These sensors can be divided into two categories: hardware and software (virtual). Hardware sensors report raw data from a particular sensor on the device, while software sensors take data from one or more hardware sensors to provide an imputed output. Table 3-3 lists and provides a brief description of the commonly available hardware and software sensors found in the reviewed devices. Detailed discussions of how these sensors may contribute to the goals of this project follow.

Table 3-3. Hardware and Software Mobile Sensor Descriptions.

Mobile Hardware Sensors *(raw data)*	Accelerometer*	Measures the acceleration force on the device along three axes.
	Gyroscope*	Measures the rate of rotation of the device along three axes.
	Magnetometer*	Measures the geomagnetic field surrounding the device along 3 axes.
	Light Sensor*	Measures ambient light.
	Proximity*	Measures the distance between the sensor and a nearby object.
	Thermometer	Measures the temperature of air surrounding the device.
	Hygrometer	Measures the humidity of the air surrounding the device.
	Barometer	Measures the pressure of air surrounding the device.
	Position	Measures latitude, longitude, elevation and time (UTC) and a function of a GPS.
	Microphone*	Capture audio using built-in microphone.
	Camera*	Capture video or still images using built in charge-coupled device, typically both forward and rear-facing.
Mobile Software Sensors *(imputed data)*	Gravity	Estimates the force of gravity along the three axes.
	Linear Acceleration	Estimates the acceleration force of the device along three axes, excluding gravity.
	Rotation Vector*	Describes the orientation of the screen of a mobile device.
	Speed	Output of GPS based on successive collection of lat/long/elav. Points.
	Heading	Output of GPS based on successive collection of lat/long/elav. Points.
	Step Detector/ Counter	Uses accelerometer data to estimate when a step has been taken.

*Commonly found in mobile devices

Source: Battelle

Accelerometer. The acceleration attributes of walking are unique when compared to other modes. During trips in a personal automobile, bus, or train, acceleration data is expected to reflect an output waveform that is fairly flat and lengthy duration, and can easily be distinguished from the high-frequency accelerations of walking. This high-frequency oscillating acceleration can be detected by the accelerometer sensor, and analyzed to detect when a step has been taken – see step detector, below.

Gyroscope. Gyroscopes are used to detect rotational motion along the three axes of the mobile device. When used in combination with data from the accelerometer, gyroscope data can be used to provide more precise estimates of the device's orientation, linear acceleration, and gravity vector – described below.

Light Sensor. The light sensor is usually located on the screen side of a mobile device, and detects brightness of light. One use of this sensor is to automatically adjust the screen brightness to save energy when there is a low amount of ambient light, and to increase brightness to improve visibility under high amounts of ambient light.

Proximity. A proximity sensor is located on the screen side of a mobile device, and measures the distance to the nearest object. Quite often, these sensors are low resolution – only able to detect whether there is an object within 8 cm of the device or not. However, this low resolution works as intended – for turning the screen off when a person moves the phone up to their ear while on a call, and on again when the phone is removed from the ear. It is an event-based sensor, changing in value only when an object moves into or out of range of the sensor.

Thermometer and Hygrometer. The thermometer measures the temperature of the ambient air, and the hygrometer measures the humidity of the ambient air. The thermometer sensor is not the same as the devices that detect the temperature of the processor and battery. Given that the ambient temperature and humidity are measured within a device, both readings have the ability to be affected by heat given off by other mobile device components, sunlight, and/or body heat (if the device is in a pocket, for example).

Barometer readings (unlike thermometer and hygrometer readings) are not affected by mobile device components or being indoors or outdoors. At a given location over several hours, pressure is expected to slowly vary as a result of normal weather patterns while weather fronts may result in more rapid pressure changes over shorter periods of time. However, over a relatively short period of time (the time it takes to go up/down a flight of stairs, or an elevator ride), the barometer in a moving device is accurate enough for detecting relative changes in altitude. Knowledge of the device's altitude could potentially indicate which floor of a building a device is on, or which platform a user is standing on in a transit station with multiple-levels. Such information could be useful for determining whether a user intends to transfer or exit a transit station.

Global Positioning System. Global Positioning Systems (GPS) have become ubiquitous in all present day mobile devices. While technically a communications technology, GPS is better viewed as pseudo-sensor as the device only receives data from the GPS satellites. GPS can provide an estimate of latitude, longitude, and speed of the device, as well as various measures of location reliability, number of satellites, accuracy, position dilution of precision (PDOP), horizontal dilution of precision (HDOP), and vertical dilution of precision (VDOP). Given a reliable GPS signal, a user's location can be used in combination with other spatial characteristics of the transportation network to aid in identifying travel state, as well as identify potential travel alternatives. It is also possible that GPS can be used as a time source for the device, as it is used by DSRC, however most mobile devices continue to use the mobile network to set their time.

Microphone. A necessary component to support audio 'phone' or voice-over-IP conversations, and more recently, voice-commands, a microphone might be employed to listen to and possibly detect an environment in which the mobile device is currently located.

Camera. Sensors (most phones have two) that capture discrete or continuous images (video) in support of many of the features of modern mobile devices such as personal photography/videography, video calling, social media content and code scanning. Cameras have also been used crudely for transportation applications such as lane departure warnings.

Gravity and Linear Acceleration. Both the gravity and linear acceleration sensors are software sensors that utilize data coming from the accelerometer and gyroscope to make reliable estimates regarding the force of gravity along all three axes of the device (even while the device is moving), and the acceleration forces along all three axes, excluding the force of gravity.

Rotation Vector. The rotation vector describes the orientation of the screen of a mobile device. It is a software sensor that utilizes accelerometer and gyroscope data. For example, rotation vectors can be used to change the screen layout from a vertical orientation to a horizontal orientation when the phone is turned sideways.

Speed. Function of GPS that may be suitable for corroborating walk vs. ride modes of a traveler.

Heading. Function of GPS that aid in determining path traveler is taking. When compared to a map of area, this function may be able to determine the location to lane, crosswalk, sidewalk, other.

Step Detector. The step detector is a software sensor that utilizes accelerometer data to detect when a step has been taken. Like the proximity sensor, it is an event-based sensor. When a step is taken, the timestamp of the step is reported.

Table 3-4 provides a summary of the characteristics of the sensors identified during this technology scan, including both the frequency of the measurement, and the cost, in terms of power consumption, to use the sensor. Both of these characteristics are expected to be relevant when the design of the prototype is considered in later tasks, however it is too premature to make any specific design recommendations at this time. As such, this information if presently included for the purposes of complete documentation and for the benefit of future use of this research.

Table 3-4. Characteristics of Communication Technologies – Sensor Types.

	Sensor Type	Max Data Frequency (Hz)	Typical Range	Units	Power Consumption (active)
Hardware Sensors	Accelerometer	100	±19.6133	m/s^2	0.25
	Gyroscope	100	±8.726646	rad/s^2	6.1
	Magnetometer	100	±1200	μT	6.0
	Light Sensor	100	0-60000	lux	0.75
	Proximity^	Event-based	0-8	cm (may vary, low res)	0.75
	Thermometer	1	-30-100	^0C	0.3
	Hygrometer	1	0-100	%	0.3
	Barometer	15	300-1100	mBar (or mmHg)	1.0
Software Sensors	Gravity	100	±19.6133	m/s^2	12.35
	Linear Accel.	100	±19.6133	m/s^2	12.35
	Rotation Vector	100	±1	*none*	12.35
	Step Detector^	Event-Based	N/A	*none*	0.25

^Event based sensors – only change when an event occurs (e.g. step taken)

Source: Battelle

Table 3-5 lists the availability of different hardware sensors in the six mobile devices of interest being used to assess communications technologies. Where possible, the hardware manufacturer and model were identified and listed. Accelerometers, gyroscopes, magnetometers, proximity sensors, and light sensors have been included in mobile devices over the last three years. These five sensors have become an integral component of many of the basic functionalities of mobile devices (e.g. rotating screen, turning screen on/off automatically while on a call, auto-adjust brightness), not to mention the functionalities of certain applications (e.g. games, compass). It is highly likely these sensors will continue to be included in almost all mobile devices.

More recently, barometers, thermometers, and hygrometers have been included on certain mobile devices. Air pressure sensors in phones allow more accurate altitude estimations to be made (compared to GPS), may provide data for crowd-sourced weather applications, and are used in health/fitness apps. The Galaxy S III (May 2012) and the iPhone 6 / 6 Plus (September 2014) are the first generation of phones released by Samsung and Apple (respectively) that contain a barometer. Samsung has continued the inclusion of this sensor on the Galaxy S4 and S5, and announcements indicate a barometer will be included on the Galaxy S6. Apple has not released a phone since the iPhone 6 / 6 Plus, and to date, there has not been no official announcement regarding sensors that will be included in the next offering from Apple.

Table 3-5. Sensor Hardware in Mobile Devices of Interest to this Project*.

Mobile Device	Acc'meter	Gyroscope	Magnetometer	Light Sensor	Proximity Sensor	Ther'meter	Hygrometer	Barometer
Samsung Galaxy S III	STM LSM330DLC	STM LSM330DLC	STM AKM8975	In device *(OEM unknown)*	In device *(OEM unknown)*	No	No	In device *(OEM unknown)*
Samsung Galaxy S 4	STMicroelectronics K330	STMicroelectronics K330	Yamaha YAS532	Capella Microsystems CM3323	MAXIM MAX88920	Sensirion SHTC1	Sensirion SHTC1	Bosch BMP180
Samsung Galaxy S 5	Invensense MPU-6500	Invensense MPU-6500	Yamaha YAS532B	In device *(OEM unknown)*	In device *(OEM unknown)*	No	No	STM LPS25H
Apple iPhone 5	STMicroelectronics LIS331DLH	STMicroelectronics L3G4200D	In device *(OEM unknown)*	In device *(OEM unknown)*	In device *(OEM unknown)*	No	No	No
Apple iPhone 5s	Bosch BMA220	STM	AKM AK8963	In device *(OEM unknown)*	In device *(OEM unknown)*	No	No	No
Apple iPhone 6	InvenSense MP67B Bosch BMA280	InvenSense MP67B	AKM AK8963C	In device *(OEM unknown)*	In device *(OEM unknown)*	No	No	Bosch BMP280

*Where possible, the hardware manufacturer and model were identified and listed

Source: Battelle

While it is impossible to forecast with certainty whether future mobile devices will contain barometers, the evidence presented above suggests they will continue to be included. Thermometer and hygrometer sensors have thus far only been included in the Galaxy S4. These two sensors were discontinued in the Galaxy S5, and the announcement for the Galaxy S6 indicates they will not be included on this model either. None of the iPhone models have these two sensors, nor are there indications Apple intends to include them in the future.

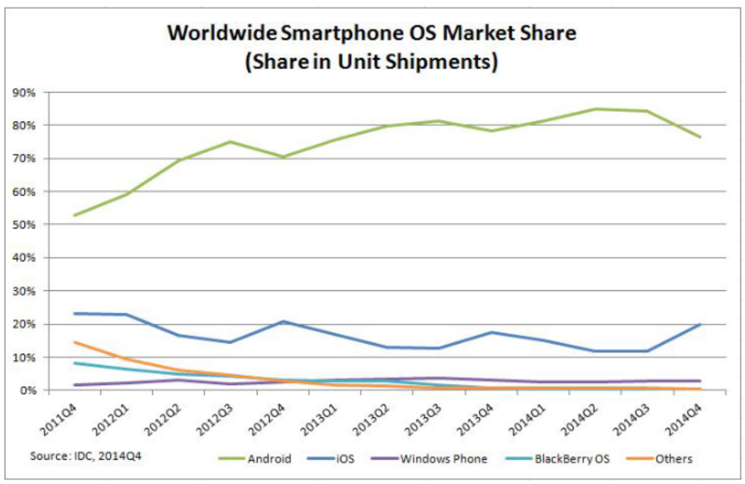
For purposes of this project, attempts will be made to use sensor technology that is available across all reviewed platforms such that the demonstration can show devices from multiple manufacturers and models.

Mobile Device Operating Systems

In addition to the hardware components discussed, the operating system (OS) is the ultimate enabler of the capability of each mobile device, allowing the device to access the sensors and communications components and to execute software applications provided by the device maker, the OS vendor and third-party applications. While several operating systems currently exist, the four major systems found in any significance include:

- Apple iOS;
- Google Android;
- Microsoft Windows Phone; and,
- Blackberry OS.

Based on 2014 end-of-year reports (Q4 CY2014), Android and iOS have maintained the bulk of the market at 77 percent and 20 percent, respectively. Lagging behind is Windows at less than 3 percent, Blackberry at less than 0.4 percent and all others combined at less than 0.5 percent.[21] In addition, Android and iOS market shares are generally trending upward while Windows shares are generally flat and Blackberry shares are generally trending downward (as shown in Figure 3-1). Based on this



Source: http://www.idc.com/prodserv/smartphone-os-market-share.jsp

Figure 3-1. Historic Data Shows Operating System Popularity Trends.

21 "Smartphone OS Market Share, Q4 2014." IDC. http://www.idc.com/prodserv/smartphone-os-market-share.jsp; "iPhone Firmware and iOS History." Abouttech. http://ipod.about.com/od/iphonesoftwareterms/a/firmw_history.htm; "Apple iOS: a brief history." The Telegraph. http://www.telegraph.co.uk/technology/apple/11068420/Apple-iOS-a-brief-history.html; "A look into: The History of iOS and its Features." Hongkaia. http://www.hongkiat.com/blog/ios-history/; "A history of iOS design from iOS 1 to iOS 8." Design Reviver. September 9, 2014. http://designreviver.com/updates/history-ios-design/

historical data, only two device platforms were further considered, the Samsung device running Android and the Apple iPhone devices running iOS.

Software Releases and Fragmentation. Both Android and iOS operating systems are updated on a regular basis, which recently has been roughly once a year between major releases, both operating systems issue minor updates to fix bugs and enhance various features.

This fact is important because with every update, fragmentation may occur. As new software comes out, both providers “leave behind” some of their older systems. Apple closely manages updates to its iOS and associated proprietary data. This results in less fragmentation across the products due to tighter control of both the hardware (as there is only one device manufacturer) and software. Alternatively, Google’s Android is run as open source software. Updates may or may not be supported depending on the mobile device manufacturer and model as well as wireless carrier decisions. As the market drives continued innovation, this trend does not seem likely to change significantly, nor can the true impact of these changes be predicted. As noted herein, Samsung had previously included support for temperature and humidity measurements on the Galaxy S4 platform only to drop this support on subsequent versions. Similarly, iOS revised their previous approach for making background location services available to third-party applications, tightening the rules for the better, but causing a significant amount of older applications to fail when attempting to run on a new version of the OS. These are both highlighted as an example of how industry-trends and the device makers have ultimate control of the future of these devices, a fact that needs to be considered as part of this analysis. Only technologies that have been employed on multiple generations of a device makers products, and hopefully across multiple device makers, will be considered. This information is critical, not only in the determination of which existing sensors to leverage for data in the PSM and PMM, but more so for future development of mobile devices natively supporting ITS endeavors for wide-spread adoption.

Features of the various Operating Systems. Table 3-6 summarizes several of the key ‘applications’ or services provided by each device maker with the latest version of their OS. Detailed discussion on each follows. These specific features are included as they have become a significant part of how people use their device, and several of these could play a role in incorporating these devices into the connected vehicle environment.

Table 3-6. Sample of Software Characteristics and Applications for Latest iOS and Android Systems.

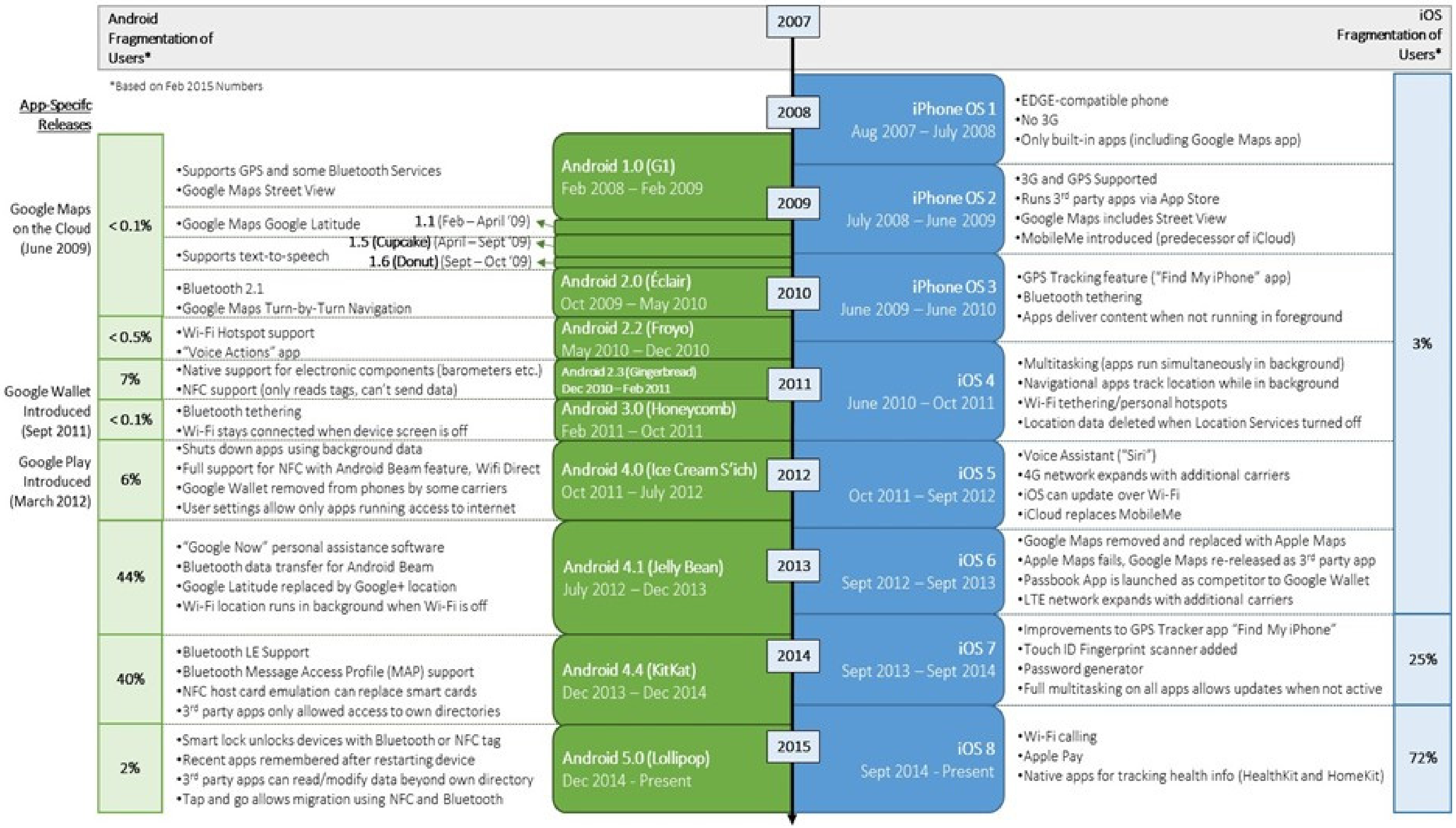
Operating System	Voice Assistant	Maps	Wireless Payment
Android 5 “Lollipop”	Google Now	Google Maps	Google Wallet
iOS8	Siri	Apple Maps	Apple Pay

Source: Battelle

Voice Assistance. Both operating systems have developed voice assistance which provides support in searching and initiating phone operations. Siri (on iOS) is an on-command assistance application. Google Now (on Android) also provides assistance on command. However, it is also designed to gather data on the user to pre-emptively offer information before being asked. Voice Assistance is expected to continue to become more reliable and expand to support even greater capabilities (i.e. commands) in the future.

Maps/Navigation. Both Android and iOS have GPS trackers and turn-by-turn navigational capabilities for pedestrians and motorists. Google Maps was originally a key built-in feature provided with iOS from its inception until Apple removed the native application when it released iOS6. Apple Maps was initially poorly received, resulting in the re-release of Google Maps as a third party application on the App Store. Google has also provided Google Maps as part of Android. Locational information may be controlled by the user on both operating systems. If turned on, both systems are able to track the user whether the screen is on or the app is running. Maps and the associated trip planning are fully expected to play a significant role in the next generation of connected vehicle applications.

Wireless Payment Capabilities. Both Android and iOS have contactless payment applications (*Google Wallet* for Android and *Apple Pay with Passbook* for iOS). Android requires NFC and a passcode while iOS requires NFC and the touch ID Fingerprint Scanner technology. Although both operating systems offer these applications on their latest releases, Apple requires users to have the iPhone 6 / 6 Plus to enable the applications, as these are the only Apple devices that contain NFC technology. In addition to using NFC for contactless payment, the Android Beam service allows users to tap phones to exchange data in the NFC Data Exchange Format (NDEF) and/or to facilitate direct Bluetooth/Wi-Fi connectivity between devices to transfer other types of data. Apple’s AirDrop functions in a similar manner, allowing for direct device-to-device data exchange using either BlueTooth or Wi-Fi Direct.



Source: Battelle

Figure 3-2. A Timeline of the iOS and Android System Features.[22]

[22] "iOS Versions and Features: iOS History – The Evolving iPad/iPhone OS." Abouttech. http://ipad.about.com/od/ipad_details/ss/iOS-Version-History-Features.htm; "A Comparison of mobile operating systems: know your OS." October 24, 2014. https://www.gazelle.com/thehorn/2014/10/24/a-comparison-of-mobile-operating-systems-know-your-os/; "Android" https://www.android.com/intl/en_us/history/; "A Brief History of Google's Android Operating System." IPWatchdog. November 26, 2014. http://www.ipwatchdog.com/2014/11/26/a-brief-history-of-googles-android-operating-system/id=52285/ and "The Android era: From G1 to Lollipop. July 2, 2012. http://www.cnet.com/news/history-of-android/

Mobile Device Applications

There have been few technologies that have experienced such a rapid growth as today's smartphone. These devices allow for tremendous innovation and rollout at unprecedented rates and scale, including applications supporting personal safety, mobility, travel planning, etc. This section presents an overview of available mobile device applications used to enhance the traveler experience within a transportation network. The applications presented are compatible with either the iOS, and/or Android (no other operating systems were considered). They have been included based on their potential to support or complement the exchange of PSM and/or PMM within the connected vehicle environment. While this list is not exhaustive, it is intended to provide a diverse set of applications which may be utilized for enhancing the PSM and PMM in a connected vehicle environment.

Table 3-7 documents several applications that were identified to have some relationship to transportation. For each application, the intended users, the requirements for use, a brief description of the user interface, and a summary of the available data is included. The applications are also grouped by the following categories:

- Navigation/Route Applications
- Multi-Modal Schedule and Location Applications, including fare purchase
- Weather-Based Applications
- Limited-Mobility Assistance Applications
- Ridesharing Applications
- Social Networking.

Table 3-7. Mobility Application Descriptions.

Intended Users	Requirements	User Interface	Data Types
Navigation/Route Applications			
Waze	**Community based dynamic traffic and navigation application edited in real-time by map editor community.** For iOS 6.0 and up, Android 3.2 and up		

Personal Vehicle Drivers
• Does not support navigating in dedicated public transit, bike, or truck lanes
• Does not include sidewalks for pedestrians
	• Active GPS Signal
	• Active Data Connection (GSM/3G/4G)
		Traffic Conditions
		• Purple line – current route
		• Yellow line – light traffic
		• Orange line – moderate traffic
		• Red line – heavy traffic
		• Brown line – standstill traffic
		Alerts
		• Hazards/incidents reported
		• Visual pop-up and sound alert
		Estimated Time of Arrival
		• Estimated time of arrival
		• Minutes remaining based on current traffic
		• Distance remaining based on current route
			Active User Data Reporting:
			• Traffic Jam (moderate, heavy, or standstill traffic)
			• Police (hidden or visible police)
			• Accident (major or minor accident)
			• Road Hazard (on road or shoulder)
			  ○ Road (object on road, construction, pothole, road kill)
			  ○ Shoulder (car stopped, animals, missing sign)
			• Weather Hazard unseen in advance of approach (fog, hail, flood, ice)
			• Camera based on local laws (speed or red-light camera)
			• Road Closure (due to hazard, construction, or event)
			• Real-Time Gas Prices
			Passive User Data Reporting:
			• Locational information (using built-in GPS on mobile device)
			• Average speed along route (using GPS as positional speedometer)
			"Other Side of the Road" Feature:
			• Includes roadside info on highways and split one-way roads

Moves	**Automatically records walking, cycling, and running by mobile device user.** For iOS 7.0 and up, Android 4.0 and up		
Non-Vehicle Users • Pedestrians • Bicyclists	• iOS devices must keep location services on (as application is always running in background)	Map • Provides routes taken on map Activity metrics Distance, duration, steps, and calories burned for each activity	Movement Data • Pedometer (recognizes walking, biking, and running) • Recognizes motorized travel as "transport" Locational Data GPS – used to detect speed and route

Table 3-7. Mobility Application Descriptions (Continued)

Intended Users	Requirements	User Interface	Data Types
Multi-Modal Schedule and Location Applications			
HopStop	**Provides real-time transit information for subway, bus, train, taxi, walking and biking. Currently utilized in 600+ cities.** For iOS 6.0 and up		
Urban Transit Users	• GPS enabled mobile device	Public Transit Information: • Door-to-door directions (with GPS) • Schedules and maps • Nearby stops Taxi Cab Information: • Estimated travel time and cost Bicycle Information: • Directions within metropolitan areas Disability-based Information: Wheelchair accessible routes	User Reported Data • Delays • Crowds • Misc. issues User Travel Preferences: • Set travel preferences (bus, subway, walking, taxi, regional rail, private vehicles etc.)
NextBus	**Provides real-time, dynamic transit arrival and departure time using GPS and proprietary algorithms to track and predict vehicle arrival time. Vehicles may include bus, rail/streetcar, ferry, university fleets, tourist services, and private use.** Available through any mobile device, computer, or telephone information system.		

• Transit Users
• Transit Operators
	• GPS-enabled mobile device (for full functionality)	Transit User Interface:
		• Location Information:
		  ○ Rider's location and nearest stop
		• Alerts:
		  ○ Real-time arrival times (email, SMS, web pop-up)
		  ○ For multiple stops and routes
		  ○ For one-time use or scheduled intervals
		Transit Operator Interface:
		• Management Tools:
		  ○ Schedule Adherence Reports
		  ○ Headway Reports
		  ○ Job/Block Reports
		  ○ Real-Time Map Interface
		  ○ Replay Map
		• NextBus ADA-Based Products Include:
		  ○ Automatic Voice Annunciation System (AVAS)
		  ○ Automatic Passenger Counts (APC)
		ADA-compliance Wayside Signage
			Sources of Information (provided to user):
			• Web-based application available on mobile device
			• Text messaging (by entering agency and stop code)
			• Public API/XML data feeds
			• LED/LCD signs at bus shelters and transit depots
			Data utilized to predict transit arrival and departure times:
			• GPS/AVL Data (current vehicle position at time of calculation)
			• Intended stop
			• Historic travel data and typical traffic patterns
			• Incident information such as accidents, delays, construction
			Data utilized for fleet operations (can be archived):
			• APC Technology (real-time updates)
			  ○ Date and Time
			  ○ Vehicle ID, Route ID, and Driver ID
			  ○ Number of passengers boarding and alighting
			Total count at moment vehicle leaves stop

Table 3-7. Mobility Application Descriptions (Continued)

Intended Users	Requirements	User Interface	Data Types
MBTA mTicket	**Allows Boston area transit users to buy tickets through their mobile devices for commuter rail and ferry trips. May purchase single-ride, round trip, 10-ride, or monthly passes.** For iOS 6.0.1 and up, Android 2.3 and up		
Massachusetts Bay Transportation Authority Commuter Rail and Commuter Boat Users	• Need mobile service to purchase ticket (not needed to display ticket)	<u>Proof of Purchase:</u> • Barcode for conductor to see proof of purchase. (Tickets are purchased prior to boarding). <u>Traveler Information:</u> • Commuter rail schedules, maps, and service alerts	<u>Payment Method:</u> • Credit card or debit card information to buy ticket <u>User Type:</u> • Reduced fare identification for student/senior/disabled users
Ridescout	**Aggregates real-time information for all available public and private transportation options (e.g., transit, bus, bike, taxi, car share, rideshare, parking and walking) allowing user to select mode based on real-time schedules and fares.** For iOS 7.0 and up, Android 4.0 and up		
All travelers	• GPS enabled mobile device	<u>Public Transit Information:</u> • Bus and subway locations • Real-time departure schedules <u>Bikeshare Information:</u> • Bikeshare availability at any station <u>Parking Information</u> • Available parking spots <u>Directions</u> • Walking, biking, and driving directions <u>Alerts</u> • Congestion alerts • On-time arrival • Navigation (step-by-step instructions)	<u>Cross-Modal Scheduling Information:</u> • Options listed by type and departure and arrival time <u>Cross-Modal Costs:</u> • Transit fares and cab estimates listed along with other cost options (i.e., private car)
Weather Based Applications			
PressureNet	**Collects atmospheric pressure measurements from network of crowdsourced weather sensors to improve weather forecasting.** For Android 3.0 and up		
Scientists/researchers to improve accuracy of weather forecasting (data collected through SDK is provided through API)	• To contribute readings, see pressure, and use widget – mobile devices must have barometers.	<u>Providing Data: via PressureNet SDK</u> • Widget to provide current weather conditions (for more accurate, localized conditions) <u>Receiving Data: via PressureNet API</u> • Animations of current conditions • Interactive Google Map with weather graphics • Pressure drop/rise alerts • Weather conditions at intervals (10 min, 1 hr., 5 hr.)	<u>Collected Through Mobile Device (live and archived):</u> • Atmospheric Pressure (collected over wide range) • Altitude <u>Collected Through User Reporting:</u> • Current Weather Conditions (expire after 2 hours)

Table 3-7. Mobility Application Descriptions (Continued)

Intended Users	Requirements	User Interface	Data Types
Limited-Mobility Assistance Applications			
AssistMi	**Allows users ability to request assistance from service providers via their mobile device in real-time prior to arrival at location.** For iOS 5.1 and up, Android 2.1 and up		
Disabled users	• GPS-enabled mobile device and two-way message streams	Customized Assistance: • User selects from list of categories for assistance and provides custom request to service provider in advance of arrival.	User Location: • Service provider notified when traveler passes through geofence. Early notification allows for preparation. User Profile: • User profile includes disability information and vehicle information (if applicable) – used by provider to verify identity and provide assistance
WheelMate	**Community based accessible toilet and parking space location application edited in real-time by wheelchair users.** For iOS 4.0 and up, Android 2.1 and up		
Users with wheelchairs	• GPS-enabled mobile device	Map • Provides locations of toilets and parking in graphical interface including locations which have been "verified", "just added", "closed" and locations that require payment.	Active User Data Reporting: • Toilets • Parking • Ratings/comments on locations listed
WheelMap	**Crowdsourced map (based on OpenStreetMap) populated by users showing wheelchair-accessible locations.** For iOS 7.0 and up, Android 2.2 and up		
Users with wheelchairs	• GPS-enabled mobile device	Levels of Wheelchair Accessibility • Green (wheelchair accessible) – location and all its rooms are wheelchair accessible. Entrance does not to have steps. Toilet (if exists) is also accessible. • Orange (limited accessibility) – location itself is accessible but not all rooms. Entrance has a max of one step. • Red (not wheelchair accessible) – place is not accessible to wheelchair users. • Gray (unknown) – status unknown and needs to be assigned.	User Reported Information • Categories include public transfer points (i.e., parking, rail, bus etc.), shopping, sports, tourism, leisure, health, government, food, education, bank post, accommodation, and misc. • Level of wheelchair accessibility (G/O/R) • Photos of location • Comments to further describe accessibility of places

Table 3-7. Mobility Application Descriptions (Continued)

Intended Users	Requirements	User Interface	Data Types
Location-Based Social Networking			
Find My Friends	**Allows the user to easily locate friends and family using their mobile device by inviting them to share locations.** For iOS 5.1 and up.		
Users sharing their respective locations with others	• GPS-enabled mobile device • Location Sharing	Map: • Displays location of all participants of the ad-hoc network.	User Location: • User shares location data with other known users.
Google+	**Allows the user to easily locate friends and family using their mobile device by inviting them to share locations** For iOS 4.0 and up, Android 2.1 and up		
Users sharing their respective locations with others	• GPS-enabled mobile device • Location Sharing	Map: • Displays location of all participants of the ad-hoc network.	User Location: • User shares location data with other known users.
Locate My Friends	**Allows the user to easily locate friends and family using their mobile device by inviting them to share locations** Android 2.3 and up		
Users sharing their respective locations with others	• GPS-enabled mobile device • Location Sharing	Map: • Displays location of all participants of the ad-hoc network.	User Location: • User shares location data with other known users.
Glympse	**Allows the user to easily locate friends and family using their mobile device by inviting them to share locations** For iOS 7.0 and up, Android version varies based on device		
Users sharing their respective locations with others	• GPS-enabled mobile device • Location Sharing	Map: • Displays location of all participants of the ad-hoc network.	User Location: • User shares location data with other known users.
Device Location			
Android Device Manager	**Allows the user to locate a lost or stolen device.** Android 2.3 and up		
User seeking location of lost phone	• GPS-enabled mobile device • Full Network Access • Location Sharing	Map: • Displays location of phone on map	User Location: • Phone shares location data with cloud service.

Table 3-7. Mobility Application Descriptions (Continued)

Intended Users	Requirements	User Interface	Data Types
Find My iPhone	**Allows the user to locate a lost or stolen device.** For iOS 4.0 and up		
User seeking location of lost phone	• GPS-enabled mobile device • Full Network Access • Location Sharing	Map: • Displays location of phone on map	User Location: • Phone shares location data with cloud service.
Ridesharing Applications (components applicable to mobile devices in CV Environment)			
Carma Carpooling	**App enables users to find nearby commuters to share trip** For iOS 6.0 and up, Android 4.0 and up		• Intended Users: On-demand carpoolers • Relevant Data: GPS, ETA, Payment Method, Payment
Sidecar **Ride and Rideshare Apps**	**Ride App connects riders with drivers; Shared Ride is discounted instant carpooling app.** For iOS 5.0 and up, Android 4.0 and up		• Intended Users: On-demand single riders, carpoolers, and drivers • Relevant Data: GPS, ETA, Payment Method, Payment
Lyft **Ride and Rideshare Apps**	**Lyft App connects riders with drivers; Lyft Line is used for carpooling** For iOS 7.0 and up, Android varies		• Intended Users: On-demand single riders, carpoolers, and drivers • Relevant Data: GPS, ETA, Payment Method, Payment
Uber	**App matches riders and drivers for on-demand trip** For iOS 7.0 and up, Android varies		• Intended Users: On-demand riders and drivers • Relevant Data: GPS, ETA, Payment Method, Payment

Source: Battelle

Existing and Emerging Architecture and Message Frameworks

The U.S. DOT has long established a robust National ITS architecture that it continues to refine and expand as the technologies evolve and new ones, such as connected vehicle, are added. Connected vehicle technology and the data-rich environment it brings has also resulted in the need for a more consistent, national approach to data capture and management, another initiative currently underway within the U.S. DOT. And finally, recent systems engineering and prototyping efforts 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 to the public for deployment as open-source projects.

These frameworks are detailed below, followed by a description of specific connected vehicle applications that may be best situated to support the incorporation of mobile devices into the connected vehicle environment. This section then goes on to detail the existing message types that are exchanged between vehicles and infrastructure and identifies preliminary definitions for the message types that mobile devices might exchange within this same context.

Existing Architectures and Practices

National Intelligent Transportation Systems Architecture. The National Intelligent Transportation Systems (ITS) Architecture 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. Subsequent updates of the Architecture to bring ITS user services into the future are discussed below.

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. Table 3-8 illustrates the range of the National ITS Architecture components. This same table also highlights the User Services that may contribute to future connected vehicle deployments. Within the framework of the National ITS Architecture, information such as project definition and requirements, standards, information exchange requirements, system evaluation criteria, cost estimates, communication protocols, and the benefits of deploying specific ITS applications are provided for future implementers. As a result of upfront planning and analysis, implementers are able to use this standardized approach to save time and resources, exchange data, and improve the interoperability of regional, state, and national ITS deployments.

Table 3-8. 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**
• Public Transportation Management* • En-Route Transit Information* • Personalized Public Transit* • Public Travel Security **Electronic Payment** • Electronic Payment Services*	• Longitudinal Collision Avoidance • Lateral Collision Avoidance • Intersection Collision Avoidance* • Vision Enhancement for Crash Avoidance • Safety Readiness • Pre-Crash Restraint Deployment • Automated Highway Systems

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

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

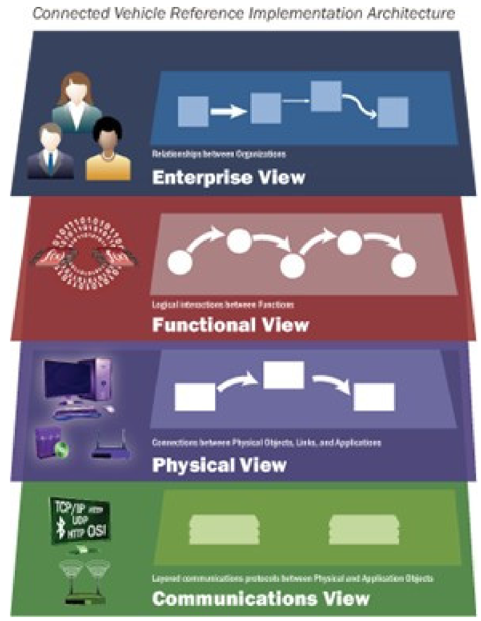
Since the initiation and development of the National ITS Architecture in the 1990s, the program has made important advancements in the standardization and functionality of ITS framework. In 2012, the U.S. DOT released version 7.0 of the National ITS Architecture. This latest version incorporates updates to the existing ITS framework, as well as new components such as the connected vehicle environment, Active Transportation and Demand Management (ATDM) strategies, Electronic Freight Manifest research, Integrated Corridor Management tools, and the Commercial Vehicle Information Systems and Networks Roadside Inspection system. This update, along with future updates will allow state and local implementers to streamline their interoperability efforts and remain on the cutting edge of ITS deployment technology.[23]

[23] U.S. DOT, About ITS Standards. http://www.standards.its.dot.gov/LearnAboutStandards/NationalITSArchitecture).

Regional Unified Model Architecture/CV Reference Implementation Architecture. In 2014, the U.S. DOT initiated a new effort, the Connected Vehicle Reference Implementation Architecture (CVRIA). Now known as the Regional Unified Model Architecture, it is a component of the National ITS Architecture and defines standards and processes associated with connected vehicles and its interfaces.[24]

Currently in the process of completing the first guidance document, the Connected Vehicle Standards Development Plan. This document will:

- Provide a basis for identifying and prioritizing standards and key interfaces for connected vehicle;
- System architecture viewpoints that describe the functions, physical and logical interfaces, enterprise relationships, and application dependencies within the connected vehicle environment;
- Provide guidance and protocols to integrate the Connected Vehicle Reference Implementation Architecture with the National ITS architecture; and
- Identify and explore policy considerations for certification, standards, core system, and potentially other elements of the connected vehicle environment.



Source: http://www.iteris.com/cvria/

Figure 3-3. CVRIA.

Key outputs of this architecture work include the introduction of a new set of messages based around situational awareness (discussed further below), as well as standardized dialogs and notations for representing this architecture, as captured in the Systems Engineering Tool for Intelligent Transportation. Beyond simply a drawing tool however, the RUMA embodies architectural flows that have been successfully demonstrated as part of past and ongoing U.S. DOT connected vehicle testing.

The Systems Engineering Tool for Intelligent Transportation (SET-IT). SET-IT is a software tool that integrates drawing and database tools with the Regional Unified Model Architecture. SET-IT allows users to develop project architectures for connected vehicle pilots, test beds and early deployments. The latest version of the software includes support for developing physical and enterprise views of a project architecture, as well as the ability to create a ConOps. Although a date for the next release is undetermined, enhanced functionality and features are likely to be added to future versions.[25] SET-IT and the architecture it represents will be further considered as the demonstration messages and techniques are further designed and developed as part of later stages of this task order, serving as both a tool to represent these flows, but also as a source of knowledge based on the prior instance captured in the tool set.

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

[25] (U.S Department of Transportation, Joint Program Office. Retrieved from: http://www.its.dot.gov/arch/set_it.htm)

U.S. DOT Test Beds. U.S. DOT test beds are facilities that promote the exchange of connected vehicle information and a standardized process for connected vehicle technologies. The test bed facilities offer test vehicles, infrastructure, and equipment to serve the needs of public and private sector stakeholders. The vision for the test bed program is to support the development of a common technical platform, and advance research, testing, and prototyping of connected transportation system concepts, standards, applications, and innovative products. Currently, the U.S DOT has six federally funded test bed facilitates located in Michigan, Virginia, Florida, California, New York, and Arizona. Each location specializes in specific testing capabilities.[26]

Work being performed at these test beds has already been considered as part of the literature review conducted under this task order. In Southeast Michigan, the CVRIA and the newer RUMA both continue to be vetted as part of ongoing testing there and Battelle regularly participates in the meetings organized for this work. The test beds in California and Arizona were both contributors related to the body of work captured in both the MMITSS project, as well as a smaller, but no-less-important, pedestrian-crossing related small business incentive research (SBIR) conducted by Savari Networks in cooperation with Maricopa Co. and the University of AZ.

Relevant Connected Vehicle Program Research

The U.S. DOT connected vehicle program is an ongoing initiative to facilitate wireless communications among vehicles, infrastructure, and most recently, personal communications devices. The program aims to make the surface transportation system safer, more efficient for travelers while also providing environmentally friendly outcomes and increased operator benefits. Current research extends across more than two dozen applications, ranging from concept development to a fully developed prototype efforts. As indicated in the task order proposal request, our team considered the outcomes and impacts of this prior research as it relates to mobile devices, the results of which are summarized below. The applications considered, consistent with the organization as defined by the connected vehicle program, are divided into the following categories:[27]

- **V2I Safety:** Applications that transmit information from vehicle to infrastructure, and vice-versa, to prevent collisions and other safety incidents.
- **V2V Safety:** Applications that allow vehicles to transmit information between each other in order to prevent collisions and other safety incidents.
- **Mobility:** Applications that improve traveler's experience by implementing strategies to reduce congestion, increase visibility to travel alternatives and other gains, by exchanging traveler information in order to optimize the use of existing infrastructure.
- **Environment:** Applications that reduce fuel consumption and encourage environmentally-friendly use of the transportation systems.
- **Agency Data:** Applications that allow for more efficient management of agency operations by automating routine data collection duties using connected vehicle technology.

[26] (U.S Department of Transportation, Joint Program Office. Retrieved from: http://www.its.dot.gov/testbed.htm)

[27] Connected Vehicle Pilots Deployment Project. http://www.its.dot.gov/pilots/cv_pilot_apps.htm

- **Road Weather:** Applications that facilitate the exchange of advanced road weather information to enhance driver safety and optimize agency maintenance operations.
- **Smart Roadside:** Applications that enhance commercial truck operations and inspection.

As one of the initial activities under this task order, the team of subject matter experts brainstormed a list of known, mobile-device related applications for consideration on this project. The team then conducted a cursory literature review of the remaining, less-familiar applications, and further expanded the list of applications to be considered. This list of applications stems from existing U.S. DOT research and has focused primarily on V2V and V2I safety and mobility, there are several instances where hand-carried mobile devices are a component. And while this isn't the charge of this project to directly affect these other applications, the role and impact of mobile devices will be considered with respect to each of these as the message related to mobile devices are further refined.

The summaries below represent the pilot projects that were determined to be candidates to support the incorporation of mobile devices into the connected vehicle framework. They are organized by mobility and safety applications.

Mobility Applications

Mobile Accessible Pedestrian Signal Systems (PED-SIG). This application is a prime example of the use of a 'coordinated' mobile device in conjunction with the connected vehicle environment. PED-SIG integrates mobile device sensors with traffic signal information, providing real-time assistance for visually impaired pedestrians crossing intersections. Unlike stand-alone Accessible Pedestrian Signal (APS) systems, mobile PED-SIG allows visually impaired pedestrians to cross an intersection without having to move away from their path of travel to locate and use a push button control system.[28] Instead, mobile devices integrate GPS information, Wi-Fi and Bluetooth sensors, and Signal Phasing and Timing (SPaT) information to help users cross intersections safely.

Typically, the PED-SIG technology employs two simple user input commands, which include a single-tap and double-tap command. The single tap command allows users to request for intersection geometry information, such as street names, direction, and number of lanes. While pointing the mobile device in the direction of travel, the double tap command re-confirms the direction of travel, requests a pedestrian walk signal, and then wirelessly requests signal timing and phasing information from the traffic signal controller via the mobile device application. Text to speech feedback can then be conveyed to the visually impaired pedestrian through the mobile device application interface.[29]

Additionally, and while not presently a capability, this pedestrian awareness could be extended to the intersection and subsequently approaching vehicles to provide enhanced safety benefits as well.

Accessible Transportation Technologies Research Initiative (ATTRI). Accessible Transportation Technologies Research Initiative (ATTRI) is a joint research program formed and co-led by the Federal Highway Administration (FHWA) and Federal Transit Administration (FTA), with support from the ITS Joint Program Office, and several other federal agencies. The program was created in 2013 and is a five-year initiative focused on strategies and technologies to enhance the mobility and quality of travel for those with disabilities. The mission of ATTRI is to implement new integrated technological solutions that improve the reliability and choices of disabled travelers. Through the partnership with

[28] Accessible Pedestrian Signal-Guide to Best Practices; Retrieved from: from http://www.apsguide.org/", 2010.

[29] University of Minnesota, Traffic Observatory, Development of Mobile Accessible Pedestrian Signals for Blind Pedestrians at Signalized Intersections, 2011.

other federal agencies, ATTRI can leverage a network of accessible resources and technological solutions. These solutions include vehicle-and-infrastructure-based technologies that connect wireless communications, mobile devices, vehicles, and other technology based innovations that provide access to a wealth of information, including transportation data, municipality data, points of interest data, crowd sourced data, and disability data.[30]

In addition to improving the capabilities of disabled travelers, ATTRI also focuses on the aging population. Projections from the National Center for Health Statistics indicate that the fastest growing subgroup in 2030 will be adults over the age 75. While older adults are living longer, healthier and more active lives than prior generations, the likelihood of a person developing a disability, chronic illness, or mobility impairments increases with age. As a result, the increase in the elderly population creates both opportunities and challenges in creating technologies that increase their quality of life and allow them to travel safely, efficiently and independently.[31]

At the time of the literature review, the ATTRI project had not yet advanced beyond early planning and concept stages itself, but it is a project that will be monitored for any mutually beneficial outcomes.

Dynamic Transit Operations (T-DISP). T-DISP application links multi-modal transportation options with travelers through dynamic transit vehicle scheduling, dispatching, and routing capabilities. T-DISP, one of three mobility applications identified within the Integrated Dynamic Transit Operations (IDTO) “bundle”, allows travelers to request a trip via a mobile device and have itineraries containing multiple transportation services (public transportation modes, private transportation services, shared ride, walking, and biking) sent to them in real time.

T-DISP leverages existing transit technologies, specifically computer-aided dispatch/automatic vehicle location systems, and integrates other travel modes, along with inputs from the traveler regarding points of origin, destination, and desired arrival and departure times.

T-DISP provides benefits to both the user and the transportation provider. For the traveler, T-DISP provides the ability to access, in real-time, the broadest range of transportation choices. It also equips the traveler with all the information they need to effectively manage his or her trip, including information on costs, predicted departure and arrival time, and walking distance to the final destination (if any). For the transportation provider, T-DISP permits dynamic routing and scheduling, and the functionality to manage operations based on traffic conditions, demand/capacity, origin and destination, and other factors.[32] These last benefits, focused to the operator/provider, are an example of how a coordinated device can provide data to benefit both travelers and operators alike.

Dynamic Ridesharing (D-RIDE). The Dynamic Ridesharing application, D-RIDE, is another one of the three applications within the IDTO bundle. D-RIDE allows travelers to arrange carpool trips using a mobile device and an automated ride matching system. Unlike conventional ride matching services that must pre-plan, D-RIDE can process inputs from passengers and drivers pre-trip, during the trip, and post-trip. Essentially, travelers can offer or request rides, in real-time, minutes before a departure time, or make scheduled appointments for one-way trips. The D-RIDE application takes the travel and

[30] (Mobility Services for All America, Research Overview. Intelligent Transportation Systems Joint Program Office. Retrieved from: http://www.its.dot.gov/msaa/)

[31] Older Americans with Disability: 2008-2012, U.S Department of Health and Human Services, 2014. Retrieved from: http://www.census.gov/content/dam/Census/library/publications/2014/acs/acs-29.pdf

[32] Dynamic Mobility Applications, Intelligent Transportation Systems Joint Program Office. Retrieved from: http://www.its.dot.gov/dma/dma_development.htm#idto

driver input data and then determines an optimal pairing based on the origin and destination of both users.

D-RIDE offers many benefits to its users, including the flexibility to make shared vehicle trips without committing to a particular route, schedule, or group of individuals to travel with. Based on inputs to the system, D-RIDE creates pairings that are both time- and cost-effective, thereby reducing congestion, pollution, and travel times resulting from a more static approach to travel planning.[33] When coupled with T-DISP, D-RIDE can also help facilitate complete start-to-finish trip planning for commuters.

Enabling Advanced Traveler Information System (EnableATIS). The objective of the EnableATIS is to foster transformative traveler information technologies that leverage the connected vehicle research and the overarching strategies that have and will be generated through the DMA program. EnableATIS is unique in that it is not a specific application or system, but is an effort that seeks to guide, influence and facilitate the development of technologies and platforms that enhance the traveler information market.[34]

EnableATIS uses advanced traveler information, which includes data from connected vehicles, user mobile devices, and other sources, such as environmental monitoring stations, traffic management systems, and roadside infrastructure. The goal of EnableATIS is to provide a suite of traveler technologies that promote multimodal, customized end-to-end trip planning, data collection and sharing, predictive analytics, and decision support for both the general public and network and infrastructure managers. As highlighted in the EnableATIS Strategy Assessment Report, the information that is collected and shared through EnableATIS has the potential to:

- Improve traveler decision-making, both by individual travelers, as well as by groups of travelers such as rideshare groups, a fleet of commercial vehicles under centralized dispatching or participants in a Transportation Management Association (TMA);
- Improve transportation systems management and operations planning including freeways, arterials, managed lanes, toll ways, and transit systems. The technologies generated also have the potential to assist in integrated corridor management efforts by improving the coordination and synergy between transportation system components; and
- Provide valuable data on travel patterns and traveler characteristics to third parties such as planners or marketing groups.[35]

Incident Scene Work Zone Alerts for Driver and Workers (INC-ZONE). INC-ZONE, is one of the applications within the DMA Program R.E.S.C.U.M.E bundle. The INC-ZONE application has two components—one that warns drivers that are approaching temporary work zones at unsafe speeds and/or trajectory, and another that warns public safety personnel and other officials working in the zone through various audible and haptic warning systems.

INC-ZONE is a communication application that improves the protection of responders at accident and crash sites, or where responders are present and traffic is stalled or has been redirected. The process involved in staging a temporary work site or incident zone is often very confusing for motorist, and can

[33] Dynamic Mobility Applications, Intelligent Transportation Systems Joint Program Office. Retrieved from: http://www.its.dot.gov/dma/dma_development.htm#idto

[34] Dynamic Mobility Applications, Intelligent Transportation Systems Joint Program Office. Retrieved from: http://www.its.dot.gov/dma/dma_development.htm#idto

[35] EnableATIS Strategy Assessment, February 2014. UDSOT, FHWA-JPO-14-113)

include lane closures, barricades, temporary signage, auxiliary warning lights, and other coordinated strategies. The INC-ZONE application enhances the safety of these zones and delivers real-time notifications to drivers and responders

A second aspect of the INC-ZONE application involves a built-in in-vehicle messaging system that provides merging and speed guidance around an incident to on-coming vehicles. For example, vehicles approaching the incident at speeds that pose a risk to themselves as well as to the incident zone responders will be detected by on-scene portable sensors or other detection methods. They will receive a message generated by the INC-ZONE application notifying them of the dangerous speed and advising a speed reduction.[36]

INC-ZONE is an example of how both coordinated and uncoordinated mobile devices might co-exist and function simultaneously to support the needs of this personal safety application.

Emergency Communications and Evacuation (EVAC). Evacuation of a metropolitan area, or some subset of a metropolitan area, is a challenging endeavor for both those being evacuated and those responsible for the safety and efficiency of the evacuation. Given their variable nature, evacuations may involve a large region with days of advance notice, such as with an approaching hurricane; or it may be rapid and local such as during a hazardous material spill.

Evacuation involves coordination of many agencies and functions including emergency management, public safety responders, public and private transportation service providers, and DOTs. Evacuations involve two categories of people—those individuals or groups who have the means and capabilities to evacuate themselves, and the functional needs population. The planning and execution of an evacuation must consider all categories of functional needs. According to the National Fire Protection Association, people with access and functional needs include those who may need additional care before, during, or after an incident in functional areas including, but not limited to:

- Individuals with disabilities, and others with access and functional needs;
- Individuals from religious, racial, and ethnically diverse backgrounds;
- Individuals with limited English proficiency;
- Individuals with physical, sensory, behavioral and mental health, intellectual, developmental and cognitive disabilities, including individuals who live in the community and individuals who are institutionalized;
- Older adults with and without disabilities;
- Children with and without disabilities and their parents;
- Individuals who are economically or transportation disadvantaged;
- Women who are pregnant; and,
- Individuals who have acute and chronic medical conditions; and those with pharmacological dependency.

[36] Battelle, Response, Emergency Staging, Communications, Uniform Management, and Evacuation Concept of Operations, 2012.

The purpose of the EVAC application is to facilitate coordination for evacuees in both categories and those who support them in order to execute an evacuation that is as safe and efficient as possible. The EVAC application supports the needs of three general groups of people: those able to evacuate themselves, those in need of assistance, and those supporting the evacuation, which includes a range of public safety personnel and transportation service providers.

The EVAC application is included within the DMA Program R.E.S.C.U.M.E bundle and addresses the needs of two different evacuee groups, those using their own transportation and those requiring assistance. For individuals with their own transportation, EVAC provides dynamic route guidance information; current traffic and road conditions; available lodging location; and location of fuel, food, water, cash machines, and other necessities. For individuals requiring assistance, EVAC provides information to identify and locate them and available resources and providers to support them.

During an evacuation the EVAC application has the ability to push information such as evacuation orders by evacuation zone to registered users of the system and provides a Return of Evacuees Function to provide evacuees with information regarding when they can return to their area of the jurisdiction, as well as providing the best route of return.

The EVAC application can provide the features mentioned above through integrated use with a jurisdictions existing technologies, including established communications systems (i.e., mass warning and notification systems), functional needs pre-registration databases, geographic information systems (GIS), global positioning systems (GPS), computer-aided dispatch (CAD), automatic vehicle location (AVL), traffic information, and weather data.[37]

Mobility Services for All Americans (MSAA). Many Americans have difficulty accessing some of their basic needs, particularly seniors, individuals with disabilities, and the economically disadvantaged, because they must rely on human service transportation systems which are often fragmented, unreliable and inefficiently operated. Lack of coordination is the leading obstacle to meeting the mobility requirements of the people who need these services most. Initiated by the U.S. DOT in 2005 as part of the national United The team Ride campaign, the Mobility Services for All Americans (MSAA) initiative seeks to improve transportation services and access to employment, healthcare, education and other community activities through a coordinated effort enabled by various ITS technologies and applications.

The MSAA initiative aims to bring all users, service providers and funding institutions together in a coordinated effort, with the an overarching goal of creating an ITS-enhanced human service transportation system that is efficient, accessible, and provides quality transportation services to all.[38]

[37] Battelle, Response, Prototype Development and Demonstration for Response, Emergency Staging, Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.) Information Broker Framework Analysis, 2015.

[38] (Mobility Services for All America, Research Overview. Intelligent Transportation Systems Joint Program Office. Retrieved from: http://www.its.dot.gov/msaa/)

Vehicle to Infrastructure (V2I) Safety Applications

Pedestrian in Signalized Crosswalk Warning. Reports of transit vehicles striking pedestrians in crosswalks are pervasive. In Chicago, 30 pedestrians were killed in 2010 due to transit vehicle strikes; 80 percent of all pedestrian-to-vehicle incidents occurred in crosswalks while the walk signal was active. Pedestrian detection has been deployed in limited scale in both vehicle-based and infrastructure based scenarios. Infrastructure-based applications typically consist of a detector (camera, infrared, microwave, etc.) in conjunction with the pedestrian call to the signal controller, while vehicle-based solutions involve video capture capabilities which are processed using detection algorithms.[39]

In order to facilitate continued progress in these capabilities, the U.S. DOT sought to develop a transit retrofit package (TRP) that included pedestrian detection to assist transit drivers in avoiding such strikes. The Pedestrian in Signalized Crosswalk (PCW) Warning application is a component this TRP and is one application under the V2I Safety umbrella. The goal of this application is to alert transit vehicles of pedestrians in crosswalks via Dedicated Short-Range Communications (DSRC) and on-board applications. When an intersection is within range, the application categorizes it as green (no hazardous vehicles or signals), yellow (a pedestrian has pressed the call button for a crosswalk), or red (a pedestrian has been detected crossing the street). To facilitate this warning system, TRP includes the following system elements and functionality:[40]

- TRP On-Board Equipment (OBE) Device: a wireless safety unit that transmits and receives messages via DSRC while interacting with the vehicle's controller-area network (CAN) bus and a driver-vehicle interface (DVI).
- Data Acquisition System: a system that interfaces and stores data from the vehicle CAN bus, video cameras, radar units, and safety applications.
- Crosswalk Motion Sensor: a unit that detects pedestrian presence in intersection crosswalks in support of the Pedestrian Warning application.

In addition to offering the PCW, these components enable a Vehicle Turning Right in Front of Bus Warning (VTRW), which alerts the driver of a vehicle passing or navigating through the blind zone, with the potential to turn into the transit vehicle's direction of travel. TRP also comes pre-loaded with the following basic safety applications: A Curve Speed Warning (CSW) that alerts the driver if the vehicle is entering a curve too quickly for the conditions; an Emergency Electronic Brake Light (EEBL) application that warns the driver of an upcoming emergency braking; and, a Forward Collision Warning (FCW) that warns the driver of an impending rear-end collision with a vehicle ahead in traffic.[41]

[39] Transit Safety Retrofit Package Development: TRP Concept of Operations. http://ntl.bts.gov/lib/54000/54000/54069/14-117.pdf

[40] Transit Safety Retrofit Package Development: TRP Concept of Operations. http://ntl.bts.gov/lib/54000/54000/54069/14-117.pdf

[41] Transit Safety Retrofit Package Development: TRP Concept of Operations. http://ntl.bts.gov/lib/54000/54000/54069/14-117.pdf

Other Technologies Considered

The rapid pace of technology advancement as well as the intent in capturing a wide segment of technologies allowed for many emerging and mainstream technologies to be reviewed, but were determined to be outside of the scope of this effort. These include the following:

- **Wearable biometric sensors.** (e.g., Fitbit, Jawbone etc.). Devices with step counters and heartrate monitoring features in a wearable device could be used to determine whether an individual is walking, running, or otherwise moving. However, after considering the current and future market penetration, the team determined these devices / sensors do not constitute a sufficient market share to warrant consideration for this project at this time.
- **Data outside of the connected vehicle environment.** This project will collect and share data from connected traveler and mobile devices for use by traffic management and operations-related applications in support of a transportation management system. Any data generated by these devices when they are not in range of traffic management systems, and any data unrelated to traffic management systems, will not be addressed as a part of this project.
- **Carry-In Devices and Integrated Devices.** As defined by the U.S. DOT, mobile devices include smartphones, tablets, and other hand-held devices that have their own power source, are capable of hosting one or more applications, and are carried by the system user throughout a trip. Carry-in devices are specifically designed to be carried into a vehicle and powered by that vehicle. An integrated device is permanently located within a vehicle and is unable to be relocated. Both carry-in devices and integrated devices are not expected to support decision making outside of a vehicle and as such, are not envisioned to communicate the PSM or PMM messages. However, the existence of these devices in the vehicle are expected to play a role in the coordination of mobile devices with the vehicle.
- **Operating Systems beyond iOS and Android.** As described in the body of this document, the Battelle Team researched several operating systems along with their corresponding market penetration. The data and associated trends showed that Apple's iOS and Google's Android Operating Systems have maintained- and continue to trend upwards in terms of market share. Given this, the scope of the project includes only iOS and Android operating systems as it relates to the mobile devices.
- **Developing New Connected Vehicle Applications.** The scope of this project does not include the development of new applications within the connected vehicle environment. Rather, the team is assessing what existing data are useful along a traveler's route along the various transportation systems between origin and destination.
- **Influencing Operator Decision-Making.** Similar to above, the scope of this project includes evaluating available data and messaging schemes to support the movement of the traveler throughout the trip chain. The project does not include messaging schemes intended to influence mode operators.

- **<u>The "Internet of Things" (IoT)</u>.** The Internet of Things is a term used to describe the connectivity of all forms of commercial and consumer devices to the internet for purposes of data exchange, typically to support operations and support of these connected devices. While the concepts encompassed by this evolution of the internet, and the 'big data' that coincides with this movement, the scope of this project focuses on the conscious decision of a traveler to "opt-in" to the connected vehicle environment and to interact with it specifically.
- **<u>Smartwatches</u>.** (e.g. AppleWatch, Samsung Gear 2, Motorola Moto 360) This recently emerging class of wearable devices expand on the 'wearable' concept by adding advanced features such as gestures, larger displays, and tight integration with compatible Smartphone. Several of these devices can run 'applications' similar to those on a Smartphone. After considering the current and future market penetration, the team determined these devices do not constitute a sufficient market share to warrant consideration for this project at this time.

Summary of Technology Scan

The scan of technology yielded several opportunities that could directly support the goals of this research, utilizing functionality that exists in today's mobile devices, and maintaining interoperability with emerging U.S. DOT architectures. Common to all devices evaluated, wireless technologies including Wi-Fi, Bluetooth and the mobile network itself are available. Similarly, onboard sensors, including GPS, accelerometers, gyroscopes and proximity sensors are also ubiquitous and available for use via the respective application programming interfaces (APIs). Near-field communications is also rapidly becoming common place, both as part of the devices and as part of the infrastructure, particularly with respect to point-of-sale locations. Collectively, a combination of possibly several different types of these communication protocols and sensors could be used to identify the current mode and state of a traveler and enable coordination of the mobile devices within the context of a connected vehicle/infrastructure environment.

Finally, a broad set of existing connected vehicle applications were reviewed. The PED-SIG application, part of the MMITSS bundle is a highly relevant application that uses Wi-Fi and Bluetooth to support mobility purposes at signalized intersections.

Chapter 4 Standards Assessment

Standards Overview

A key goal of this project is, identify and if possible, adapt existing or emerging communication approaches, to support the dissemination of personal safety and mobility messages. This assessment includes researching technologies deployed both domestically and international, including those which support the transportation community specifically, as well as the broader telecommunications industry. This chapter further identifies the standards and specifications that support these communications, and provides an assessment of whether they are relevant to this project. As it is presently too early to determine all of the specific gaps that might exist between the needs that will be defined and what is already present in current standards, a final determination of both the specific standards to be recommended and the changes associated with them cannot be made at this time. However, the information presented in this section focus on identifying and justifying the standards that may be of interest to the project, and where necessary, attempting to ratify the choice of which standard to use in the case of 'competing' standards.

Related, the project expects to use different communication technologies (e.g., DSRC versus mobile network data) for different data exchanges. The technology scan has revealed that modifications to any of the underlying *protocols* and *specifications* that enable these communications should not need to be made. However, modifications to the high-layer *message* and *data exchanges* that occur on these various forms of wireless communications are necessary. In that context, this research will identify the additional needs to exchange information that have not yet been defined and will propose new data concepts, to be added to standards, to support these exchanges.

The standards have been organized as follows:

- **ITS Message Sets:** This section identifies standards that define ITS-related information that might be of interest to the project. Although the standards were initially developed to support the exchange of information between transportation operation/management centers (center-to-center) and TMC to roadside components (e.g. traffic signal controllers, ramp meters, dynamic message signs), the data defined within these standards may be applicable for mobile device interactions as well, allowing the reuse of existing data elements.
- **Connected Vehicle Communications:** This section identifies the standards that define the lower-level communications stack for the Dedicated Short Range Communication (DSRC) environment that is used for most V2V, V2I, and I2V communications.
- **Mobile Network Data Communications:** This section identifies the standards that define mobile network data communications (i.e., 3G, LTE) as found on most mobile devices within the US.
- **Bluetooth Communications:** This section identifies the Bluetooth standards that many mobile devices support.

- **Wi-Fi Communications:** This section identifies the Wi-Fi standards that most mobile devices support.
- **Payment Standards:** This section identifies the NFC standards that some mobile devices support.
- **In-Vehicle Communication Standards:** This section identifies standards for exchanging data between a vehicle and any on-board mobile devices.

ITS Message Sets

Within the ITS community, there are standardization efforts underway at both the national and international levels. In some cases, these efforts are complementary and in others they reflect a difference in North American and European approaches to the connected vehicle environment.

Table 4-1 identifies the predominant domestic standards that implement messages and data elements that may be relevant to this project. SAE J2735 is of particular interest as it relates directly to the DSRC environment that current V2V and V2I deployments utilize, and are potentially the standard which could house future mobile device messages as defined herein. Additionally, J2354, while not originally designed for DSRC communications, offers several message dialogs associated with mobile devices and information sharing. Even if this last consideration doesn't hold, these standards are expected to serve as a foundational building block and common data dictionary for future mobile device messages.

Table 4-1. 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. It is a candidate to house the resulting PSM and PMM as well. A detailed discussion of these messages is included below.
SAE J2945.x	Dedicated Short Range Communications (DSRC) Minimum Performance Requirements	Minimum performance requirements for SAE J2735 messages. This standard does not define messages, only their use.
SAE J2354	Message Sets for Advanced Traveler Information System (ATIS)	Messages and data elements 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 (IT IS) 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 the exchange of information related to transit operations. Additional discussion of messages from these standards is included below.
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 shares common data elements with the SPaT Message found in J2735:2009, 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 found in the SAE J2735 standard.

Source: Battelle / Trevilon

The standards in Table 4-1 above, while common in the U.S. are not restricted to domestic use only. For instance, the international ITS community, particularly in Europe and Japan, has long been deploying ITS technologies and are now too implementing wireless connected vehicles / smart road technologies. Recently, heightened international standards harmonization efforts have taken place between the U.S. and other nations, particularly as it relates to the SAE J2735 message set and the IEEE 1609.X standards related to wireless access in a vehicle environment, both of which are discussed later in this section. Besides these however, numerous other ITS and CV standards have been developed on the international front and have proven successful. Table 4-2 identifies the additional international standards that may be relevant to this project and were further evaluated for their applicability as well.

Table 4-2. International Standards Overview.

Identifier	Title	Description
ISO 19091	Intelligent Transport Systems – Cooperative ITS – Using V2I and I2V communications for applications related to signalized intersections	Data for interfacing wireless devices, especially vehicles, to a traffic signal. Additional discussion of this standard is included below.
ETSI 102 637-2	Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service	Defines the Cooperative Awareness Message (CAM), which is the main message sent by ITS Stations (ITS-S, such as moving vehicles) to notify other ITS Stations of its location. This message is conceptually very similar to the Basic Safety Message (BSM) as defined in SAE J2735. No additional data elements were identified from this message that need to be considered for the PMM or PSM.
ETSI 102 637-3	Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service	Defines the Decentralized Environmental Notification Message (DENM), which is used by ITS Stations to report road hazard warnings. It is conceptually similar to messages defined in SAE J2735. Additional discussion of this standard is included below. No additional data elements were identified from this message that need to be considered for the PMM or PSM.
ETSI EN 302 895	Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Local Dynamic Map (LDM)	Defines the base model of a local dynamic map upon which information can be overlaid. This is useful for onboard applications, but a link to the mobile device applications is not apparent.
ETSI TS 102 894-2	Intelligent Transport Systems (ITS); Users and applications requirements; Part 2: Applications and facilities layer common data dictionary	This standard provides a broad, common, data dictionary for cooperative ITS exchanges as currently defined in the European community. The data elements contained within this standard focus on vehicle or infrastructure attributes or characteristics, and as such, are not applicable to the PSM or PMM.

Source: Battelle / Trevilon

Following are details of our assessment of the available message from within each of the applicable message set standards, both domestic and international.

SAE J2735 – Dedicated Short Range Communications (DSRC) Message Set Dictionary

SAE J2735:2009 defines Message Set Dictionary that is presently 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, however, others are beginning to find relevance as the connected vehicle environment expands from the original V2V concepts. Further research activities, looking to find solutions for an expanded set of user needs, have produced additional messages that are likely to be considered for future inclusion in this same standard. Based on our review of the past and ongoing research, as well as the stated intent as prescribed in J2735, we include the following types of connected vehicle messages for further consideration:[42]

A la Carte (ACM)	This message allows for the construction of a message using the data frames and data elements available in J2735.
Basic Safety Message	Contains vehicle safety-related information that is broadcasted to surrounding vehicles
Common Safety Request	Provides a means for a vehicle to request additional information for another, specific vehicle.
Map Data	Defines the geometric intersection description
Probe Vehicle Data	This message is used to convey vehicle position data to the infrastructure in groups known as snapshots.
Roadside Alert Message	Provides congestion, travel time, and signage information as well as road weather conditions
Signal Phase and Timing	Information about the current state and time remaining of each phase of a traffic signal controller.
Signal Status Message	Contains the status of any pending or active preemption or priority events as controlled by the traffic signal controller.
Vehicle Situation Data Message	New message not currently embodied in the standard. Contains status information about the vehicle to enable travel information related to a particular road segment

Under the standards established by SAE J2735, time-sensitive safety messages are transmitted via DSRC; non-time critical mobility applications can use both DSRC as well as other means of wireless transmittal. The basic safety message (BSM), probe vehicle data message (PVD) and vehicle situation data message (VSM), all satisfy this criteria. These messages provide a framework for the personal safety message (PSM) and personal mobility message (PDM) that this project aims to define in future phases.

[42] U.S. DOT, SAE J2735 – Dedicated Short Range Communications (DSRC) Message Set Dictionary. 2013. http://www.standards.its.dot.gov/Factsheets/Factsheet/71

Basic Safety Message

Vehicle to Vehicle (V2V) messages are exchanged in a basic safety message (BSM) that is sent via DSRC technology. The BSM contains two parts: Part 1 contains core data elements such as vehicle size, position, speed, heading, acceleration, and break speed status and is transmitted approximately 10 times per second; Part 2 contains a variable set of data elements (such as anti-lock brake and stability control status, which vary by make and model) and is sent less frequently.[43]

The BSM is intended for the low latency, localized broadcast required by V2V safety applications. However, it can also be used to provide vehicle data in support of mobility applications. Where roadside units are deployed, the BSM can support such mobility applications as cooperative adaptive cruise control, speed harmonization, queue warning, transit signal priority, and incident scene work alerts. When Part 2 data elements are added, weather data and vehicle data can also be exchanged.[44]

The BSM is specific to vehicle usage as it contains mandatory parameters that can only be provided or make-sense for a motorized-vehicle. In order to provide some level of interoperability however, it is likely that any PSM and PMM prototype under this project will start with BSM as the foundation, and revise from it.

Figure 4-1 and Figure 4-2 identify the data elements associated with the BSM Part 1 and Part 2 message respectively. As seen in these figures, several data frames and elements are applicable for use with a mobile device and the generation of the personal safety and mobility messages. These include:

- Location: latitude, longitude, elevation, heading, and possibly speed
- Path History and Path Prediction (BSM Pt. 2)
- Sun Sensor, Rain Sensor, Ambient Air Temp and Ambient Air Pressure (if so equipped)
- AccelerationSet4Way.

However, included in the BSM message are also several elements which have no equivalent in the mobile device environment, including, but not limited to, Wiper Status, Lights, Brake Status, Steering Angle and Road Friction.

Finally, based on our preliminary research, the BSM message types are missing key elements necessary for proper mobile device operation, including, but again, not limited to:

- Mode (pedestrian vs. passenger vs. driver, etc.)
- Mobility Characteristics (motorized scooter, wheelchair, others)
- Destination (where do you want to go, not necessarily how do you get there)
- Association (is this device on a scooter or tethered to another device)
- Request for Service (chairlift, etc.)

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[43] U.S. DOT, About ITS Standards. http://www.standards.its.dot.gov/LearnAboutStandards/NationalITSArchitecture)

[44] U.S. DOT, About ITS Standards. http://www.standards.its.dot.gov/LearnAboutStandards/NationalITSArchitecture

As one can see, while the foundation of the BSM is supportive of the goals, it is impractical to revise the current BSM to the extent necessary to support the needed mobile device message types.

BasicSafetyMessage		
-- Part I		
msgID	DSRCmsgID	1 byte
blob1	BSMblob	
msgCnt	MsgCount	1 byte
id	TemporaryID	4 bytes
secMark	DSecond	2 bytes
-- PositionLocal3D		
lat	Latitude	4 bytes
long	Longitude	4 bytes
elev	Elevation	2 bytes
accuracy	PositionalAccuracy	4 bytes
-- Motion		
speed	TransmissionAndSpeed	2 bytes
heading	Heading	2 bytes
angle	SteeringWheelAngle	1 byte
accelSet	AccelerationSet4Way	7 bytes
long	Acceleration	
lat	Acceleration	
vert	VerticalAcceleration	
yaw	YawRate	
-- Control		
brakes	BrakeSystemStatus	2 bytes
-- VehicleBasics		
size	VehicleSize	3 bytes

Source: Battelle

Figure 4-1. Basic Safety Message (Part 1).

-- Part II	
safetyExt	VehicleSafetyExtension
events	EventFlags
pathHistory	PathHistory
pathPrediction	PathPrediction
theRTCM	RTCMPackage
status	VehicleStatus
lights	ExteriorLights
lightBar	LightbarInUse
wipers	
statusFront	WiperStatusFront
rateFront	WiperRate
statusRear	WiperStatusRear
rateRear	WiperRate
brakeStatus	BrakeSystemStatus
brakePressure	BrakeAppliedPressure
roadFriction	CoefficieintOfFriction
sunData	SunSensor
rainData	RainSensor
airTemp	AmbientAirTemperature
airPres	AmbientAirPressure
steering	
angle	SteeringWheelAngle
confidencwe	SteeringWheelAngleConfidence
rate	SteeringWheelAngleRateOfChange
wheels	DrivingWheelAngle

accelSets	
accel4way	AccelerationSet4Way
vertAccelThres	VerticalAccelerationThreshold
yawRateCon	YawRateConfidcne
hozAccelCon	AccelerationConficence
confidenceSet	ConfidenceSet
object	
obDist	ObstacleDistance
obDirect	ObstacleDirection
dateTime	DDateTime
fullPost	FullPostionVector
throttlePos	ThrottlePostion
speedHeadC	SpeedandHeadingandThrottleConfidence
speedC	SpeedConfidence
vehicleData	
height	VehicleHeight
bumpers	BumperHeights
mass	VehicleMass
trailerWeight	TrailerWeight
type	VehicleType
vehicleIdent	VehicleIdent
j1939data	J1939data
weatherReport	
isRaining	NTCIP.EssPrecipYesNo
rainRate	NTCIP.EssPrecipRate
precipSituation	NTCIP.EssPrecipSituation
solarRadation	NTCIP.EssSolarRadiation
friciton	NTCIP.EssMobileFriction
gpsStatus	GPSstatus

Source: Battelle

Figure 4-2. Basic Safety Message (Part 2).

Probe Vehicle Data Message

In conducting a similar analysis of the Probe Vehicle Data Message, of which the contents are shown in Figure 4-3, a similar result is observed. Certain elements, such as those related to location, speed and heading, are included in the PVD, and of use to the mobile device messages, but again, extraneous data elements, such as the VehicleSafetyExtension and the VehicleStatus data frames are not relevant to the desired messages. Finally, like BSM, there are several data elements expected to be necessary in the forthcoming messages that are not practical to include in the PVD message as currently implemented, and likely in the future as well.

```
ProbeVehicleData
  msgID                  DSRCmsgID
  segNum                 ProbeSegmentNumber
  probeID                VehicleIdent
  startVector            FullPositionVector
  vehicleType            VehicleType
  cntSnapshots           Count
  snapshots              SEQ of Snapshot
     thePosition         FullPositionVector
        utcTime          DDateTime
        long             Longitude
        lat              Latitude
        elevation        Elevation
        heading          Heading
        speed            TransmissionAndSpeed
        posAccuracy      PostionalAccuracy
        timeConfidence   TimeConfidence
        posConfidence    PostionConficenceSet
        speedConfidenc   SpeedandHeadingandThrottleConfide
        e                nce
     safetyExt           VehicleSafetyExtension
     datSet              VehicleStatus
```

Source: Battelle

Figure 4-3. Probe Vehicle Message.

Vehicle Situation Data Message

The Vehicle Situation Data Message (VSM), a recent addition to the set of ASN.1 messages used for conveying vehicle state information, is a Vehicle to Infrastructure (V2I) messages that bundles up to ten vehicle situation data records into a single message for transmittal to a local current situation data warehouse, where it can be used for a variety of purposes related to traffic management and planning. In addition to the position vector (similar to the BSM), the VSM includes weather, environmental, fuel consumption and emissions data. Steering wheel angle, anti-lock brake status and windshield wiper status are an example of some of the elements included.

The VSM can be used to supply information to roadway operations, planning, and maintenance applications, as well as for providing travelers with roadway conditions. The United States is currently collaborating with Japan to identify potential uses for this replacement to the probe data message (PDM).

SAE J2354 – Message Sets for Advanced Traveler Information System (ATIS)

This SAE standard describes standardized messages used by information service providers to convey what is known as Advanced Traveler Information Systems (ATIS) data. The messages contained within the 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 the other direction. With that being said, the standard does facilitate a request/reply combination that allows for information exchange. These request/replies are typically asynchronous in nature however, and as such, require additional information that would not necessarily be expected with today's mobile devices and wireless communications. The messages include the following:

- **MSG_TravelerInformationRequest** – Used by the traveler to request data from the data source. One or more message, in the form of the MSG_TravelerInformationReponse would then result. The primary information needed for this request includes:
  - Location (in LRMS format)
  - Time Period
  - Agency (from where do you want the data)
  - Severity Level
  - Send To
- **MSG_TravelerInformationResponse** – A message structure sent from the data provider (i.e. agency) that includes one or more reply messages given the subscription / request criteria provided to the traveler. The content of these messages include information about incidents, routes, detours, parking, weather, and others.
- **MSG_AdvisoryInformation** – This message is defined to be a provider initiated message, similar to the Traveler Information Response Message, sent to travelers (or other centers) on the occurrence of specific events for which a traveler had previously subscribed. The content of these messages include information about incidents, routes, detours, parking, weather and others, albeit typically at a higher severity level.

Another group of messages, including the MSG_TravelerDeviceSetting, MSG_TravelerSettingsReply and MSG_TravelerSettingsRequest are used to register and subscribe to information sources, providing the mechanism for two way communications between the traveler and the information source.

Specific to this project, there is only a loose coupling between the personal mobility message and the messages governed by J2354. However, the data frames and data elements embodied within this standard can serve as a lexicon for developing the PMM, ensuring consistency in data definitions when exchanging data used by other systems.

APTA-TCIP-S-01 – Transit Communications Interface Profiles (TCIP)

The TCIP standards were developed to support standardize message exchanges between various ‘business’ systems within a transit system, as well as amongst transit systems and other external agencies. These systems and there corresponding process include operations, revenue and fare collection, scheduling, security and incident management, asset management, personnel and work assignment management, data collection, spatial data management and customer information. In practice, this translates to information exchanges between systems such as CAD/AVL, fare box, passenger counters, mobile data terminals, garage systems, annunciators, message sign and others.

Given the timeframe when this standard was developed, there is the concept of mobile device usage, but in the form of personal digital assistants (PDAs) and prior generation mobile phone technology. Saying that, the message and dialogs documented in this standard are not necessarily outdated, however, in practice, other technologies and approaches supporting similar information exchanges have come into existence and are not necessarily in line with this standard.

Version 4.1 of the TCIP Standards identify a total of 363 distinct messages, of which several are candidates for consideration under this work. These messages include, but are not limited to:

- CcAnnouncementInfo – provides data to the onboard sign and annunciator for destination and next stop information.
- CcConnProtReq, CcConnProtAck, CcConProtWait, CcConnProtAppr, and CcConnProtDeny collectively support the concept of transfer connection protection.
- CcWheelchairReq, CcWheelchairAck, CcWheelchairAppr, CcWheelchairDeny and CcWheelchairPickup collectively support coordination of vehicles facilitating wheelchair accommodations.

ISO 19091 – Intelligent Transport Systems – Cooperative ITS – Using V2I and I2V Communications for Applications Related to Signalized Intersections

This standard embodies similar information as contained in the SAE J2735 SPAT, MAP, SRM and SSM messages. Recent harmonization efforts between the various standards bodies, to include ISO, CEN and SAE have led to modifications to the SAE J2735 standard, released April 2015, to embody these changes. As such, our focus will continue to point towards use of J2735 and possible extensions of it.

Connected Vehicle Communications

Specific to the deployment of wireless technologies to support low-latency, safety critical information exchange, and consistent with the recent vehicle and infrastructure prototype and demonstration programs, it is fully expected that there will be a build out of 5.9GHz wireless networks domestically over the next decade. And while the reach of this network initially is not expected to reach the breadth of the current mobile network, it is expected to be located in high volume and dense urban traffic areas, including intersections, urban freeways, ramps, and curves, as well as work zones, schools, etc., areas of critical safety concerns. And while it is not expected that all mobile devices will add this specific frequency band to their current offering, those that are intended to serve safety-critical purposes, such as vulnerable road user applications, will likely need to employ the DSRC stack to ensure the timely interaction with nearby vehicles and infrastructure not unlike the current DSRC-based V2V and V2I exchanges. The current protocol stack for domestic DSRC includes the standards identified in Table 4-3. These standards continue to evolve in response to both the outcomes of recent test activities, as well as international harmonization activities, and as such, our team will continue to monitor their ongoing development activities, and where appropriate, actively engage the working group as it relates to the needs of this project.

Table 4-3. International Standards Overview.

Identifier	Title	Description
IEEE 1609.2	IEEE Standard for Wireless Access in Vehicular Environments – Security Services for Applications and Management Messages	Defines how to secure mobile, wireless ITS data exchanges
IEEE 1609.3	IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Networking Services	Provides a more efficient, alternative stack to TCP/IP for DSRC data exchanges
IEEE 1609.4	Standard for Wireless Access in Vehicular Environments (WAVE) – Multi-Channel Operations	Enhances IEEE 802.11 Media Access Control to support multichannel WAVE operations
IEEE 1609.11	Over the Air Data Exchange Protocol for Intelligent Transportation Systems (ITS)	Services and messages for secure electronic payments
IEEE 1609.12	Identifier Allocations	Defines identifier values for higher level protocols
IEEE 802.11p	IEEE Standard for Information Technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments	Physical and media access control layers for wireless communications in a vehicular environment

Source: Battelle / Trevilon

Mobile Network Data Communications

Similar to the previous discussion related to Connected Vehicle Communications (DSRC stack), similar protocol layers have been standardized and deployed to facilitate wireless communications via a mobile network, otherwise known as cellular. Today's mobile networks in the U.S. are built primarily on two distinct, but similar digital technologies, Code-Division Multiple Access (CDMA) and Global System for Mobiles (GSM). GSM is more prevalent globally, but CDMA, as a result of an aggressive nationwide deployment, was at least initially, the major technology available domestically. The list of the specific technologies, by carrier and device were documented in Chapter 3. A distinct advantage of the GSM network is the ability to allow for simultaneous voice and data exchanges to occur. This capability is critical in instances where continued network access is necessary to support an application's needs.

Recently, a move towards Long Term Evolution (LTE), as defined by the 3rd Generation Partnership Project (3GPP), has occurred, with all four of the major U.S. carriers, AT&T, Sprint, T-Mobile and Verizon all making the transition. Similar to the GSM/CDMA distinction from the prior generation of technology, there are differences in how each of the carriers choose to implement LTE, whether it is the specific frequency bands, the approach used for voice calls, or simply for legacy network support. This creates two challenges. First, for the most part, it is still necessary to purchase equipment specific to the carrier of choice. While this is not the case for all carriers and handsets, this simply indicates that these devices are not all interchangeable. Second, and more important to this project, is the capability of these devices to support simultaneous voice and data exchanges. With LTE, this concern is quickly becoming irrelevant as the continued evolution of this technology has allowed for this simultaneous capability to be realized, but it does need to be a consideration nonetheless. Table 4-4 offers a comparison of the major US mobile network carriers, and the data standards used for both the 3rd generation (3G) as well as for their 4G offering, showing how LTE, when fully deployed, will allow for the simultaneous voice and data network wide.

Table 4-4. Comparison of Major U.S. Mobile Network Carrier Standards/Technologies.

Carrier	3G Data Technology	Simultaneous Voice & Data?	4G Data Technology	Simultaneous Voice & Data?
AT&T	EDGE, HSPA+	Yes	LTE	Yes
Sprint	EV-DO	No	WiMAX, LTE	Imminent
T-Mobile	EDGE, HSPA+	Yes	LTE	Yes
Verizon	EV-DO	No	LTE	Yes

Source: Battelle

As it relates specifically to the needs of this project, there is little need to provide additional mobile network details beyond what is included. It is not expected that this project will have any influence or bearing on the next generation of mobile network specifications, nor is there any expectation that that would be necessary. Furthermore, the analysis of these mobile network standards revealed that no specific message standard unique to mobile networks existed, and that any higher-level protocols necessary for data to be exchanged on this network was not unlike that of other wireless and even wired technologies. TCP/IP and UPD/IP are both readily supported to the extent that this project would take advantage of those protocols.

Bluetooth Communications

Mobile devices frequently support Bluetooth communications, a wireless technology categorized as a wireless personal area network (WPAN). A WPAN is intended to operate in a very short range, often to eliminate wires from peripheral devices such as headsets, mice, keyboards, and others. Recently, the industry had expanded beyond this 'classic' Bluetooth technology, and has added both Bluetooth Low Energy and Bluetooth High Speed, as part of the 4.0 specification maintained by the Bluetooth Special Interest Group (SIG) and as adopted in 2010.

Bluetooth does not prescribe any specific message protocols or formats that must be used, but instead, serves as the lower-layer transport layer to support the exchange of messages. Bluetooth connections using TCP/IP or UDP/IP are enabled using the Bluetooth Network Encapsulation Protocol (BNEP).

The Bluetooth Standard[45] specifies three basic security services: authentication, confidentiality, authorization. Additionally, there are four security modes that dictate when security is initiated in the connection process. Of these modes, Security Mode 4, is mandatory for communications between devices using Bluetooth v2.1 and higher.

Wi-Fi Communications

Wi-Fi, as used in this context, refers to the wireless communications protocol specified by IEEE 802.11, and includes the a, b, g, n and ac revisions to this standard. Support for Wi-Fi is nearly ubiquitous in today's mobile device platform, and thus, this technology is a viable option for data communications intended to serve this project. Table 4-5 lists the available WI-FI standard for each of the top six (6) devices in use today.

Wi-Fi does not prescribe any specific message protocols or formats that must be used, but instead, serves as a lower-layer transport mechanism to support the exchange of messages. Wi-Fi connections using TCP/IP or UDP/IP are standard, and allow for the exchange of message in ASN.1, XML, or other.

Table 4-5. Wi-Fi Device Standards for Select Mobile Devices.

Mobile Device	Wi-Fi Standards
Samsung Galaxy S III	IEEE 802.11a/b/g/n (HT40)
Samsung Galaxy S 4	IEEE 802.11a/b/g/n/ac (HT80)
Samsung Galaxy S 5	IEEE 802.11a/b/g/n/ac (VHT80) MIMO(2x2)
Apple iPhone 5	IEEE 802.11a/b/g/n (802.11n 2.4GHz and 5GHz)
Apple iPhone 5s	IEEE 802.11a/b/g/n
Apple iPhone 6	IEEE 802.11a/b/g/n/ac

Source: Battelle

45 Guide to Bluetooth Security - National Institute of Standards and Technology

Wi-Fi Protected Access II (WPA2) is the current standard for secure communication over Wi-Fi.[46] It is more secure than previous standards, which includes Wi-Fi Protected Access (WPA) and Wired Equivalent Privacy (WEP). It is currently based on the Advanced Encryption Standard (AES) and IEEE 802.1X. WPA2 is based on the IEEE 802.11i standard and provides 128-bit AES-based encryption and mutual authentication with Pre-Shared Key in personal mode or with Extensible Authentication Protocol in Enterprise mode. Since 2006, all Wi-Fi certified equipment is required to contain WPA2 security features.

Electronic Payment

In addition to the normal exchanges of information, mobile devices are starting to be used for electronic payment transactions. Although this project is not focused on the payment details, the transaction location and technology associated with these payments are both possible triggers for transitioning between coordination modes within the systems. As such, various, popular methods that are supported by today's smartphone devices have been considered. These include:

- **SMS-based transactional payments:** Achieved by sending an SMS message to a service who performs transaction and returns a response
- **Direct mobile billing:** Charges the user's mobile account using a PIN
- **Mobile web payments:** Charges to a credit card or on-line financial account via access codes
- **QR Codes:** After one-time configuration with user account information, the mobile device is able to display a QR code that uniquely identifies the user's account, which can be read by a special device at the point of sale.
- **NFC:** Similar to QR codes, except the interface to the reader is wireless rather than a visible QR code on the device.

Table 4-6. Payment Standards Overview.

Identifier	Title	Description
ISO 18000-3	Information Technology – Radio frequency identification for item management – Part 3: Parameters for air interface communications at 13.56 MHz	Near field communication (NFC) protocol framework for payment transactions at a range of less than 10 inches
ISO 18092	Information technology – Telecommunications and information exchange between systems – Near field communications – Interface and Protocol (NFCIP-1)	Communication modes for NFC

Source: Battelle

[46] The State of Wi-Fi Security - Wi-Fi Alliance

In-Vehicle Communications

In addition to the above standards, there are multiple other groups working on standards for exchanging data between a vehicle and on-board mobile devices, including:

- Open Mobile Alliance: Develops platform-independent, international standards for the mobile device industry
- AllSeen Alliance: An Internet of Things open-source solution for connected devices to one another in a secure way. Automobiles could be one such device.
- Car Connectivity Consortium: Developing MirrorLink™, a technology that allows a mobile device to connect with a host vehicle and to use the host vehicle's infrastructure (e.g., display screen, speakers, microphone, buttons, etc.) as the user interface rather than the mobile device. The specification will allow refinements on what information can be displayed and how it is displayed to increase safety.
- Open Automotive Alliance: Dedicated to integrating Android (Google) environment with the host vehicle
- CarPlay: Dedicated to integrating the iOS (Apple) environment with the host vehicle.

While an open standard is not yet deployed to associate any mobile device to a vehicle, it would appear that such a standard will likely exist in the near future. However, it also appears that no existing group is working on some of the pairings that may be desired by this project (e.g., a mobile device becoming aware of when it is on a transit vehicle).

Summary of Standards Assessment

No existing standard(s) were found to be directly suitable for use as a current message standard supporting the concept of a personal safety message and a personal mobility message. As such, it is expected that the appropriate safety and mobility messages will need to be formulated under this effort. These new proposed messages should be developed consistent with the structure and methods presently used for the SAE J2735 standard, including the use of ASN.1 and following, to the extent possible, the existing 'transportation' domain terminology set forth in this and other related standards (i.e. SAE J2354, TMDD, others). This will allow for an efficient adoption by those who deploy technology within this domain, and not introduce unnecessary complexity by specifying these messages under a different standard body or methodology.

In terms of the available transport mechanism, all identified mechanisms included herein; DSRC, cellular, Wi-Fi, Bluetooth and NFC, have the ability to support some or all of the needs of this research task. In particular, for mobility only, any of the specified technologies could be used. In terms of safety messages, some of the higher-latency mechanisms may not be able to support the delivery of information within the timeframe required.

APPENDIX A. Definitions

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

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

System Engineering Tool for Intelligent Transportation (SET-IT)	A single software tool that integrates drawing and database tools with the Regional Unified Model Architecture so that users can develop project architectures for pilots, test beds and early deployments.
Thermometer	Hardware sensor that measures he temperature of air surrounding the device.
Transmitting	The state in which a traveler has opted in and is sending/receiving messages via mobile device.
Traveler advisory message	Connected vehicle message type which provides congestion, travel time, and signage information.
Trip Chain	A term used to describe the duration of a trip from origin to destination, including all nodes and links that a traveler encounters.
Trip Chain Phase	A duration of a trip chain in which a traveler is either at a node or traveling within a link. A phase can only include a node or a link, not both.
Uncoordinated	Messages are coordinated when one or more mobile devices have boarded a single vehicle (i.e. multiple passengers have boarded a bus), and are interpreted as a single, cohesive sender/recipient.
Weather Condition Message	Connected vehicle message type which communicates area specific weather information.
Wi-Fi	Local area wireless technology that allows enabled devices to connect to the Internet.

APPENDIX B. Acronyms

3G	3rd Generation (of mobile telecommunications technology)
ADA	Americans with Disabilities Act
AERIS	Applications for the Environment: Real-Time Synthesis Program
APC	Automatic Passenger Counts
API	Application Program Interface
APS	Accessible Pedestrian Signal
ASC	Actuated Traffic Signal Controller
ATDM	Active Transportation and Demand Management
ATIS	Advanced Traveler Information System
ATTRI	Accessible Transportation Technologies Research Initiative
AVAS	Automatic Voice Annunciation System
AVL	Automatic Vehicle Location
BLE	Bluetooth Low Energy
BSM	Basic Safety Message
CAD	Computer-Aided Dispatch
CAM	Cooperative Awareness Message
CAN	Controller-Area Network
CDMA	Code Division Multiple Access
ConOps	Concept of Operations
CSW	Curve Speed Warning
CVRIA	Connected Vehicle Reference Implementation Architecture
D-RIDE	Dynamic Ridesharing
DCM	Data Capture and Management
DENM	Decentralized Environmental Notification Message
DMA	Dynamic Mobility Applications Program
DMS	Dynamic Message Signs
DSRC	Dedicated Short Range Communications
DVI	Driver-Vehicle Interface
EDGE	Enhanced Data Rates for GSM Evolution
EEBL	Emergency Electronic Brake Light Application
EnableATIS	Enabling Advanced Traveler Information System
ETA	Estimated Time of Arrival
ETSI	European Telecommunications Standards Institute

EVAC	Emergency Communications and Evacuation
FHWA	Federal Highway Administration
FCW	Forward Collision Warning
FTA	Federal Transit Administration
GIS	Geographic Information System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Telecommunications
GTM	Government Task Manager
HDOP	Horizontal Dilution of Precision
HSPA	High Speed Packet Access
HSPA+	Evolved High-Speed Packet Access (HSPA+)
I2V	Infrastructure-to-Vehicle
IEEE	Institute of Electrical and Electronics Engineers
INC-ZONE	Incident Scene Work Zone Alerts for Driver and Workers
IDTO	Integrated Dynamic Transit Operations
iOS	Apple iPhone Operating System
ISO	International Organization for Standardization
I2V	Infrastructure-to-Vehicle
ITS	Intelligent Transportation Systems
LAN	Local Area Network
LCD	Liquid-Crystal Display
LED	Light-Emitting Diode
LTE	Long-Term Evolution
MAC	Medium Access Control
MAW	Motorists Advisories and Warnings
MIMO	Multiple Input, Multiple Output
MSAA	Mobility Services for All Americans
NDEF	NFC Data Exchange Format
NFC	Near Field Communication
NFCIP	Near Field Communication Interface and Protocol
OBE	On-Board Equipment (DSRC)
OEM	Original Equipment Manufacturer
OS	Operating System
PCW	Pedestrian in Signalized Crosswalk Warning Application

PED-SIG	Mobile Accessible Pedestrian Signal Systems
PHY	Physical Layer
PDOP	Position Dilution of Precision
PMM	Personal Mobility Message
PSM	Personal Safety Message
R.E.S.C.U.M.E	Response, Emergency Staging, Communications, Uniform Management, and Evacuation
RFID	Radio Frequency Identification
RESP-STG	Incident Scene Pre-Arrival Staging Guidance for Emergency Responders
RWIS	Road Weather Information System
SAE	Society of Automotive Engineers
SDK	Software Development Kit
SET-IT	Systems Engineering Tool for Intelligent Transportation
SPaT	Signal Phasing and Timing
SSID	Service Set Identifier
SysReqs	System Requirements
TCP/IP	Transmission Control Protocol/Internet Protocol
T-DISP	Dynamic Transit Operations
TOC	Transportation Operation Center
TRP	Transit Retrofit Package
UMTS (WCDMA)	Universal Mobile Telecommunications System (Wideband Code Division Multiple Access)
U.S. DOT	U.S. Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VDOP	Vertical Dilution of Precision
VDT	Vehicle Data Translator
VSL	Variable Speed Limit
VSM	Vehicle Situation Data Message
VTRW	Vehicle Turning Right in Front of Bus Warning
WAVE	Wireless Access in Vehicular Environments
Wi-Fi	Wireless Fidelity
WxTINFO	Weather Responsive Traffic Information
XML	Extensible Markup Language

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