Sharing and Using Connected Device Data to Improve Traveler Safety and Traffic Management—Concept of Operations, Use Cases, Traveler Information Needs, Messages, and Requirements

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FOREWORD

New and emerging sources of data generated from travelers using mobile devices, vehicles, infrastructure, and other sources provide agencies with opportunities to change how they manage traffic and their transportation systems. These data sources offer agencies an incentive to enhance or develop the capabilities of their transportation management systems to collect, compile, save, use, and share the data.

The Federal Highway Administration Office of Safety Operations, Research and Development (HRSO-1) is pleased to present this report, which provides information and strategies that can assist agencies as they evaluate, plan, or explore efforts associated with electronic message sharing in support of improving the safety, mobility, and experience of travelers using mobile devices.

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Director, Office of Operations
Research and Development

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16. Abstract
The ability to exchange electronic messages with mobile devices in realtime can to improve travel safety, mobility, and the experience for users of the surface transportation systems. Intelligent transportation system devices and traffic management systems using information derived from electronic messages travelers, vehicles, and other sources agree to offer new options for agencies to consider how to improve how they manage traffic and travelers. This report provides information and strategies that can assist agencies as they evaluate, plan, or develop efforts associated with electronic message sharing with mobile devices. As an introduction to the topic, the report provides an overview of the components involved with sharing and using these electronic messages and the needs of travelers to process and use this information.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1,000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ACRONYMS

3G	third generation
4G	fourth generation
5G	fifth generation
API	application programming interface
ATTRI	Accessible Transportation Technology Research Initiative
BIM	basic information message
BSM	basic safety message
CAM	cooperative awareness message
CANbus	Controller Area Network bus
CAV	connected autonomous vehicles
ConOps	concept of operations
CORS	continuously operating reference station
CV	connected vehicle
C-V2X	cellular vehicle-to-everything
DENM	decentralized environmental notification message
DMS	dynamic message sign
DSRC	dedicated short-range communications
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
GNSS	Global Navigation Satellite System
HMI	human-machine interface
HOT	high-occupancy toll
ID	identification
IT	information technology
ITS	intelligent transportation system
LTE	long-term evolution
MAP	map data message
MMTP	multimodal trip planner
MPO	metropolitan planning organization
MUTCD	*Manual on Uniform Traffic Control Devices*
NFCs	near-field communications
O&M	operations and maintenance
OBU	On-board unity
O/D	origin-destination
PDM	probe data management
PII	personally identifiable information
PSM	personal safety message
PVD	probe vehicle data
RFID	radio-frequency identification
RSE	roadside equipment
RSU	roadside unit
RTCM	Radio Technical Commission for Maritime Services
SE	systems engineering

SPaT	signal phase and timing
SRM	signal request message
SSM	signal status message
SysRS	systems requirements specification
TIM	traveler information message
TMC	traffic management center
TMS	traffic management system
TSMO	transportation systems management and operations
V2X	vehicle-to-everything
VRU	vulnerable road user

CHAPTER 1. INTRODUCTION

In the context of this document, mobile devices are defined as computers that can connect to the Internet and with other local devices, both stationary (i.e., traffic signal) and mobile (i.e., connected vehicles (CVs) or other mobile devices). The device is expected to be small enough for a traveler to hold and operate in their hand (e.g., mobile device, tablet). The device would typically have a liquid crystal display or an organic light-emitting diode flat-screen interface, and it would provide a touchscreen interface with virtual buttons and a keyboard. The connectivity feature and the ability to exchange electronic messages with other devices in realtime is fundamental to the goal to improve traveler safety and the experience for surface transportation system users. Information derived from electronic messages that travelers, vehicles, and other sources generate new options for agencies to improve how they manage traffic and travel when they are connected to existing intelligent transportation system (ITS) devices and traffic management systems (TMSs).[1] In addition, sharing electronic messages with mobile devices could be integrated into and used by TMS or transit management systems to support and enhance the performance of these systems while providing information that could support new services for travelers using a connected mobile device.

Although the concept of travelers agreeing to allow their connected mobile devices to share electronic messages with other connected mobile devices, connected and automated vehicles, or TMSs is still relatively new, early testing and research show the potential to improve traveler safety, mobility, and experience. Sharing and using these electronic messages offers users the following potential real-time and near-real-time applications:

- **Realtime**—Roadway hazard monitoring, speed warnings, cooperative intersection collision systems, probe data collection, and electronic payments.
- **Near realtime**—Traffic incident management (e.g., identification and verification of incidents), traffic signal operation and control, ramp management (e.g., metering), lane management, traffic information, weather monitoring, and parking management.

When appropriately configured, TMSs could share electronic messages with travelers using mobile devices to complete travel and traffic management-related tasks. Due to the many varieties of travelers using connected mobile devices, the information needed to share to support specific types of trips, operating environments, and desired outcomes, implementations may be unique to each agency. As such, agencies must understand the needs, implications, and resources that could be necessary to develop the ability to share and integrate electronic messages sent from connected mobile devices into managing and operating TMSs.

This report provides information for agencies to consider if they evaluate, plan, or pursue efforts to share electronic messages with travelers using connected mobile devices. This report also provides an overview of the components, technologies, and issues to consider when enabling

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[1] As more connected devices of different forms become available and are integrated into daily activities, additional electronic messages become available. Some of these messages may require or facilitate user consent to share (at least initially), but many, such as those generated by CVs, are shared as a function of their use in the connected ecosystem.

TMSs to share, collect, and process electronic messages with travelers using connected mobile devices. This report details the processes an agency could consider when developing a project or fostering an ecosystem to enable travelers using connected mobile devices to exchange electronic messages with TMSs and other service providers for a range of different services or scenarios (e.g., parking, incidents, travel time, roadway condition information, and other possible uses). These processes could be initiated with a planning study (e.g., feasibility study, planning project) or by the development of a project followed by additional design and eventual implementation. Agencies are encouraged to follow a structured systems engineering (SE) process to ensure the proposed effort would align with the agency, an operations program, or TMS goals and with the needs and expectations of travelers who use connected mobile devices and agree to share and use electronic messages.

The concept of operations (ConOps), scenarios, and use cases included herein demonstrate how technology can serve the needs of travelers who agree to allow their connected mobile devices to share and use electronic messages to improve their trips, depending on the TMS or transit management system's vision, objectives, and capabilities. Several concepts, scenarios, and use cases are provided as examples of how the SE process can be used to align the unique needs of an agency as it assesses the feasibility and plans for a prototype or deployment of project or initiative to enable its TMS and/or transit management systems to share and use electronic messages with connected mobile devices.

SHARING OF ELECTRONIC MESSAGES WITH CONNECTED MOBILE DEVICES

The collection of electronic messages and their sharing among transportation agencies' TMSs, travelers using connected mobile devices, and others managing or supporting travelers on the surface transportation network has historically relied on permanent or portable ITS devices (e.g., changeable message signs, portable changeable message signs, rotating signs). In the past, travelers obtained information and directions solely through traffic control devices (e.g., signs, pavement markings, changeable message signs). While transportation agencies could monitor system conditions and collect data through various ITS components and TMSs, one limitation of TMSs was the inability to shift the location of installed vehicle detectors, surveillance cameras, and other sensors. The advent and prevalence of cellular phones—and particularly smartphones—provide a significant opportunity for agencies to share and collect electronic messages with these mobile sources to improve how they manage and operate the surface transportation system.

The current functionality and data available to travelers through their smartphones is significantly greater than 10 yr ago and continues to advance. Travelers use smartphones with nearly every travel mode—automobile, pedestrian, bicycle, transit—to plan routes, make en route adjustments, and even pay for services. These functions are typically performed by using applications installed on a mobile device or by using data generated and transmitted wirelessly by a service provider (e.g., subscription or service fee). This wireless transmission of information to or from a traveler's mobile device requires an Internet connection (e.g., Wi-Fi, third generation (3G)/fourth generation (4G), and Long-Term Evolution (LTE)), which is typically obtained through a paid subscription service from a data provider. Although there are limitations to these proprietary Internet access subscription services to allow mobile devices to share and receive electronic messages, the value of these data is apparent in the growing use of third-party data aggregators. These third-party companies—through user agreements—compile and sell information based on the use of this archived data from individual app services that show user locations and routing data.

While not commercially available, as defined in this document, a mobile device would possess the same general capabilities and features as a smartphone, with the added ability to communicate directly with other devices or local infrastructure via short-range wireless communication technologies. Previous CV demonstration projects have modified and enabled mobile devices to send and receive electronic messages (e.g., tethering smart phones with a dedicated short-range communications (DSRC) radio in the 5.9-GHz spectrum). The specific technology is not critical, however, as long as it is interoperable with other mobile devices. Research has shown that this configuration of handheld mobile devices could further leverage electronic messages through direct device-to-device or device-to-infrastructure interfaces, which would increase the functionality available to both travelers and agencies.(1)

In addition to the features generally provided on today's smartphones, a mobile device's wireless communication may allow for the following key benefits:

- Communication of a device's current location with a high degree of accuracy.
- Communication of safety-critical information at low latency.
- Communication with other devices without user input.

An added benefit (or expectation) of the short-range feature of the mobile devices is that it does not require use of a traditional mobile Internet service provider (i.e., no data plan). Thus, the messages exchanges are "free" when thought of in the context of traditional cellular plans.

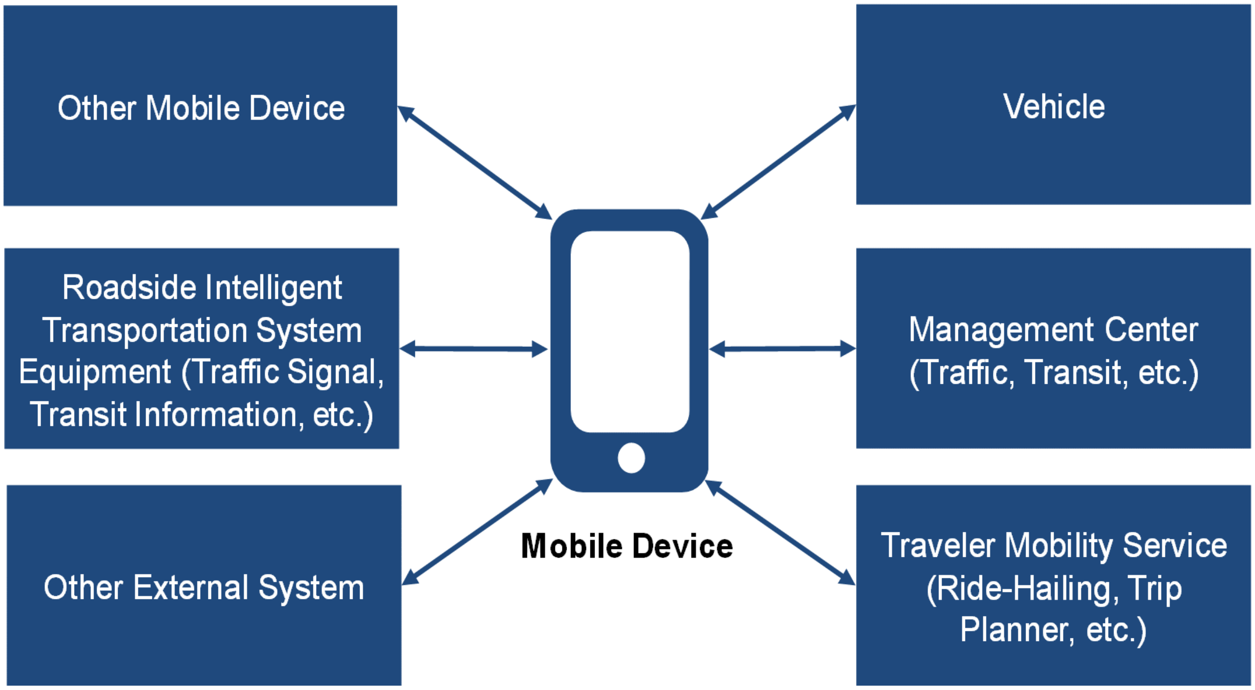
Limitations exist, however, including the following two:

- Global Navigation Satellite Systems (GNSS) (known as the Global Positioning System in the United States), which are often used to determine device location, are subject to reduced accuracy or no service when a mobile device is located inside of a traveling vehicle, and even more so, when that vehicle is traveling in dense urban environments, tunnels, parking structures, and other locations where a clear sky is not available.

- The hardware that supports low latency information exchange was generally designed by using fixed location installation with reliable power, and it was not battery powered. This installation type may limit the operational time for these mobile devices.

Neither of these limitations prevents mobile devices from performing as indicated in most of the use cases. Limitations aside, these features of a connected mobile device allow it to share data on user surroundings, thus eliminating required user actions and broadening the availability of service to the user. Agencies that opt to deploy infrastructure that allows mobile devices to wirelessly connect with local infrastructure are then able to aggregate data to better understand traveler behavior and system performance.

Figure 1 provides a simplified overview of the breadth of systems that a traveler with a connected mobile device could choose or elect to exchange electronic messages. Later chapters in this report describe how sharing these electronic messages could occur, along with the requirements and resources (e.g., application programming interface (API), software, antennas to send and receive messages) to enable this exchange.



Source: FHWA.

Figure 1. Diagram. Mobile device communications with external systems.

CURRENT CAPABILITIES

The concept of sharing electronic messages with connected mobile devices to improve a TMS' traffic management capabilities is still relatively new. Research has been conducted nationally on the data that may need to be shared to meet a traveler's decision and information needs for specific trips or use cases.[2]

Related to vulnerable road user (VRU) safety, several transportation agencies have commenced pilot deployments of these concepts beyond simply preliminary research. New York, NY, and Tampa, FL, have both initiated systems by using connected mobile devices in two similar applications: mobile accessible pedestrian signals, and pedestrian-in-signalized-crosswalk warnings.(2,3) A mobile accessible pedestrian signal system allows low-vision or blind pedestrians to request a pedestrian crossing from a traffic signal controller using a portable personal device (e.g., smartphone) and provides audible information to the pedestrians regarding the signal status, thus improving their ability to safely cross the street. The pedestrian using a signalized crosswalk warning application uses mobile devices and pedestrian detection

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[2] Use cases are used to define the purpose of systems and software. Use cases are often characterized as scenarios that demonstrate the interaction of systems and software from the viewpoint of the user.

infrastructure to deliver warnings to CVs, alerting the vehicles of pedestrians in the roadway. At the same time, pedestrians who carry a mobile device could be warned of any vehicles nearing them by using the same direct wireless technology, which would allow the pedestrian to take action to avoid conflict.

Currently, while many service providers offer free traveler-related information, there is no standard for the exchange of electronic messages with travelers using connected mobile devices Instead, each agency would decide to work with users of connected mobile devices and companies that support mobile devices to enable the agency to share and/or collect data with these devices.

PURPOSE OF THIS REPORT

This report is intended to support public agencies interested in planning for or developing a project or initiative to enable a TMS or transit management system to share and collect data from a connected mobile device being used by a traveler. This report presents how the SE process, including the development of a ConOps, scenarios, use cases, and requirements could lead to the sharing and use of data generated by connected mobile devices and traffic and transit management systems. Specifically, the report performs the following actions:

- Explores how ConOps and use cases could be developed or used when planning, developing, and designing projects to facilitate data sharing between connected devices, vehicles, and TMSs.

- Identifies how agencies could develop or use system requirements, electronic messages and data elements, and other issues that support any project to share or collect data between these devices, systems, and vehicles.

The report identifies issues from previous research and development efforts to consider when assessing the capability of current or any planned future improvements to an agency's TMS and or transit management systems in support of collecting, saving, using, and sharing electronic messages with connected mobile devices. The SE concepts detailed in this report can be used to support tracing the applicable vision, goals, and objectives that may exist within a strategic plan to the expected outcomes and performance of a proposed project by developing ConOps and operational scenarios. Several examples are provided of how the SE process can be used to identify and address the issues unique to the environment, where a project is being contemplated to enable the sharing and use of electronic messages with a TMS or transit management systems.

INTENDED AUDIENCE AND HOW TO USE THE REPORT

The target audience for this document is primarily transportation operations professionals involved in managing, participating in, and/or supporting efforts that collect or share messages, compile data, and use this information in operating TMS, transit applications, or transit management systems. Although the range of users may be large, the primary audience is anticipated to be the following types of audience groups:

- **Transportation agency information technology (IT) staff**—IT staff involved with supporting the data management and security issues surrounding the data exchange.

- **Transportation agency project managers—**Research and/or project managers charged with delivering a framework for the data exchange.

- **TMS leadership—**Managers of the TMS who operate and oversee the data exchange.

Each of the aforementioned audience groups have different roles, responsibilities, and concerns, and each agency's project or use case would differ. A reader may focus on individual chapters, depending on which information is most necessary from their individual role or responsibility to move a project forward. The use of this report may include gathering background information; learning the requirements needed to share electronic messages; planning and developing a project; or defining a process for developing user needs, scenarios, use cases, and requirements. As such, the report is organized in a manner that does not require it to be read cover to cover. Early chapters provide foundational information, and concept development is widely understood. Later chapters, which focus on specific use-case development and technical requirements, are intended for operations and SE staff.

DOCUMENT ORGANIZATION

Each chapter of this report is described as follows:

- **Chapter 1. Introduction:**
    - Provides the motivation for this research effort.
    - Explains the scope of the document.
    - Presents the target audience and document organization.

- **Chapter 2. Mobile Device Data Sharing and Uses—**Describes the operations of existing systems that motivate the development of the proposed mobile device-based system.

- **Chapter 3. Concept Development—**Presents considerations for developing mobile device-based system concepts.

- **Chapter 4. Information Needs of Travelers Using Connected Mobile Devices**:
    - Outlines the types of information travelers need.
    - Outlines spatial and temporal aspects of decisionmaking.
    - Introduces the concept of positive guidance.

- **Chapter 5. Developing A Desired Operating Environment**:
    - Discusses the process of developing and defining the scope of a project, which could occur during the concept stage of a project.
    - Introduces the SE processes that would allow the desired environment to be successfully realized.

- **Chapter 6. ConOps:**
    - Provides an approach to support evaluating what may be needed to enable TMSs and transit management systems to support collecting and sharing messages with connected mobile devices.
    - Identifies and addresses typical issues encountered in studies to assess and evaluate what improvements could be needed to support use cases where connected devices may share data with TMSs.

- **Chapter 7. Requirements for Sharing Electronic Messages with Mobile Devices—** Identifies possible system requirements to enable TMS and transit management systems to share messages with connected mobile devices.

- **Chapter 8. Concept 1: Traveler Walking and Using a Connected Mobile Device—** Explores the process and issues to consider with developing or using a use case specific for TMS and transit management systems that share messages with a pedestrian's connected mobile devices.

- **Chapter 9. Concept 2: Traveler Riding on a Bicycle and Using a Connected Mobile Device—**Explores the process and issues to consider with developing or using a use case specific for TMS and transit management systems that share messages with a bicyclist's connected mobile device.

- **Chapter 10. Concept 3: Traveler Using Public Transit while Using a Connected Mobile Device—**Explores the process and issues to consider with developing or using a use case specific for TMS that share messages with a transit rider's connected mobile device.

- **Chapter 11. Concept 4: Traveler Riding in a Motor Vehicle Using a Connected Mobile Device—**Explores the process and issues to consider with developing or using a use case specific for TMS and transit management systems that share messages with a driver's connected mobile device.

- **Chapter 12. Concept Implementation—**Discusses items local/State agencies could consider in the planning and possible deployment of the concepts described in chapters 8–11.

- **Chapter 13. Systems Issues to Consider**—Presents the potential implications (e.g., operations, maintenance, and organizational impacts) of making the changes to a TMS and transit management system to collect and share messages with connected mobile devices.

- **Chapter 14. Analysis of Mobile Device-Based Systems**—Analyzes the benefits, limitations, advantages, disadvantages, and alternatives and tradeoffs considered for the proposed changes to a TMS and transit management system to collect and share messages with connected mobile devices.

CHAPTER 2. MOBILE DEVICE DATA SHARING AND USES

CHAPTER OVERVIEW

Sharing information between a transportation agency, service provider, and travelers using connected mobile devices requires a complex system of components working together in a collective ecosystem. To successfully transmit and receive messages, each connected mobile device, system (e.g., TMS, transit management system), or component needs to serve a defined role and contribute to the overall system. Understanding these components and their relationship within the ecosystem is an important step before any project planning, SE, or design takes place.

This chapter provides a high-level overview of each component required within the mobile device data-sharing ecosystem, including the following elements:

- **Mobile devices—**Hardware that enables the information sharing to/from the traveler.
- **Electronic messages—**Information that is exchanged or shared between various devices.
- **Software—**Program that generates or synthesizes the shared information for the benefit of the traveler or the system (TMS, and so forth).
- **Communication services—**Medium over which information is exchanged, including security and latency.
- **TMS (or similar infrastructure systems or devices)—**Platform that collects and synthesizes traveler data to monitor and manage operations and provide information to the traveler.

Each of the aforementioned components can be satisfied from a range of various options (i.e., vendors), which could potentially result in numerous ecosystems that are unique combinations specific to the situation. Agencies must understand each component as it applies to the specific situation. This document does not convey any of these components, but simply describes what capabilities must exist to fulfil the exchanging of electronic messages with a mobile device used by a traveler.

The computing hardware, software, messages, and communication services that comprise the mobile device, as well as the types of information exchanges, would need to be identified for each situation and location. This assessment would ensure that the needs specific to the location, the modes of travel, and the traveler's desired actions are considered. Similarly, the interface to display information or allow for traveler interaction on the mobile device can also vary, based on the project.

Although there are numerous types of standardized electronic message to support the exchange of information, each situation might involve different electronic messages. As an example, specific information in new types of electronic messages may be needed to obtain the status, location, or issue and to receive an active request (e.g., request walk indication at traffic signal). The ecosystem within which this exchange of electronic messages occurs includes the hardware (e.g., mobile device, ITS device), software (e.g., mobile device API, ITS device), and available communication methods to enable the transmission and receipt of these messages. This ecosystem enables an agency or service provider to collect, distribute, and store information generated from these messages in support of managing and operating these services.

Detailed descriptions and examples for each of these components follow. This information is provided to identify the current capabilities of a TMS (i.e., would the TMS enable the required transmission and receipt of electronic messages) to prepare, send, receive, process, and use data from electronic messages to carry out the required functions to incorporate this information into the mobile device and TMS operation. A standalone planning study would be appropriate to evaluate the needs of travelers, agency resources that may be needed, changes required to ITS devices and the TMS, and other issues to consider as a part of a larger project scope to develop and initiate the ecosystem to enable the exchange of these electronic messages.

SHARING INFORMATION WITH TRAVELERS

Many travelers rely on the ability to send and receive information to plan and execute their trips. The type of information that may be needed differs for each user, depending on the type of trip, mode of travel, and decisions by the traveler. The timing of information could also differ, depending on whether the decisions are made by the traveler en route or pretrip.

What, when, and where information is needed by a traveler may vary based on the type of decision being made, mode of travel (e.g., driver of vehicle, pedestrian), facility (e.g., freeway, local street), and location (e.g., midblock, approach to intersection). Drivers require roadway network information for routing decisions and roadway and weather conditions for timing decisions. Roadway users require information for avoidance decisions. Pedestrians and bicyclists rely on many of the same types of information as drivers but with additional nonmotorized needs related to comfort and safety, crossing availability, and potential accessibility accommodations. Transit and shared-mobility users require information on service availability, schedules and routing, amenities, and cost. Transit and shared-mobility modes have the additional requirements of requesting service and providing payment.

Traditional en route methods of information exchange are one-way and occur through agency-owned infrastructure within the public right-of-way. The information exchange is based on the location of the traveler, the decision being made, and the priority of what information could be provided through an agency’s traffic control devices. For roadway travel, signs are placed in advance of when a driver would need that information and are based on the driver’s expected speed of travel, visual ability, and perception and reaction times. For transit, exchanges typically occur at the station or on the vehicle when service is provided. Traffic control devices notify road users of regulations and provide warning and guidance needed for the uniform and efficient operation of all elements of the traffic stream.

What, when, and where information is needed by a traveler will vary based on the type of decision being made, mode of travel (e.g., driver of vehicle, pedestrian), facility (e.g., freeway, local street), and location (e.g., midblock, approach to intersection).

Based on the type of traffic control device, the exchange of information can be visual, audible, or haptic in delivery—whereby each relies on a different human sensory reception, traveler's expectation, type of device, and information being conveyed. Examples of visual information exchanges include traditional roadway signs, pavement markings, and electronic displays. Audible information could include vehicle horns or sirens, accessible pedestrian signals, and public address announcements. Haptic information exchanges occur when there are changes in the texture of a surface, such as surface treatments (e.g., transverse and longitudinal rumble strips, raised pavement markers, tactile curb ramps), or when feedback is received from input devices (e.g., vehicle switches, crosswalk pushbuttons, haptic feedback from a smartphone).

Over time, the addition of ITS devices has allowed for more dynamic and real-time information sharing, but that information sharing has largely remained static in location. As an example, an agency could use loop detectors in a static location to detect congestion in realtime, which could then be converted to travel time and posted on a dynamic message sign (DMS).

Drivers are becoming increasingly accustomed to using smartphones, integrated in-vehicle systems, or other connected devices to receive information in near realtime about wayfinding, crashes, and traffic conditions. Some travelers also use these devices to report information such as crashes observed while en route.

ELECTRONIC DATA EXCHANGES

Information exchange with transportation users, regardless of mode, has recently evolved to include many forms of portable electronic methods, such as websites, smartphone apps, radio-frequency identification (RFID) tags, near-field communications (NFCs), and stored-value payment cards. Each of these methods is described in the following subsections.

Websites

Websites provide transportation users, agencies, and service providers with a wide range of information exchange options. Information can be disseminated to users related to roadway conditions (e.g., closures, construction activity), traffic conditions (e.g., speed, congestion, incidents), service schedules (e.g., bus, train), and other data. This information dissemination can be static or realtime in nature, although real-time information is more useful for user decisionmaking.

Transportation agencies typically host data on agency websites (e.g., a 511 (traveler information) website) that allow a limited one-way information exchange. Transit service agencies and providers typically utilize websites for two-way exchanges by offering account management, status requests, service requests, and payment options. Access to these information sources requires Internet access, and users may need to visit separate sites for each entity. Advances in open-source data and the monetization of transportation-related data has led to aggregator websites that combine numerous data sources and provide a single platform for users to plan, develop routing decisions, and execute their trips. However, the ability to make reservations and payments for all applicable services may not be possible through aggregator websites.

Smartphone Apps

Smartphone apps operate like websites and provide much of the same information and utility as the full websites but in a mobile form. Like websites, these apps are distinct and self-contained programs that run on the smartphone operating system. The primary benefit of apps is the portability of the data, which allows en route updates and real-time decisionmaking. Users can interface with the app through the smartphone's controls and touchscreen.

RFID

RFID, in the transportation environment, allows one-way information exchange to take place between an issued tag (user) and an infrastructure-based reader (owner). This technology is widely used in electronic tolling, parking, weigh-in-motion, fuel dispensing, and fleet management applications. RFID tags, which consist of a memory chip and antenna, are assigned a unique identifier that is linked to personal information, including, but not limited to, vehicle, driver, and account information. Infrastructure-based RFID radios detect the passage or presence of an RFID tag typically mounted on or carried within a vehicle. The technology allows for data exchange at high travel speeds and without contact—tolling on interstates is an example of both benefits. By linking the unique identifier to stored account information, the RFID systems can include payment transactions.

NFC

NFC is a specialized subset of RFID technology that is characterized by devices being capable of being a tag and a reader. NFC is based on higher radiofrequencies and requires much closer proximity (several centimeters), which allows for more secure transactions. Nearly all smartphones sold in recent years contain NFC capabilities, which have allowed the development of contactless payment apps. These apps—once set up with payment information—can be used at a service provider's payment terminal that is also equipped with NFC. The benefit of such payment services is that they are relatively quick, and an Internet connection is not needed for the transaction.

Stored-Value Payment Cards

Stored-value payment cards are similar in form to credit or debit cards but differ significantly in their function. Unlike credit and debit cards, stored-value payment cards are not linked to financial institutions and are not associated with an individual or account. The amount of money stored on the card is deposited at the time of purchase and may be reloaded with additional funds or may be a one-time use. The cards are widely used in public transportation systems and parking venues to manage fare payment while eliminating the need to manage cash—funds are withdrawn directly from the card. Connecting or communicating with a central system is not needed to process the payment because there is no account. Like cash, stored-value payment cards are anonymous because any person holding the card can use the funds. One drawback is that lost cards cannot be traced to the previous owner.

Although the electronic data exchange methods described in this chapter provide utility and convenience to the user and agency or service providers, several key shortcomings exist:

- The most robust of the service platforms requires Internet access through cellular 3G/4G LTE service or Wi-Fi (privately or publicly accessible) connectivity. In areas where Internet access is limited or for people who do not subscribe to a data plan, these platforms and services may not function.

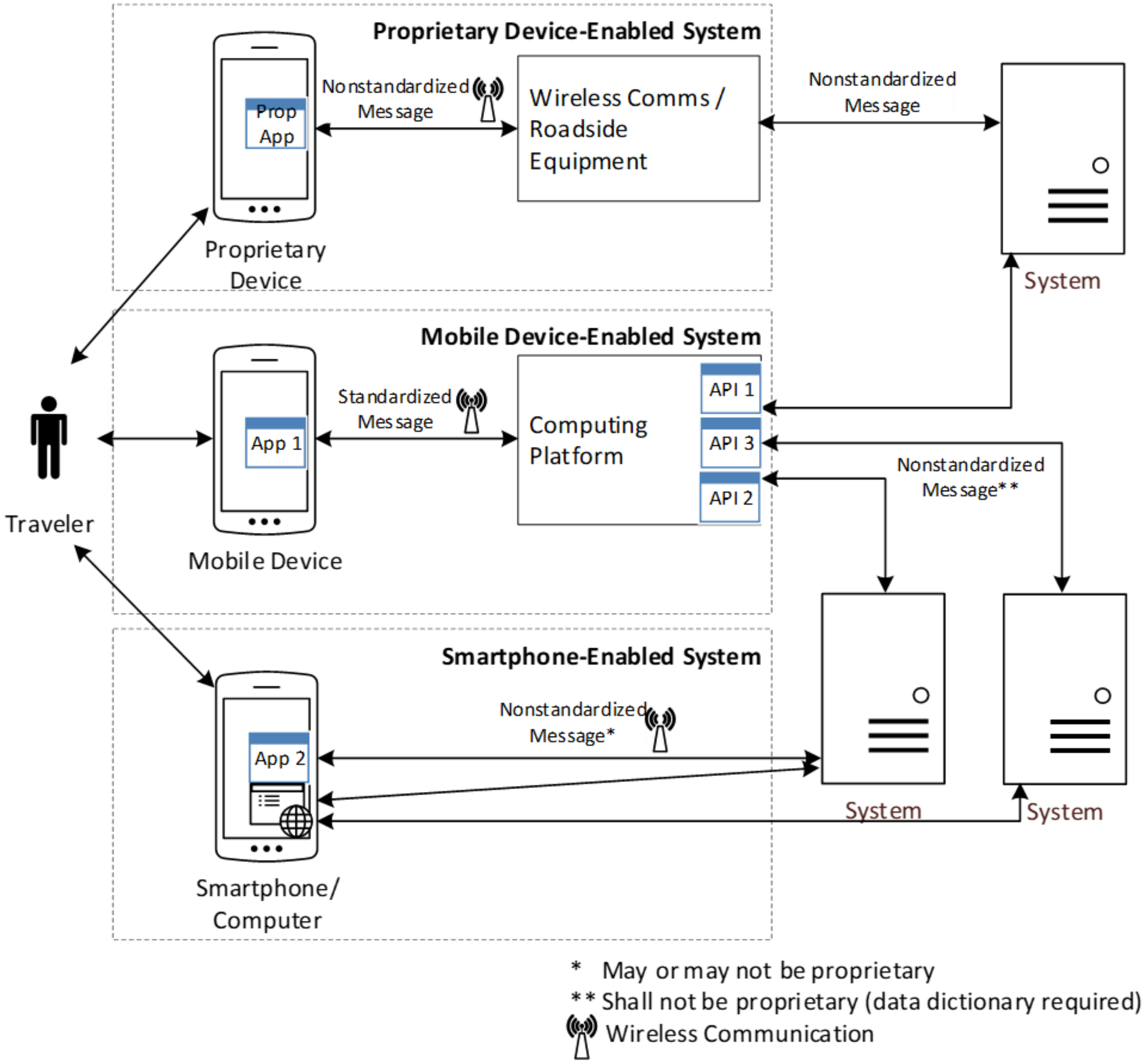
- Several systems are limited to data consumption only and do not broadcast data, which prohibits any communication with other devices. This communication constraint limits functionality to user-provided input and eliminates potential data collection by the system owner/operator, which could increase real-time situational awareness and future planning efforts.

- Most of the systems are typically operated on proprietary platforms and/or devices requiring travelers to access and utilize different specialized applications to interact with each service. Because the interface and content are based on proprietary and nonstandard data messages, interoperability is limited, and data—even if provided open source—require significant manipulation.

MOBILE DEVICES

As mentioned in chapter 1, a mobile device is a computer that can connect to the Internet, is small enough for a traveler to hold and operate in the hand, and has the same capabilities and features of a smartphone but potentially with the added ability to communicate via other wireless communications methods such as DSRC or cellular vehicle-to-everything (C-V2X). Since smartphones do not presently have vehicle-to-everything (V2X) capability, either in the form of DSRC or C-V2X, a mobile device consisting of a smartphone tethered to a mobile battery powered V2X radio via Bluetooth® would transmit and send electronic data.

One aspect that differentiates mobile devices from other existing technologies is the ability to communicate standardized messages with a computing platform. The computing platform utilizes APIs that “translate” similar types of data from different types of systems into standardized messages, which are then communicated to the mobile device via a wireless communications method. The advantage of mobile device communications is interoperability between multiple systems that have infrastructure that supports communications with mobile devices. Figure 2 illustrates the functionality of mobile devices in relationship to devices/platforms and smartphones and the role of APIs.



Source: FHWA.
Comms = communications.

Figure 2. Flowchart. Communications paths for mobile devices versus other technologies.

The extent to which a mobile device exists in today's transportation environment is dependent on smartphones and other wireless electronic devices such as tablets' ability to support the desired features of a mobile device. Thus, identifying the specific features of smartphones that provide utility to mobile devices is important. Smartphones are characterized as handheld computers exhibiting a set of standard features, such as an operating system, access to various communications technologies, and hardware/software sensors. Applications (apps) are the software installed on the smartphone that take advantage of the smartphone's features to provide a service to the user. All components mentioned previously are contained in a mobile form designed to be carried on the person.

The operating system manages the smartphone’s hardware (e.g., processor, memory, sensors) and software (i.e., application) resources. As of August 2022, the market share of smartphone operating systems in the United States is dominated by iOS (57.02 percent) and Android™ (42.69 percent) with less than 2 percent of smartphones using an operating system other than Android or iOS. Smartphones exhibit a variety of communications media, including cellular (3G/4G LTE), satellite, Wi-Fi, Bluetooth, and NFC, which are discussed in chapter 2, Communication subsection.[1]

Smartphones contain several sensors that detect movement and proximity of the device. An accelerometer and gyroscope detect linear and angular acceleration along three axes. A magnetometer detects direction with respect to the smartphone’s reference axis. A proximity sensor determines whether there is an object within a certain distance of the face of the phone (typically used during phone calls to determine when the screen should automatically turn off). In addition, ambient light sensors are included (typically used to autoadjust screen brightness to enhance usability).

Certain smartphone features may also be found in other forms, including, but not limited to, tablets and laptops. Though these devices are generally not as widely used as smartphones by travelers in the transportation environment, the use of these alternative methods to access data while en route should be considered.

ENABLING ELECTRONIC MESSAGE SHARING WITH MOBILE DEVICES

The operation of a mobile device depends on the collective capabilities of systems within a region that provide the ecosystem that enables electronic message sharing and use with mobile devices. This ecosystem ultimately determines which traveler-based use cases can be supported; enables agencies and communities to improve safety, mobility, and reliability; and enables agencies and communities to provide increased services to travelers who carry a mobile device.

The information needed by travelers to make informed decisions throughout a trip relies on other (external) systems that make that information available. For instance, a transportation agency maintains a system that makes transportation-related data available, or a transportation service provider maintains a system that makes the location of its fleet available. These external systems can take several different forms:

- **Management systems—**A traffic management center (TMC) (e.g., traffic speed data), transit management system (e.g., real-time transit data), a toll management system, or a system that manages a ridesharing/ridesourcing platform or service.
- **Infrastructure—**Traffic signal controller, a DMS, an electronic toll sign, or a transit arrivals board.

The information needed by travelers to make informed decisions throughout a trip is reliant on other (external) systems that make that information available.

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[1] GlobalStats Stat Counter. n.d. “Mobile Operating System Market Share United States Of America” (web page). https://gs.statcounter.com/os-market-share/mobile/united-states-of-america, last accessed September 12, 2022.

- **Payment systems—**Transit payment system, a toll payment system, or a parking payment system.

- **Mobile systems—**In-vehicle CV devices, smartphones, or other mobile devices.

These external systems need data transmission and data collection capabilities and use methods compatible with mobile devices. Enabling electronic data sharing with mobile devices is characterized by the following three features:

- Electronic messages (content).
- Software and hardware (processing).
- Communication media (transmission).

The remainder of this chapter provides an overview of these features of mobile device-based systems to send and receive messages with vehicles, other mobile devices, or systems (e.g., transit management, traffic management).

Electronic Messages

The transmission of electronic messages between mobile devices and other connected devices or systems relies on wireless technologies. These messages support the decisionmaking needs of the traveler. The transmission contains the necessary data related to the user, the transportation system, and/or the requested service to provide the intended use case. However, if every system provides different data or even the same data in a different format, any device that intends to receive electronic messages from any of those systems would need to know the format of that data to make use of it. Messages sent between mobile devices and other systems allow for interoperability across agencies and service providers and across geographic regions.

Three primary standards are related to electronic messages in transportation:

- SAE J2735.(4)
- European Telecommunications Standards Institute (ETSI) TS 102 637.(5)
- General Transit Feed Specification—Realtime.(6)

The following existing types of messages developed for SAE J2735 contain many of the elements that may be needed for future user applications.(4) It is possible that these messages could directly support future operations; however, new electronic messages might also be needed to fully develop future concepts:

- **Basic Safety Message (BSM)—**The BSM is used in a variety of applications to exchange safety data regarding vehicle location and motion. This message is broadcast frequently to surrounding vehicles with data content as needed for safety and other applications. Transmission rates are beyond the scope of this standard, but a rate 10 times per second is typical when congestion control algorithms do not prescribe a reduced rate.

- **Signal Phase and Timing (SPaT) message—**The SPaT message provides signal phase and timing information for a signalized intersection. It can be linked to movements defined in a map data message (MAP) so that signal states can be applied to each movement.

- **MAP—**The MAP contains intersection/roadway geometry data and is typically broadcast from the roadside unit (RSU) and received by vehicles and mobile devices so that these devices can determine their position with respect to the roadway. At an intersection, a MAP can be paired with SPaT data so that an intersection state can be applied to each intersection movement.

- **Traveler Information Message (TIM)—**The TIM contains advisory information used by vehicle operators. A TIM is sent from the roadside to vehicles that subscribe to receive TIMs. The TIM protocol provides the location and situation (e.g., vehicle speed) parameters that must be met for the TIM to be delivered to the vehicle operator. For instance, a TIM that advises a vehicle operator of a speed limit in a designated area would only be displayed to the vehicle operator when the vehicle is approaching the area and if the vehicle operator is traveling above the speed limit within the area.

- **Signal Request Message (SRM)—**The SRM contains data used to request signal preemption or signal priority from a signalized intersection. These data include the desired movement, the priority type (priority or preempt), and the priority level. In addition, the SRM includes the estimated time of arrival and duration of service data fields. These data items are essential to ensuring that all vehicles traveling in a platoon can be accommodated in the priority request and can move through the intersection at once if the request can be granted. These messages are sent from vehicles that require preemption or priority at an intersection and are received by a RSU and forwarded to the roadside equipment (RSE). When SRMs are received from multiple vehicles, the transportation service center or other processing equipment arbitrates the requests based on the priority level of the request.

- **Signal Status Message (SSM)—**The SSM contains data regarding the operational state of the intersection (e.g., normal, priority, preempt). This message is sent from an intersection to relay information to a vehicle regarding whether the signal priority request parameters were accepted by the intersection. Data contained in this message can be populated by using the output from a National Transportation Communications for Intelligent Transportation System Protocol 1202-compliant traffic signal controller.(7)

- **Personal Safety Message (PSM)—**The PSM transmits a mobile device's position, speed, and heading, among other information. For a general collision avoidance application, surrounding vehicles could receive the PSM, and along with its own telematics, determine whether a collision is imminent. The V2X Hub broadcasts an early prototype version of this message that is slightly different than the approved standard but contains the same core elements.(8)

- **Probe Vehicle Data (PVD) message—**The PVD message collects vehicle status data over a defined distance and/or time in a structured manner and provides it to the infrastructure. The infrastructure can forward these data to a TMC, where they can be used for traffic management purposes. A vehicle is expected to provide PVD in accordance with parameters specified in the probe data management (PDM) message.

- **PDM—**The PDM message could specify the data, the frequency of collection, and delivery from the connected autonomous vehicles (CAV) or connected mobile device back to the RSE. The limited range or number of RSU could influence the use of PVD messages (as described in the previous bullet) to fill in the gaps in coverage, in case cellular technology is not available. The probe management process involves sending the PDM message from RSUs to the vehicles to specify how the vehicles gather and report data (i.e., at what frequency and including what detail).

The following are existing messages developed for ETSI TS 102 637 that contain many of the elements required for future user applications.(5) These messages could directly support future operations; however, new electronic messages might also be needed to fully develop future concepts:

- **Basic Information Message (BIM)—**A BIM is a proposed new message format that enables the transmission of all required data elements for vehicle-to-infrastructure safety applications in a single message and is extensible to support future event-based applications. This concept of message structure uses existing SAE J2735 data elements.(4)

- **Decentralized Environmental Notification Message (DENM)—**The DENM provides information regarding 13 use cases: emergency electronic brake light, wrong way driving warning, stationary vehicle (e.g., accident, stationary vehicle), vehicle problem, traffic condition warning, signal violation warning, road work warning, collision risk warning, hazardous location, precipitation, road adhesion, visibility, and wind.

- **Cooperative Awareness Message (CAM)—**The CAM provides information on presence and positions as well as the basic status of communicating ITS stations to neighboring ITS stations located within a single-hop distance. This information includes vehicle position and vehicle basic data (e.g., acceleration, path history, curvature, vehicle size). CAM supports 32 use cases in 4 application classes, including active road safety (e.g., emergency vehicle warning), cooperative traffic efficiency (e.g., regulatory speed limit notification), cooperative location services (e.g., parking management), and global Internet services (e.g., insurance and financial services).

A known standard allows any device to receive the message, understand the data, and act on the information. When the data frames and data elements that are included in standardized messages are developed, data contained in the message could enable the applications that they are intended to support.

While existing standards are relatively robust, a specialized data structure may be needed, based on specific situations, to deliver content that current standards do not support. When specialized data structures are used, it is especially important to develop accompanying support materials (e.g., a data dictionary and an API) to make the message data available, to support the developers of systems that may need to populate, or to decode the data contained in the specialized data structure.

Software and Hardware

The communication between mobile devices and other connected devices or systems relies on software and hardware that allow the devices or systems to carry out specific functions, tasks, or actions. These software and hardware typically involve taking a data input, processing it (potentially also using data from other sources), and generating an output that could be used as input to another device.

Connected device hardware includes a processing unit, internal memory, communications antennas, and a human-machine interface (HMI) (e.g., audio, visual, and haptic). These physical components can be integral to infrastructure equipment and vehicle apparatus or provided in a separate form.

Software installed on the mobile device and connected devices/systems provides functionality. On a mobile device, for example, this software performs the computations necessary to interpret data received in an electronic message, determine whether conditions are met for an electronic message to be sent, determine whether information must be provided to the traveler near a decision point, or determine whether conditions warrant sending a safety warning to a traveler. On external systems, these software platforms could be APIs that allow system data to be communicated in electronic messages to mobile devices (or to receive electronic messages from mobile devices) and to decode and use these data for system management purposes.

Applications (service packages) are a combination of one or more functions that work together to deliver a given service and the information flows that connect them with other important external systems. Mobile devices typically access data provided by various external services using an API, which provides a means of receiving/providing data from/to systems using proprietary nonstandard messages.

One unique aspect of mobile devices is the concept of an intermediary computing platform that enhances connectivity between mobile devices and other connected systems. This computing platform enables the integration of data streams from multiple sources and standards and provides connectivity between various systems, such as ITS hardware, traffic or transit management centers, shared-mobility providers, smartphones, cloud services, and vehicle systems, using any number of communications methods. The major benefit of intermediary computing is that it can provide a single point of contact for the mobile device to allow it to connect to multiple external services.

As an example, the V2X Hub, which was developed as part of the U.S. Department of Transportation's ITS program, is a software platform that enables CVs to talk to existing infrastructure and systems.(8) The V2X Hub simplifies integration by translating communication between different standards and protocols through APIs. On the roadside, a computing device hosts the computing platform and supports the exchange of electronic messages (such as BSM, SPaT, and MAP) between several devices on the roadside, including, but not limited to, a V2X radio, traffic signal controller, DMS, and TMSs (via backhaul). The in-vehicle device provides the interface between a V2X radio and a driver. The key feature of the V2X software is its modular architecture and use of customizable plugins, which allows the solution to be tailored to suit the needs of agencies, drivers, and mobile device users and allows an agency to easily expand or reconfigure the solution as needed.

Communication

The data sharing between mobile devices and other connected devices or systems requires a communications path. Due to the nature of mobile devices, available communication methods are wireless. Wireless forms of communication available to mobile devices include cellular (3G/4G LTE), satellite, Wi-Fi, Bluetooth, and NFC. Emerging wireless technologies include C-V2X (based on LTE) and fifth generation (5G), which allow for low-latency, peer-to-peer connectivity:

> The major benefit of intermediary computing is that it can provide a single point of contact for the mobile device to allow it to connect to multiple external services.

- **4G LTE mobile network**—4G LTE is one of the most common methods of providing information to travelers. One of the major benefits of 4G LTE is its coverage area, particularly on highly traveled corridors. However, because communication between devices on a 4G LTE network are routed though fixed-location transceivers, communications latency could preclude a system network relying on 4G LTE from supporting safety-of-life applications. The 4G LTE network is managed through wireless telecommunications providers, so a subscription to a mobile data plan is required for individual access to 4G LTE.

- **GNSS**—GNSS is a generic term for systems available for satellite geolocation. GNSS is generally considered to provide position, speed, and time information for receivers. This information exhibits varying degrees of accuracy, depending on conditions such as the number of satellites and interference.

- **Wi-Fi and Wi-Fi Direct®**—Wi-Fi allows mobile device users to access a network when in range of Wi-Fi routers. When connected to a Wi-Fi router, the mobile device can send data to, and receive data from, other Internet-connected systems. Private Wi-Fi networks can be password protected, although owners can choose to keep these networks free or open, which many retail establishments do as an amenity to patrons. The coverage of a Wi-Fi network depends on the locations and range of accessible Wi-Fi routers. Wi-Fi Direct allows two consenting Wi-Fi-enabled devices to directly communicate information between each other.

- **Bluetooth**—Bluetooth establishes a consenting device-to-device connection and is generally used for data transfer and audio streaming. Triangulation of Bluetooth signals also allows for added precision for indoor positioning in places where other locating methods are not as accurate or accessible.

- **RFID and NFC**—NFC is a specialized subset of RFID technology that supports low-latency information exchange and has low power consumption requirements. A powered device is capable of energizing and reading information from a tag (that does not necessarily have to be self-powered). A mobile device can function as a tag or a reader. Range depends on the power of the device; however, this dependence on power could be considered a security benefit because power can be adjusted to physically limit the potential of other unintended devices to receive information. The use of secure channels further improves the likelihood that only authorized devices (the intended recipients) can receive the information.

- **DSRC**—DSRC is a two-way, short- to medium-range wireless communications capability that permits data transmission critical in communications-based active safety applications. DSRC is characterized by low-latency transmission of data and had been a major focus of CV research over the past several years. Recent FCC rulemaking has effectively rendered DSRC obsolete, however, and the technology is expected to be superceded by C-V2X.

- **C-V2X**—C-V2X was developed by the 3GPP as a competitor to DSRC with the advantage of using the same chipset for both V2X communications as well as traditional cellular 'network' communications.(9) The latter interface allows a device to communicate with the cellular network (known as the Uu interface). The Uu interface does require a subscriber identification (ID) module card, more commonly known as a SIM card,(and associated data plan from a service provider) to function. The former interface, known as PC5, can directly communicate to other devices independent of the cellular network. Current C-V2X technology is based on the LTE standard, but it has a forward-compatible evolution path to the 5G version of C-V2X.

- **5G mobile network**—5G is based on the 3GPP release 15 with enhancements found in both release 16 and, most recently (March 2022), release 17. 5G is quickly becoming the standard for U.S.-based cellular carriers and the rollout continues in more dense regions. 5G promises higher speeds, greater capacity, and lower latency than LTE. Similar to 4G, a C-V2X (PC5-type) interface is available, but to date, very little work has been done with prototype of this next generation V2X technology.

Each medium has its advantages, disadvantages, and limitations; therefore, there may be certain situations under which it makes sense to use one communications media over another. The communications media selected to transmit a message is generally a function of coverage (i.e., range), reliability, and latency of the given data flow. Regardless of which communications medium is chosen, security protocols are followed to protect the authenticity and privacy of transmitted data to ensure trust and authenticity for users and systems connected by the network.

PREPARING FOR SUCCESSFUL OPERATIONS

The successful data sharing with mobile devices involves not only the technical form and functions identified thus far, but also various institutional and organizational components. From the onset, participating agencies and service providers need to adequately address business requirements that may be needed to operate the mobile device-based systems.

A planning study is expected to have taken place before the system development process. An agency may have a transportation systems management and operations (TSMO) strategy or plan (e.g., integrated corridor management, TMS, or ITS), whereby the need and overall framework around which the message sharing with connected mobile devices and the public agency managed systems (e.g., traffic, transit) would be documented. A part of the planning for this environment and the enabling systems (e.g., TMS, transit management) would support the sharing and use of data with travelers using connected mobile devices.

Facilitating a comprehensive concept development process and developing a ConOps would identify the partnerships and institutional resources needed to accomplish the desired use case. Agencies and service providers must understand their roles and the data, equipment, or manpower that may be expected of them before developing and building a mobile device-based system. As part of that effort, key stakeholders would answer and develop consensus on the following questions:

- What service does the traveler, agency, or service provider want to use?
- What information is needed to accomplish the desired service?
- What connectivity is needed to allow this communication to take place?
- At what time and location does the information need to be provided to make effective decisions?
- What equipment, hardware, or software is needed to provide the functionality?
- How will the data be collected and used within agencies and service providers?

Although the answers to these questions are specific to the function of the connected system, they would also lead stakeholders to identify their internal shortcomings in terms of policy, business processes, staffing, and finances. Identifying and addressing these issues early would further develop the technical aspects of the data-sharing ecosystem. These same steps could be implemented later in the implementation or operation stages, when changes would be proposed to ensure stakeholder collaboration throughout the development.

In some use cases, it would be advantageous to establish a lead agency to develop, test, and sustain the ecosystem. This ecosystem may involve project charters, interagency agreements, or contracts with third-party providers to memorialize the organizational structure and allow certain access or control of partner assets. In addition, rules governing data use would need to be established between agencies that own a connected system and other entities wanting to access the data.

The operations of a managed toll lane facility is an example where coordination between multiple agencies would be needed for the system to operate as intended. Typical toll operations would include the following institutional stakeholders:

- An agency or entity responsible for all toll tags for an entire region.
- A traffic management agency responsible for freeway operations.
- A group responsible for operations of the toll facility (e.g., monitoring real-time conditions, setting tolls).
- An agency responsible for managing the backhaul network, the devices connected to it (including RFID tag readers), and the data that flow across it (toll tag account numbers).

- A group responsible for collecting tolls (e.g., managing customer accounts, payment information, customer billing).
- An entity responsible for marketing and community outreach.

Bringing stakeholders to the table, defining the relationship between stakeholders, and defining roles and responsibilities for each stakeholder would be key components toward ensuring cooperation for a successful operation of the system.

CHAPTER 3. CONCEPT DEVELOPMENT

CHAPTER OVERVIEW

The concept development process is a critical step in defining a project as it establishes the overall parameters for the information exchange between travelers and transportation agencies/services. A well-defined concept incorporates each stakeholder, their needs, and their roles and responsibilities in the overall process. Understanding a traveler's environment, their interface abilities, their desired actions or decisions, and the available infrastructure and resources provides input to refining the information exchange needs. The resulting concepts subsequently provide the basis for further project development and SE efforts.

This chapter provides an overview of the traveler (user class) and the desired action (use case). User classes are included for travelers using a variety of modes, including walking, cycling, driving, and using mobility options for transit and shared services. Use cases are provided for a variety of common applications, including requesting a traffic control change, conflict avoidance, rerouting, service reservations, and payments. Although examples are provided for both user classes and use cases, these examples do not comprise an exhaustive list. However, agencies could use the descriptions, combined with the messages and methods of message delivery described in the chapter 2, to develop their own concepts unique to their needs.

This chapter concludes with a list of considerations that an agency would account for during the concept development, including a traveler's need for information and decisionmaking, electronic messages, software and hardware, communication, and agency management systems. These categories are like those in chapter 2, Communication subsection, but provide specific issues, challenges, and questions that would be answered within the SE process.

USER CLASSES

The way mobile devices are used may ultimately drive their form and function. Different users may need different types of information, different methods of interface for input and/or feedback, or even different spatial or temporal considerations. Users who have similar needs, encounter similar issues, and are expected to benefit in a similar fashion from the deployment of a system are arranged into groups called user classes. A common starting point for dividing users into user classes is by their mode of travel.

This classification helps identify the appropriate user needs through the concept development and, ultimately, the system requirements. For each user class, example needs are listed that would apply to the users before or during their trip. Specific needs unique to an agency or region would be developed during the concept development.

Although the needs of each user class are presented separately, there may be overlap between user classes that would be identified and addressed during the concept refinement. These overlaps can provide for synergies if they can be addressed through the communication of similar electronic messages.

As an example, one of the central needs of most users is access to a trip planning service both pretrip and en route. Access to a trip planning service allows users to determine whether there are better alternatives for reaching their destination as conditions change and whether those alternatives are on a different route on the same mode or a different mode. Because there are benefits of trip planning data for users of all modes, a synergy could be to provide a consistent message that can be used for multiple types of modes. Another common need is the ability to pay for a service. In these modes, a synergy could be provided through a common electronic message to request payment (from the provider to the user) and authorize payment (from the user to the provider).

Pedestrian

This user class represents travelers who are walking to complete their trip. These pedestrians typically use sidewalks, where available, and crosswalks to travel across portions of the right-of-way, which is primarily used by motorized vehicles and bicyclists. Pedestrians are classified as VRUs because they are prone to physical harm when involved in a crash with a vehicle. Thus, drivers need to be made aware of pedestrians, especially when pedestrians are in a portion of the right-of-way where vehicles could be present. This classification also includes travelers using wheelchairs, electric personal-assisted mobility devices (e.g., a mobility scooter or a wheelchair), and bicyclists who use sidewalks (in jurisdictions where operating a bicycle on a sidewalk is legal). Examples of a range of pedestrian needs that could involve different electronic data exchanges are provided in the following text box. (Note: This list of needs is not intended to be exhaustive.)

Pedestrians need to:

- Know when they are approaching a signalized intersection crosswalk.
- Be able to activate a pedestrian crosswalk phase.
- Have additional time to complete crossing a crosswalk if they are still in the crosswalk and the pedestrian phase clearance time will soon expire.
- Have their presence in a crosswalk be known to approaching drivers.
- Have wayfinding and navigation solutions (for pedestrians with disabilities) to a complete trip between an origin and destination in the public right-of-way. (Note: The traveler needs wayfinding and navigation information before staring the trip and must be updated throughout the trip to account for changing conditions, such as a pedestrian signal.)

Bicyclist

This user class represents travelers using a bicycle to complete their trip. Bicyclists are a distinctive type of user because the use of a mobile device while en route may be particularly distracting because both hands are generally needed for the biking task. Interacting with the mobile device while on a bicycle could cause the bicyclist to make unpredictable movements, reducing their own safety and that of other road users. Therefore, the needs of bicyclists would be able to be met only if the system does not need the bicyclist to provide input to the mobile device (which is significantly distracting) while in the public right-of-way. This user class covers bicyclists riding in the roadway as opposed to those on a sidewalk, and includes those using dedicated bicycle lanes (see Pedestrian class). Examples of bicyclist needs that may involve different electronic data exchanges are listed in the following text box. (Note: This list of needs is not intended to be exhaustive.)

Bicyclists need to:

- Activate a phase that they intend to utilize at a signalized intersection.
- Have their presence in the roadway known to approaching drivers.

Traveler Using Personal Vehicle

This user class includes travelers who would use a personal vehicle to complete a trip and who would receive information before making the trip and en route. While en route, the driver would want continuous information on the most efficient route and adjust the trip in realtime to reduce delays. The user class could also use available toll facilities to reach their destination, but these facilities also may involve payment for use. For drivers to make an informed decision about whether to take a toll facility, they need information about the toll facility, such as travel time savings and associated costs for the length along the driver's proposed route. Travelers using a personal vehicle have a unique need to park their vehicle when they reach their destination. In these cases, the driver must be provided with information regarding the availability and cost of parking facilities in the vicinity of the driver's destination. Example needs for travelers using a personal vehicle that could involve different electronic data exchanges are provided in the following text box. (Note: This list of needs is not intended to be exhaustive.)

Travelers using personal vehicles need to:

- Have spatially and temporally relevant roadway signage information.
- Have traveler information that is customized to a predetermined route.
- Be able to constantly check for alternative routes to their destination to determine if they are on the most efficient route.
- Obtain tolling information for toll facilities that could be used to get to their destination when using a personal vehicle.
- Have information about the location and cost of parking facilities in the vicinity of their destination.
- Have a method to pay for tolls.
- Have a method to pay for parking.

Traveler Using Transit

This user class uses one or more modes of transit to complete their trip (e.g., bus, train, streetcar, or ferry). This user class requires pretrip and en route information that enables the traveler to choose or change modes or routes to obtain the most efficient trip. Users can measure efficiency differently; some may select trips based on total time, whereas others may look to minimize costs or transfers. Furthermore, travelers using transit need a method to conveniently pay for the service(s) that they utilize. Examples of needs for travelers using transit that could involve different electronic data exchanges are provided in the following text box. (Note: This list of needs is not intended to be exhaustive.)

Transit users need to:

- Access to a multimodal trip planning service.
- Have alternative route or mode options that can be used by the traveler while en route to the destination.
- Be able to view the amount of time until the next arrival or locations of nearby transit vehicles occur.
- Obtain information about approaching transit vehicles when waiting at a transit stop.
- Be able to notify the transit vehicle operator when they intend to disembark from the transit vehicle.
- Be able to notify a transit manager (or transit management system) when they intend to make a scheduled connection.
- Be able to know the fare to take a trip using transit.
- Have a method to pay for a trip taken using transit.

Traveler Using Ride-Hailing Service

This user class represents travelers using mobility service providers to travel, including, but not limited to, on-demand (e.g., flexible route) transit, taxis, ridesharing, and transportation network companies. Because these services operate outside traditional, fixed routes, the user needs to determine the availability of the services in a given area. In addition, their use often requires sending and accepting a request for service, the agreement of the fee, and a method by which to conveniently pay for the service. Examples of a range of needs for travelers using a ride-hailing service that could require different electronic data exchanges are listed in the following text box. (Note: This list of needs is not intended to be exhaustive.)

Ride-hailing users need to:

- Obtain information on the availability of flexible ride-hailing services in their vicinity.
- Be able to request service from the provider.
- Be able to know the fare of the ride-hailing service.
- Have a method to pay for a trip taken using ride-hailing services.

Traveler Using Shared Mobility

The designation of shared-mobility devices is constantly growing and can include car sharing, bike sharing, scooter sharing, or other similar types of alternative transportation services. Users of these devices are unique from users of ride-hailing services in that these travelers also operate a shared-mobility device (i.e., a traveler using a ride-hailing service does not operate the vehicle). Users may opt for these modes in areas where the convenience is greater than walking, driving a personal vehicle, or transit options. The use of these modes requires the availability of devices and a payment typically measured by time or distance. Examples of a range of needs for travelers using a shared-mobility device that may require different electronic data exchanges are provided in the following text box. (Note: This list of needs is not intended to be exhaustive.)

Shared-mobility users need to:

- Obtain information on the location and availability of shared-mobility devices in their vicinity.
- Be able to reserve the device for a given timeframe.
- Know the cost of the service.
- Have a method to pay for a trip taken using shared-mobility devices.

Traveler with Disabilities

Travelers with disabilities include those with vision, hearing, cognitive, mobility, or other disabilities. Users with different disabilities have varying limitations that may require different types of information from a mobile device to complete their trip. This user group may also require unique methods by which information is input and presented to effectively communicate (e.g., enlarged text, haptic responses, or text-to-speech conversions). Travelers in this user class may also fall into other user classes, and needs from both classes could be combined. Examples of a range of needs for travelers with disabilities that may involve different electronic data exchanges are provided in the following text box. (Note: This list of needs is not intended to be exhaustive.)

Travelers with disabilities users need to:

- Have adequate interface options to fit their disability (e.g., enlarged text, text-to-speech, or haptic responses).
- Have complete wayfinding and navigation solutions for the entire trip while en route.

Multimodal Traveler

The multimodal traveler user class includes travelers who utilize more than one mode to complete their trip. Like the traveler with disabilities user class, the multimodal traveler falls into multiple user classes during their trip. Travelers using more than one mode may need not only the information associated with the current mode but also additional information on all other options and a method to compare costs, convenience, and time associated with each option. Depending on real-time conditions, the multimodal traveler may prioritize using one mode over the other while en route.

USE CASES

Use cases need to identify how mobile device users make decisions during typical trips, what information is needed and how the user can interface with the device, how the information can be packaged and sent as electronic messages, when the messages need to be delivered temporally and spatially, and how these messages can be sequenced.

Once user needs have been defined and the synergies between them have been identified, an agency or region could identify use cases that are expected to address these user needs. Due to the nature of mobile devices and the focus on satisfying user needs, use cases are framed from a mobile device user perspective. Specifically, the use cases need to identify how mobile device users make decisions during typical trips, ascertain what information is needed and how the user can interface with the device, determine how the information can be packaged and sent as electronic messages, know when the messages need to be delivered temporally and spatially, and recognize how these messages can be sequenced.

As a traveler completes their trip from origin to destination, one or more of the use cases could occur. Ultimately, the use cases could be organized into scenarios to describe the entirety of a trip.

Example use cases are provided in the following subsections to illustrate the potential use cases and to highlight the types of issues to be included in each. This list is not exhaustive because there are many use cases within each user class as well as specific use cases to individual agencies or regions.

Place Pedestrian Phase Call

In the process of completing a trip, a pedestrian may need to cross a street at one or more signalized intersections. In some cases, the crossing requires the pedestrian to provide an input to activate the pedestrian phase at the next available opportunity in the signal timing plan. Pedestrians typically press a pushbutton to complete this activation and then monitor the signal indication to determine when the crossing is allowed.

Mobile devices could allow a pedestrian to request a pedestrian phase at an intersection. Such an application could also provide specialized functionality to support the needs of travelers with disabilities. The app could assist pedestrians with low vision who may have difficulty locating the pedestrian pushbutton, or pedestrians with a mobility impediment who may not be able to access a poorly placed pushbutton. The mobile device could also provide audio and haptic information regarding a signal state or the lack of a crossing to travelers who require additional inputs because of limited vision. This app could help pedestrians with intersections that may not have audible signals.

To support this use case, the pedestrian needs information about the location of the intersection, the signal state, and the ability to provide a signal priority request to the traffic signal controller. The MAP contains intersection geometry information that allows the mobile device to position itself in relation to the intersection, and SPaT contains information about the state of each movement as well as timing details (e.g., minimum time remaining, expected phase change). To initiate the use case, a pedestrian with a mobile device would wirelessly issue an SRM to actuate the pedestrian phase at the signal. By using the mobile device, the pedestrian would indicate which crosswalk they intend to use, and they could cancel the request at any time. The SRM would contain information such as an intersection identifier, an identifier for the movement request, and the type of service requested (e.g., normal actuation, priority, preemption), which the traffic signal would receive. An SSM would be provided back to the mobile device to provide information regarding which signal requests would be served and the estimated timing of service.

Pedestrian in Crosswalk Intersection Safety

In environments where vehicles and pedestrians interact, an incident could occur. Pedestrians are prone to injuries or fatalities when they are involved in a crash with a vehicle, so it is especially important for drivers to be aware of the presence of pedestrians. Pedestrians and similar users are considered VRUs.

A mobile device could support the safety of the VRU by broadcasting the location and motion information of the VRU to other connected devices. Equipped vehicles would then process the information and provide a driver with advisories and warnings about the presence of the VRU. Similarly, the VRU could receive location, speed, and motion information from the vehicle to alert the VRU when a vehicle is approaching and a potential collision could occur unless immediate action is taken.

To support this use case, the VRU and surrounding vehicles need information regarding each other's location, direction, and speed. The mobile devices would have to continually broadcast the information through standardized messages. Because this use case is for safety, it would not require any user input or activation.

Place Bicycle Phase Call

Bicyclists riding on the roadway may not be detectable by traditional means (e.g., in-pavement loop detector or video detection) because these devices are typically calibrated to detect vehicles. In scenarios where the signal is not programmed to automatically service the signal phase that the cyclist intends to utilize, the bicyclist may have to dismount to activate a pedestrian pushbutton, wait for excessive periods, or cross against a red signal.

Mobile devices could allow a bicyclist to request a pedestrian phase at the intersection in the direction of travel, which would prevent the bicyclist from traveling on the sidewalk or making unsafe maneuvers. Although this action could be completed during a stopped condition, it would be beneficial if the actions were automatic and generated from a planned route to prevent a bicyclist from handling a device and not the handlebars of the bicycle.

To support this use case, the bicyclist would need information about the location of the intersection, the signal state, and the ability to provide a signal priority request to the traffic signal controller. The MAP contains intersection geometry information that allows the mobile device to position itself in relation with the intersection, and SPaT contains information about the state of each movement and timing details (e.g., minimum time remaining, expected phase change). To initiate the use case, a bicyclist with a mobile device would wirelessly issue an SRM to actuate the pedestrian phase at the signal. The SRM would contain information—such as an intersection identifier, an identifier for the movement request, and the type of service requested (e.g., normal actuation, priority, preemption)—which the traffic signal would receive. An SSM would be sent back to the mobile device to provide information regarding which signal requests would be served and the estimated timing of service.

En route Adjustment for a Driving Trip (Alternate Route)

Traffic conditions continuously change, and congestion caused by incidents or other temporary factors may result in additional delays to a planned vehicular trip. Under these circumstances, an alternate route may be available that provides better travel time than the original route. Drivers would need real-time comparative data to identify the alternate route and make the decision to reroute.

Mobile devices could provide access to a trip planning service that considers current roadway conditions and user location to develop route options while en route. The trip planning service would obtain the information from the mobile device regarding current location, ultimate destination, and any vehicle characteristics or preferences that could limit (or provide) access to certain roadway facilities. This information, used along with an algorithm and information on system conditions, would determine an alternate route, which would then be returned to the mobile device.

To support this use case, the driver would have to develop a pretrip itinerary that identifies the destination and determines a baseline routing decision. The mobile device would automatically track progress en route and communicate standard messages (including location, direction, and speed) to the trip planning service in realtime. The trip planning service would determine alternate routes based on travel-time comparisons and deliver updated options to the mobile device via messages. The mobile device could provide the planned route to the driver as navigation instructions with limited interface to avoid distractions.

Driving Wayfinding—Tailored Roadway Signage

Transportation agencies provide permanent roadway signage for traffic control at locations where conflicting movements occur to warn traveler about changes in roadway conditions and to offer directional guidance. These types of signs follow standard *Manual on Uniform Traffic Control Devices* (MUTCD) formats and are located at fixed positions for known, permanent conditions.(10) Examples include signing for intersections, curves, and stadiums. In situations where the condition is temporary, users often lack information because traditional signage is not applicable and dynamic message boards are not ubiquitous.

Mobile devices could provide real-time information to the driver based on prevailing conditions in the immediate area. This information could warn of traffic incidents, temporary weather impacts (e.g., flooding), detours, or severe congestion that might affect the planned trip.

To support this use case, the mobile device would automatically communicate standard messages (including location, direction, and speed) to the TMC in realtime. The TMC would determine whether any temporary unexpected conditions exist in the area and deliver warnings to the mobile device via messages. The mobile device could provide the warning to the driver via audible interface to avoid distractions.

Provision of Toll Facility Information

Toll facilities users visually digest a significant amount of information regarding pricing, vehicle eligibility, hours of service, and enforcement/fines. The possibility of information overload increases when drivers are unfamiliar with their surroundings and are relying on guidance signs for directions. Drivers who are sensitive to pricing may also need to calculate total cost before committing to the toll facility.

A mobile device could be configured to deliver tailored information to a toll user to ensure the driver clearly understands the tolling information relevant only to the segment/duration applicable to their route. Furthermore, a mobile device would allow information to be arranged and displayed in various dynamic modes to reduce the burden on the user of remembering information that is placed only periodically along the freeway.

To support this use case, the user would have to develop a pretrip itinerary that identifies the desired route adjacent to a toll facility. While en route, the mobile device would automatically track progress and communicate information to the toll management agency in realtime. The information may include planned route, current location and speed, and ultimate destination. The toll management agency would evaluate the adjacent toll facility for potential use, based on the current location and destination, and then communicate back the location of adequate entrance and exit points. If there is an adequate route using the toll facility, the toll management agency would send information pertaining to the associated total travel time and total cost based only on the segment(s) pertaining to the user.

Adjust Transit Operations (Connection Protection)

Travelers on a multileg transit trip depend on reliable connections to arrive at their destination in a timely manner. If the traveler misses the connection, waiting for the next transit vehicle to service the stop may drastically increase travel time. Connection protection is the coordination between intersecting transit lines to protect the rider's transfer. However, a transit agency may require certain conditions be met to allow connection protection (e.g., a threshold on the number of travelers needing to make the transfer or a requirement for the connecting route to be low frequency in nature).

A mobile device could be used to facilitate connection protection by communicating a traveler's anticipated transfer location and arrival time to the transit agency en route. This process could apply for connections within a single transit agency or across multiple agencies. While the notification could be completed through user input, it would be beneficial if the actions were automatic and generated from a planned route to eliminate distractions if the user is multimodal.

To support this use case, the user would have to develop a pretrip itinerary that identifies the desired transit route both in terms of location and time. While en route to the transit boarding location (regardless of current mode), the mobile device would automatically track progress and communicate information to the transit provider in realtime. The information required would include desired transit route, boarding location, anticipated arrival time, and ultimate destination. If the ticket fare was prepaid, there may be a need to commute reservation data, and the transit agency would evaluate the transfer based on their policies and communicate back the availability for connection protection. If the transfer is not possible, the transit agency could utilize the user's current location and ultimate destination and send alternative routes, alternate boarding locations, and a list of the next boarding times.

Driver Notification of Passenger Waiting at Stop

Transit vehicle operators generally look for the presence of travelers waiting at a stop along the route to determine whether they provide service to the stop and allow boarding. There may be instances under which it might be difficult for the driver to see the waiting traveler due to physical objects on the roadside that may occlude the travel from the driver's view. Similarly, during periods of low light, it might be difficult to see a traveler waiting at a bus stop, especially if it is not well lit. In addition, many designated transit stops serve multiple routes, meaning that waiting passengers could be waiting for a different transit vehicle. Knowing whether passengers are waiting for pickup and and for which route would help increase the efficiency of the transit operator and reduce unnecessary stops. A mobile device carried by the transit user could be configured to communicate with the transit vehicle operator to ensure that the transit vehicle stops when needed and the traveler boards the correct route.

To support this use case, the user would have to preselect the transit service and desired route for their trip. At the stop, the mobile device would broadcast a message to the operator of the approaching transit vehicle—either directly or through a transit management center—providing a notification that the traveler is waiting for pickup. The information sent could include the location of the stop, the intended route and direction of travel, and any special needs such as handicap access.

Reserving Use of a Shared Mobility Device

Travelers planning on using a carshare, bikeshare, or scooter-share service as a means of travel need to ensure that the equipment is available when the traveler arrives. In some instances, the shared equipment may no longer be available by the time the traveler arrives at the designated pickup location. To prevent this equipment unavailability from occurring, a reservation system would hold the shared equipment for a given amount of time based on the user's request.

Mobile devices could provide a common interface for shared mobility services to integrate with existing reservation systems. This interface would not only add convenience for a traveler when utilizing multiple systems but could also allow users the option to locate shared mobility devices from competing services, if the selected mode is unavailable.

To support this use case, the user would select the preferred type of shared mobility equipment and a pickup location, either through a pretrip itinerary or realtime at their current location. The mobile device would send location information to the different services requesting the location and availability of equipment in the vicinity of the request. The user would need to select the preferred equipment based on previously identified preference or costs. The mobile device would send a reservation request to the system responsible for managing the shared equipment, including the location, time of pickup, and travelers trip information. If the reservation is accepted, the user would be provided confirmation.

Transit Fare Payment (Pay When Boarding/Pay at Fare Gate)

Transit users typically pay for service before entering the transit vehicle, and most transit agencies have their own fare collection systems. However, completing a trip that uses multiple modes of travel (or that uses multiple transit agencies) can become burdensome, particularly if users carry multiple stored-value payment cards.

A mobile device could provide a common interface for fare payments and integrate with the various fare collection systems. This process would not only add convenience for a traveler when utilizing multiple systems but could also allow fare transfers if multiple trips are taken within a given timeframe.

To support this use case, the user would first enter financial account information in an app to allow a transaction to occur. Although most users may elect to use credit card accounts, the app could also accept payment from a common payment account that provides other options (e.g., cash) to promote equity among users who do not have access to credit. At either the transit fare gate or boarding location, the transit agency would request payment via a message containing the transit route, boarding location, fare cost, and date/time. The user would accept the terms and pay for the transit trip by returning a message containing the financial account information. The mobile device would then be used in lieu of a ticket or receipt.

Pay for Parking

Parking facilities charge users a fee for parking that is typically based on the length of stay. Some systems require prepayment, whereas others require payment on exit. Although most systems use cash or credit cards for transactions, employment-based garages may also include a proprietary system for regular users (e.g., monthly pass).

Similar to transit fare payments, a mobile device could provide a common interface for parking payments that integrates with the various parking collection systems. Users could pay in advance of arriving to the parking facility (for a reserved parking spot) or as they enter or exit the parking facility (for a spontaneous or unplanned trip).

To support this use case, the user would enter financial account information in the mobile device on an app to allow a transaction to occur. Although most users may elect to use credit card accounts, the app would also accept payment from a common payment account that provides other options (e.g., cash) to promote equity among users who do not have access to credit. Either at the parking facility or in advance of arrival, the parking manager would request payment via a message containing the facility name, parking spot ID, parking duration, cost, and date/time. The user would accept the terms and pay for the parking by returning a message containing the financial account information. The mobile device would then be used in lieu of a ticket or receipt. In prepayment or hourly agreements, the mobile device could warn the user of expiration and allow the user, via mobile device, to increase payment to extend the parking duration.

EXPECTED ISSUES AND CHALLENGES

There are issues and challenges to consider when sharing electronic messages to meet or supplement the information needs of travelers based on current conditions and the decisions travelers make while they complete their trip. It is important to think about what, where, and when information is needed. Whereas chapter 2 provided some high-level details regarding the mobile device-based system concepts of electronic messages, software and hardware, and communication, this section highlights specific issues to consider for each of these areas.

Travelers' Needs for Information and Decisionmaking

The key purpose of developing a ConOps is to elicit the needs of users of the system that would be developed. Thus, determining the travelers' needs for information and decisionmaking is one of the most important steps of ConOps development. Interviews, workshops, and surveys are some of the techniques used to perform this activity. Without proper methods like these techniques, it may be difficult to differentiate between user needs (which are essential to the function of the system) and wants (which would be nice to have but are not essential).

When an elicited user need involves providing information to a traveler, another issue to consider is the determination of when and/or where that information must be provided to make the most effective use of it.

Electronic Messages

Data-producing capabilities and data needs change as technology evolves and new innovative services/mobility providers are established, and, thus, the types of data contained in messages could be updated to reflect such changes. Standardized messages might not include data frames and data elements that may be needed to carry these new data elements. If there is a use case that can be better supported using this new data, then it may be advantageous to update the standard to accommodate the new data element. However, committees responsible for managing message standards might only periodically make changes to the standard to reflect the types of data that systems or travelers may need.

It is not ideal to change standards frequently, because devices in a network would have to update firmware to be compliant with the updated standard. Firmware updates are not a trivial task for organizations that use the affected standardized messages.

Message size is also important to consider. In an environment with a growing number of mobile devices, the bandwidth of mid- to long-range communications (where many mobile devices are within communications range of each other) may limit the amount of data that can be wirelessly transmitted.

Software and Hardware

One of the major tasks associated with a mobile device is the ability to broadcast and receive messages to and from other, previously unknown, devices that a mobile device encounters during a trip. This messaging process requires the requisite software and computing hardware capabilities to be available on the mobile device. While today's smartphones can utilize several forms of communication, the direct device-to-device communications necessary to support the use cases of a mobile device as described within this ConOps do not currently exist as an integrated product. Examples of this technology include DSRC and a newer technology, C-V2X, which is expected to replace DSRC.

Developing applications and APIs is one of the largest challenges to realizing a designed system. An app on a mobile device is software that processes various inputs (e.g., traveler input, mobile device sensor data, and data received via wireless communications media) to enable travelers to access various services and provides outputs to travelers that help them make informed decisions throughout the course of taking a trip. An API is a feature of a service or system that allows a mobile device (or another system) to provide data to or receive data from it. Data required by the traveler (or data that a traveler must provide) must be provided (or received) by the service or system.

Communication

There are issues to consider with using different telecommunication methods to send and receive messages from mobile devices. The ability to connect mobile devices with other systems depends on the availability of a communications network. Without the proper physical infrastructure in place, this communication is not possible.

Certain applications require systems and mobile devices to remain connected (and to sustain this connection throughout the entire course of a trip). Data-generating systems are static in nature—they typically connect to the Internet or to a private network through a physical backhaul. However, when it comes to mobile device connectivity, wireless communications are crucial.

Several communications media could be used to send data to, and receive data from, mobile devices. However, as discussed in chapter 2, Communication, each communications media has its advantages and disadvantages, which need to be considered when establishing a wireless network that can be accessed by mobile devices. First and foremost, the ability of a mobile device to send and receive data over a particular communications medium is the ability for a particular mobile device to communicate via that communications medium. While certain media may be considered common (e.g., Wi-Fi), others may not (e.g., NFC). The more ubiquitous a communications media is on mobile devices, the more it can be leveraged by travelers on a large scale.

Furthermore, different communications media have different areas of coverage, which influence where a mobile device can communicate with a system via that communications medium. It is important to consider what level of connectivity may be needed between the mobile device and other supporting systems. For applications where more constant connectivity is ideal, one strategy would be to allow communications to occur via multiple mediums to allow for more continuous coverage, which ultimately provides a more robust user experience. In other instances, it may be advantageous to limit communications to a small area when the need for a mobile device to be continuously connected is not required (for instance, the communication of payment information, or passing farecard credentials to gain access to a transit system).

Each communications media has inherent advantages and disadvantages, which are considered when establishing a wireless network that can be accessed by mobile devices.

Another aspect of wireless communications to consider is accessibility. Access to certain communications media (e.g., 4G LTE) requires the traveler to subscribe to a mobile Internet service provider. For a service to be ubiquitously available to all mobile device users, it would ideally be freely accessible and not require the user to subscribe to a data plan to be connected to other transportation systems. Addressing such concerns typically becomes the responsibility of local transportation or technology agencies. The local agency becomes responsible for providing the wireless communications infrastructure, backhaul connectivity (to other systems or the Internet), and a computing platform (if a translation of data is needed between systems).

Agency Management Systems

Mobile devices can only provide benefits to travelers if there are other systems sharing or using electronic messages for the mobile devices to access. If such systems are not available or are not collecting or sharing electronic messages, then the benefits that can be derived by the traveler are not realized. Specific systems that could share and use electronic messages with connected mobile devices used by travelers could include, but are not limited to, transit management systems, TMSs, shared-mobility device management systems, and payment systems.

Agencies may need to deploy a network of devices in locations where they desire to support the exchange of information with mobile devices. The primary purpose of these field devices is to send messages to mobile devices, receive messages from mobile devices, and process these messages. Furthermore, communications between these field devices and a central system, software to process data, and database(s) with APIs to receive and process data are required. Although managing such a network for communicating with mobile devices is a large undertaking, doing so could vastly broaden the accessibility of electronic data to travelers and the ability of agencies to receive data from the travelers to more effectively manage their systems.

CHAPTER 4. INFORMATION NEEDS OF TRAVELERS USING CONNECTED MOBILE DEVICES

CHAPTER OVERVIEW

Travelers can be presented with a vast amount of information in their environment that may or may not relate to travel. Understanding how the traveler prioritizes and consumes a wide variety of information is an important step to ensure that planned information exchanges between a transportation agency and service provider occur in a safe and timely manner without causing undue distraction or overload. The desired type and frequency of information exchange governs when and how agencies deliver the information to ensure recognizing, processing, decisionmaking, and acting by the traveler.

This chapter provides an overview of the human factors involved in information processing and decisionmaking. The following specific topics are discussed:

- How Travelers Use Information.
- Types of Information for Decisionmaking.
- Spatial and Temporal Aspects of Decisionmaking.
- Positive Guidance.

Each of the aforementioned topics are discussed in general and applied to mobile devices. Due to their design, mobile devices provide a new mechanism for information exchange that provides increased flexibility in terms of spatial, temporal, and formatted delivery. If used correctly, the unique characteristics of a mobile device can enhance the user's ability to ensure the correct use of the information exchange. This usage includes addressing safety concerns by categorizing information in terms of control, guidance, and navigation—each with their own requirements in terms of latency and format.

HOW TRAVELERS USE INFORMATION

Travelers use information to become aware of surrounding conditions that may influence their actions or planned trip and then react to the condition. Inherent differences in the type of information or level of importance influences how travelers use the information. This information use in turn affects the design of the mobile device-based system.

The two primary groups of data essential to travelers are safety data and mobility data. Safety data are used to make decisions related to avoidance of objects, users, and other environmental hazards that may cause personal injury. These data are transmitted constantly with high frequency and low latency to ensure they will be of use to the mobile device user. Mobility data are used to make decisions on mode choice, routing, and timing of a trip. Although low latency is not required, the data exchanges are expected to occur in near realtime. Constant connectivity is not necessary to exchange mobility data, but it is expected that intermittent connectivity is needed at a minimum as the traveler completes a trip.

Other types of information that benefit travelers are related to trip planning, wayfinding, and payment systems. Data transmitted for trip planning, wayfinding, or payment options may only be needed once for a trip, oftentimes before a trip begins or after a service is provided. Low latency and constant connectivity are not necessary for these functions. In addition, most of these functions need to coordinate with other platforms or services, which may introduce additional latency.

Travelers need information on:

- Safety.
- Mobility.
- Trip planning.
- Wayfinding.
- Payment options.

TYPES OF INFORMATION FOR DECISIONMAKING

Safety Information

Safety information is critical to the well-being of travelers themselves and surrounding travelers. This information is processed immediately to determine preventive or corrective actions that may involve the quick evaluation of multiple alternatives, each having unique advantages and disadvantages. An example of this type of safety situation is a pedestrian in the roadway. Drivers first identify the pedestrian and determine the probability of impact based on distance and current speed. Once identified, the driver determines the appropriate countermeasures (e.g., use horn, abrupt stop, lane change), prioritizes each measure based on merit, and acts on the preferred alternative. In this case, a mobile device-based system could assist in identifying the pedestrian quickly and allowing the driver to focus on the appropriate reaction.

Mobility Information

Mobility information influences the user’s trip in terms of routing, mode, and time. This information is not critical to warrant immediate processing but could be evaluated continuously during the trip to maximize efficiency. Typical users, regardless of mode, would use mobility information to weigh available options and select a preferred alternative based on time, cost, comfort, or other personal criteria. An example of this type of mobility situation is an unexpected delay on the freeway. Drivers identify the change in congestion and determine the impact to their travel time based on available information. Once identified, the driver determines appropriate options (e.g., stay on current freeway, use alternate route, switch to transit, cancel trip), prioritizes each option based on merit, and acts on the preferred alternative. In this case, mobile device-based information provided to a traveler could identify congestion and its location and then calculate the change in travel time and offer alternate routes.

Trip Planning Information

Travelers typically use trip planning information before a trip is executed but also during a trip if a modification is needed. Trip planning information is not as time sensitive as safety or mobility information; however, travelers place importance on the convenience of the information. In general, trip planning considers available options in terms of mode, route, time, costs, and other factors to allow a comprehensive evaluation. Once a trip is selected, the traveler needs access to the trip details throughout the trip. A mobile device-based trip planner could provide access and comparative data to available modes and then provide updates and reminders throughout the trip.

Wayfinding information enables travelers to identify a route, maintain the route, and arrive at their destination as planned. The information is relatively straightforward—inform the traveler of upcoming route names and necessary turn directions. Travelers need this information in near realtime and continuously through the trip. In many instances, this information is visually available through guide signs or transit maps but is not tailored to a specific traveler. A mobile device could provide tailored wayfinding and route information to a traveler and then provide estimated arrival times. Mobile devices could also provide this information verbally to avoid potential distractions to travelers.

Payment information plays an important role in traveler decisionmaking when services are available or needed. These services could take the form of transit, toll lanes, parking, shared mobility, or ride hailing. Payment information allows users to make informed decisions on whether the costs are justified for their current situation, or if the user does not have flexibility, the information allows the user to plan for the expense. Although the information does not need to be immediate, it does need to be convenient. In many cases, the various services each need separate platforms to obtain information or make payments, which can result in additional steps for a user. A mobile device could provide a single interface that allows travelers to access pertinent payment information in one place and create a transaction based on their preference.

Information to Provide to Travelers Using Mobile Devices

When considering what information to provide to a traveler, certain attributes regarding the traveler and the trip govern what data are needed. For instance, the type of trip being taken, mode being used, available alternatives, and traveler limitations/preferences play a role in what information could be displayed to a traveler to help them make decisions as they complete a trip. Examples of various types of information include, but are not limited to, the following options:

- **Safety messages—**Include a traveler's location and motion to enable safety applications that ultimately benefit the traveler.
- **Roadway and intersection geometry—**Include the infrastructure characteristics to allow users to position themselves with respect to the physical environment.
- **Signal state information and priority request messages—**Include the current signal state to allow pedestrians and bicyclists to request a crossing at a signalized intersection.
- **Payment information—**Includes fare information from service providers to provide a convenient method for paying for various modes of transportation.
- **Multimodal planning information—**Includes the most efficient route for a traveler using a personal vehicle, transit, shared mobility, and/or ride-hailing services (as specified by the traveler).

> A mobile device could tailor the spatial and temporal delivery of information to supplement what is provided within the public right-of-way, based not only on physical aspects of distance and speed, but also on user preferences.

- **Managed-lane information—**Includes toll and travel time information between various ingress and egress locations along a managed lane.
- **Roadway signage information—**Includes the location and information displayed on static and dynamic roadway signs applicable to the route.

SPATIAL AND TEMPORAL ASPECTS OF DECISIONMAKING

Information exchanges with travelers need to consider many factors that influence the decisionmaking process, but timing is essential. Travelers need time to process information, make a decision, and then take the required actions before reaching the decision point. Some of these factors are driver-specific (e.g., reaction time), whereas some factors are environment-specific (e.g., congestion). To aid the decisionmaking process, a mobile device would need to account for the spatial and temporal aspects of the traveler's information needs.

As an example, vehicles generally travel at much higher speeds than bicycles and pedestrians. Therefore, drivers need information much earlier than pedestrians due to the larger distance traveled while comprehending and interpreting the message. This reaction time varies according to whether the event is expected (more reaction time) or unexpected (less reaction time) as well as the amount of information that might need to be processed. If deceleration is required, a vehicle's weight and speed need a longer distance to safely decelerate than a nonmotorized mode. If lane changing is required in congested conditions, longer distances may be required because of the number of potential conflicts with other users.

Alternatively, a transit user is bound to a fixed route and is not actively engaged in operating the vehicle. As such, reaction times are not as important in terms of spatial and temporal delivery of information. Information delivery does need to account for transit vehicle speeds, walking distances, and service times. If a user has a planned transit ride, information would be delivered to allow enough time for the transit user to comfortably arrive at the stop before the transit vehicle.

SPATIAL AND TEMPORAL INFORMATION USING MOBILE DEVICES

One of the major benefits of delivering information through a mobile device is that a mobile device could tailor the information to the characteristics and needs of individual travelers. This type of information exchange differs from traditional signage, which accounts for an aggregated pool of users and situations when placing information in a static location. A mobile device could tailor the spatial and temporal delivery of providing this information to supplement what is provided within the public right-of-way, based not only on physical aspects of distance and speed, but also on user preference. As users age, they may need (or desire) more time (and distance) to make decisions, which a mobile device could customize. However, information provided via mobile device would be supplementary and would not be intended to replace laws, regulations, policies, or rules governing the behavior and responsibilities of a traveler for any travel mode.

POSITIVE GUIDANCE

One of the more comprehensive resources for determining when to provide information to travelers to improve their ability to make decisions is in a *User's Guide to Positive Guidance.*(11)

Although the guide mainly focuses on a driver's perspective, the concept of positive guidance is based on knowledge rooted in human factors and can be applied to a broader range of transportation users.

Humans often filter vast amounts of information to prioritize and react to the most immediate, important events. Drivers tend to prioritize information by emphasizing information that affects control and by following guidance and then navigation (figure 3). Driver priorities are typically ordered as follows:

- **Control (highest importance)—**Pertains to vehicle handling and response.
- **Guidance (medium importance)—**Involves highway design, traffic operations, hazards, and traffic control devices.
- **Navigation (low importance)—**Affects pretrip and in-transit phases and relates to routes, service, and guide signs.

Source: FHWA.

Figure 3. Diagram. Vehicle operation primacy triangle (human factors).(11)

Although the guidance is mainly focused on visual information, the concepts can also apply to audible alerts (e.g., siren or horn, audible pedestrian crossings, transit announcements) or haptic alerts (e.g., raised pavement markers, rumble strips, tactile curb ramps).(11)

Positive Guidance Techniques

As the amount of information available to a traveler increases, the required processing and reaction times increase. This same logic applies to the driver's expectancy of information—if the driver's expectancy of information is violated, the driver's reaction time increases. Positive guidance provides presentation principles and techniques that address the various considerations associated with the process of receiving and reacting to information. In general, the information regarding hazards, routes, and services displays when needed, where required, and in a form best suited to the user and task. However, too much information (overload) reduces the user's ability to prioritize and react to the critical task. Similarly, a lack of information (underload) may cause a user to miss a critical task. The following techniques can improve the delivery of information to ensure it is compatible with what drivers expect, does not surprise the drivers, and accommodates a wide range of users:

- **Spreading—**Technique that involves the spacing of information (such as longitudinally on a freeway) to reduce the chance for information overload to drivers at locations where several decisions might need to be made in a short period.
- **Coding—**Concept that translates information into a graphic symbol for faster processing. When multiple codes are merged into larger units, it is known as chunking.
- **Repetition—**Reiteration of information to ensure the intended audience is more likely to remember and act on it.
- **Redundancy—**Technique that uses multiple forms of communication (i.e., language, color, and shape) to ensure understanding.

Positive Guidance in Mobile Devices

Positive guidance concepts could be applied to mobile device users as they complete a trip. Although these concepts generally refer to the placement of information on freeways and visual techniques, mobile devices could provide visual information to a traveler on screen as well as provide audible information and haptic feedback to users.

The visual presentation of information to a traveler might be provided at a time and location in advance of a decision point (depending on how close the traveler is to that decision point) to reinforce behavior or to provide an alert about a safety situation that might demand the traveler's attention. The audible and haptic aspects of mobile devices are also important to consider, because a traveler could be focused on other activities such as operating a vehicle or crossing a street. For drivers, mobile devices could be located outside their primary field of view, which would require an unsafe change in visual focus from the roadway. For pedestrians, the mobile device could be in a pocket or a tote (e.g., a purse or backpack) that prohibits visual exchanges. In certain jurisdictions, it is illegal to engage in smartphone activity during certain activities (e.g., using a crosswalk). For bicyclists or scooter riders, using a handheld mobile device is prohibitive because both hands are being used to steer. In these situations, positive guidance could be accomplished through audio and haptic outputs from the mobile devices. These audio and/or haptic outputs could be provided to the user at the same time that the user would expect to receive a visual cue and could be similar in nature to reflect the prominence of the information and its importance to the traveler.

CHAPTER 5. DEVELOPING A DESIRED OPERATING ENVIRONMENT

CHAPTER OVERVIEW

The planning and design of information exchanges with mobile devices should involve a well-defined process to ensure that each component of the information ecosystem is properly included and integrated. Like other complex projects, it is important that a mobile device project follow an established SE process that incorporates the various components (e.g., the traveler, transportation agency/service provider, software/hardware, and communication platform). The benefit of this process is that SE follows a sequential path as a project progresses with various validation/verification checks to ensure that the product adequately represents the planning and design. For maximum efficacy, it is necessary that this process be initiated at the planning stage and align with regional goals and efforts to maximize stakeholder input and concept development.

This chapter provides an overview of the project development processes applicable to developing a mobile device information exchange. The following procedures are outlined in this chapter:

- Planning.
- SE Process.
- Agile Development.

Although each step of the project development process is described as a general reference for transportation agencies and/or transit service providers leading the development process, it is important to check for regional and/or local project development standards and guidelines. Many States and regions have developed individual SE requirements and ITS architectures.

PLANNING

Transportation services providers continually engage in a range of planning activities to advance their programs. The activities can also help to advance the development of mobile device-based systems in the following ways:

- Leveraging the interjurisdictional and interdisciplinary momentum that collaborative planning activities foster.

- Capturing the needs of diverse sets of user groups.

- Identifying opportunities to leverage current and future investments in transportation technologies.

- Defining a transportation ecosystem in which travelers using connected mobile device-based systems can be integrated into the management and operation of the surface transportation system, specific facilities, or services.

- Supporting solutions that address travelers’ purpose and need and linking those needs to enhance access to or use of existing services and facilities.

- Addressing how purpose, need, and scope of the project fit in the project and planning process.

- Adding context for creating and using solutions that encompass mobile devices and data.

- Identifying potential mobile device-based projects.

Some of the planning activities that can be leveraged in the preparations of studies, proposals, or the development of projects to facilitate sharing and using data with mobile devices or for specific services are discussed in the following subsections.

Metropolitan Transportation Plan

Each metropolitan planning organization (MPO) develops a metropolitan transportation plan to accomplish the objectives outlined by the MPO and State and local transportation service providers with respect to the development of the metropolitan area's transportation network. This plan identifies how the metropolitan area would manage and operate a multimodal transportation system (including transit, highway, bicycle, pedestrian, and accessible transportation) to meet the region's economic, transportation, development, and sustainability goals for a minimum 20-yr horizon.(12)

Opportunities to implement an ecosystem that supports information exchange with mobile devices could be found in projects related to ITS, TMSs, and transit management services. It may be advantageous to look at the goals and objectives of such systems to determine how sharing data with mobile devices could support these systems and to advocate inclusion of the components necessary for these systems to share data with mobile devices.

TSMO Plans

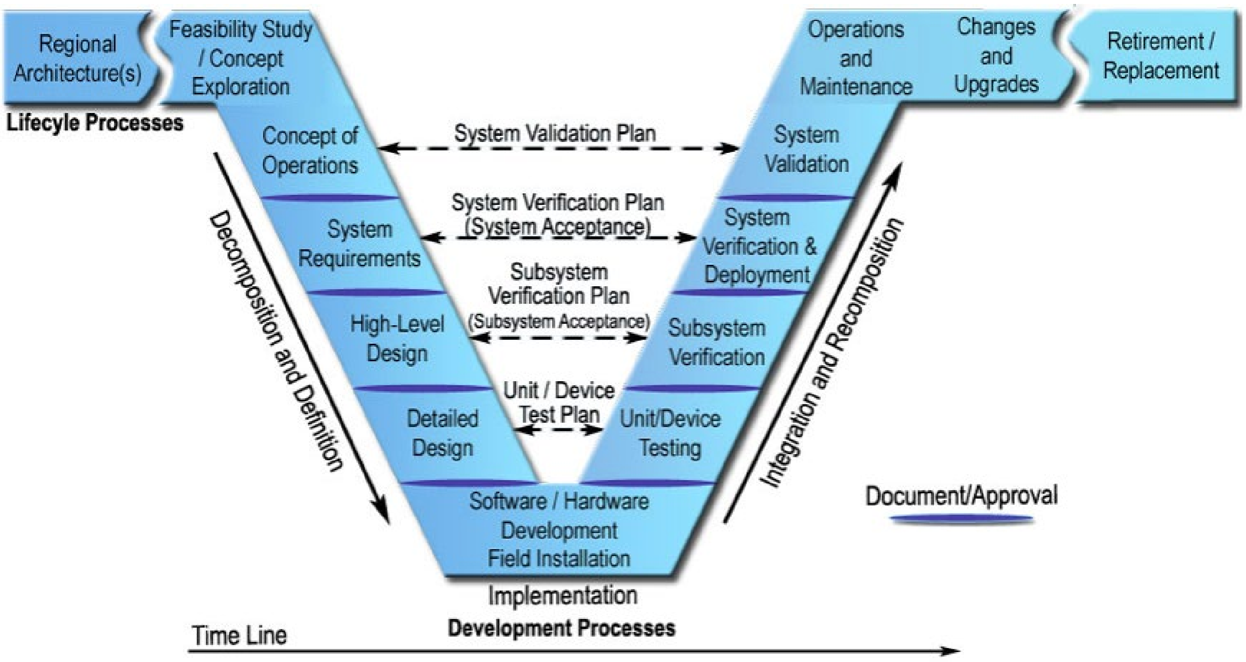
Many States and regions are beginning to develop plans that specifically focus on TSMO to provide strategic direction, to provide program development, and to define strategic activities to enhance the operations and management of transportation systems. These planning projects are collaborative efforts whereby stakeholders work together to identify a vision, mission, and goals and objectives specifically for a TSMO program. The TSMO plan articulates the organization and operational procedures available within the State/region, the necessary resources and activities available to achieve the goals and objectives, and the services and goals needed to realize the TSMO goals and objectives. Generally, TSMO plans have three elements:(13)

- **Strategic**—May include the business case for TSMO, vision and program mission, and goals and performance objectives.
- **Programmatic**—May include leadership and organizational structure, staffing and workforce needs, and business processes.
- **Tactical**—May include TSMO projects and services and implementation policies.

It is advantageous to identify the goals and objectives of within these plans where efforts to create or sustain an ecosystem for sharing messages with connected mobile devices can be included to enhance the effectiveness of the proposed system.

SE PROCESS

The SE process involves a top-down process whereby the mobile device-based system would be derived from developing functional and physical requirements as defined by stakeholders. The "Vee" diagram SE process—which can be applied to the design, development, implementation, startup, operation, and monitoring of a mobile device-based system development project—is illustrated in figure 4.(14) This is a commonly accepted process for SE for transportation technology projects, and by extension, it is applicable to mobile device-based systems.



Source: FHWA.

Figure 4. Diagram. SE Vee diagram.(14)

The SE process starts in the upper left portion of the diagram, moves down and to the right in the decomposition and definition phases, undergoes the development process, and moves upward and to the right in the integration and recomposition phases of the process. The timeline of the process progresses from right to left, while the level at which the mobile device-based system is defined for each process is represented by the vertical location on the figure. High-level processes, near the top of the figure, represent specifications more abstract in nature, whereas low-level processes, near the bottom of the figure, provide detailed specificity regarding individual components of the mobile device-based system. Each step on the downward (left) side of the process is tested, verified, or validated through a corresponding step of the upward (right) side of the process. The documentation that captures the test, verification, or validation is represented by the dashed horizontal lines that connect the downward (left) and upward (right) sides of the diagram. An overview of these steps is provided in the remaining subsections in this chapter, with the primary focus on the ConOps and the systems requirements documentation.

Regional Architecture Development

A key initial step in the planning for transportation technology projects, including mobile device-based systems, is the understanding of the existing regional and/or statewide ITS architecture. For regions where an ITS architecture does not exist, one should be developed to coordinate and facilitate the planning, development, and deployment of ITS projects.

> A key initial step in the planning for transportation technology projects, including mobile device-based systems, is the development of a regional ITS architecture.

The Federal Highway Admimistration (FHWA) defines a regional ITS architecture as "A specific tailored framework for ensuring institutional agreement and technological integration for the implementation of project of groups of projects in a region." The regional ITS architecture defines what ITS elements are linked to others and what information is exchanged between them through the following actions:(15)

- Providing each project sponsor with the opportunity to view their project in the context of other regional systems.
- Prompting the sponsor to think about how a mobile device-based system would fit within the overall transportation vision for the region.
- Identifying the integration opportunities that would be considered and providing a headstart for the SE analysis needed to plan and develop a mobile device-based system.

Developing the ITS architecture helps to understand what types of external systems and data might be available and how new components that would support the communication of electronic messages with mobile devices to share these data could be integrated with the existing system. Conversely, the architecture could be used to determine how existing ITS components could leverage information received from mobile devices to enhance operations.

Project Purpose and Objectives

A transportation service provider or some other regional entity such as an MPO may decide to further explore a mobile device-based system project, thus it would be critical to identify the purpose and objectives of the systems. The definition of the project purpose would be rooted in the various needs or opportunities as defined by the various stakeholder groups. A definition of the project purpose and objectives would document the following elements:

- Motivation for the mobile device-based system and the problems or opportunities for improvement that it is intended to address.
- Objectives that need to be achieved for the mobile device-based system to be considered successful.
- Anticipated benefits for each stakeholder and user group.

Feasibility/Concept Exploration

Feasibility/concept exploration entails making a business case for the potential mobile device-based system. As part of this process, it would be considered in the context of the technical, economic, and political feasibility of the region. The following activities would be commonly conducted during this step:

- Identify alternative concepts to address goals and objectives established by stakeholders.
- Define evaluation criteria to evaluate candidate systems.
- Conduct an initial risk analysis of each of the candidate systems.
- Evaluate alternative systems.
- Document results of the analysis activities in a format suitable for leadership use in decisionmaking.

The primary goal in conducting feasibility/concept exploration would be to gain leadership approval so the candidate mobile device-based system may move forward.

ConOps

A ConOps serves as the first in a series of engineering documents in the SE process that would focus on clearly conveying a high-level view of the mobile device-based system to be implemented from the viewpoint of each stakeholder. The ConOps would frame the overall mobile device-based system, would set the technical course for the project, and would serve as a bridge between early project motivations and the technical requirements. The ConOps would be technology independent, would focus on the functionality of the proposed mobile device-based system, and would form the basis of the project. The ConOps would also communicate the user's needs and expectations for the proposed mobile device-based system. The development of the ConOps would also provide stakeholders with the opportunity to provide input as to how the proposed mobile device-based system could function, which would help build consensus and create a single vision for the mobile device-based system being developed. Developing the ConOps would facilitate consensus among stakeholders, reduce the risks associated with the mobile device-based system being developed, and improve the quality and overall operation of the mobile device-based system. The various sequential activities that would result in the ConOps are described in the following subsections.

Current Operating Environment

Analyzing and documenting the current operating environment would help define what/how current systems operate (even if it is a mostly manual process) or state that no system exists. The analysis would also describe the motivation for developing a new mobile device-based system and would identify how the users can achieve the goals/objectives established for the existing system. Modes of operation and users of the current system would also be defined in the analysis of the current operating environment. In addition, the analysis would provide an assessment of current capabilities; define what the system is aiming to accomplish; and describe benefits to users of devices, to the operation of mobile device-based systems, and to other travelers. Furthermore, the analysis would describe any operational policies and constraints that apply to the current system or situation. Operational policies would be predetermined by management decisions regarding the operations of the current system, normally in the form of general statements or understandings that guide decisionmaking activities.

Justification for Changes

In developing a ConOps, it would be necessary to ensure that user capabilities and needs are considered and that system capabilities and/or system needs are defined. The following activities would be necessary to accomplish these goals:

- Summarize the new or modified missions, objectives, environments, interfaces, personnel, or other factors to consider for a new or modified system.
- Document and prioritize user needs as essential, desirable, or optional.
- Identify if there are any alternative nonmobile device-based technologies that were considered but not included in the concept.
- Detail the deficiencies or limitations of the current system or situation that would make it unable to respond to new or changed factors.
- Provide justification for a new or modified system.

Based on this information, performance measures necessary to assess the proposed mobile device-based system would also need to be considered at this point.

Operating Environment

In developing the ConOps, it would also be necessary to define the operating environment. This process would entail developing a summary of new or modified capabilities, functions, processes, interfaces, and other changes needed to respond to the factors identified. The summary would describe the proposed mobile device-based system at a high level, indicating the operational features that would be provided without specifying design details and the operational policies and constraints that would apply to the proposed mobile device-based system. Physical aspects of the new mobile device-based system would be defined in terms of hardware, software, system interfaces, communications, messages, facilities, security, and so forth.

Operational Scenarios

The description of the operating environment is typically followed by the enumeration of scenarios that provide a step-by-step description of how the proposed mobile device-based system would operate and interact with its users and its external interfaces under a given set of circumstances. Scenarios would be described in a manner that would allow readers to walk through them and gain an understanding of how all the various parts of the proposed mobile device-based system would function and interact. The scenarios would tie together all parts of the mobile device-based system, the users, and other entities by describing how they would interact. The scenarios could also be used to describe what the mobile device-based system would not do.

Impact Summary

Understanding operational and organizational impacts resulting from implementing the proposed mobile device-based system and considering events that could occur during development that may affect mobile device-based system design would also be critical. In documenting and analyzing the impacts, it would be necessary to consider the impacts from the perspective of each user.

System Requirements

After a ConOps has been developed and stakeholders have agreed on the content in the ConOps, the system requirements documentation could begin to be developed. Requirements govern what, how well, and under what conditions a mobile device-based system (or subsystem within a system) would achieve a given purpose.

A clear requirement statement would provide a shared understanding of the problem to be solved by a customer and a developer, a firm basis for managing project scope, the connection between user needs and mobile device-based system design, and the foundation for mobile device-based system verification/testing. If necessary, requirements could be defined as a hierarchy, whereby a parent requirement would be supported by one or more child requirements that would go into greater detail and specificity.

Quality requirements would be necessary, unambiguous, complete, measurable, consistent, achievable, testable, and technology independent. (These requirements would be important to consider because communications technologies are discussed with respect to mobile devices.). As each requirement is written, it would be inspected to ensure each of the following six criteria are met:

- **Necessary—**Traces to a user need or a parent requirement.
- **Clear—**Does not use ambiguous language (e.g., user friendly, optimum, realtime, or overly complex sentences).
- **Complete—**Traces every user need to at least one requirement and ensures the need can be fully met with the provided requirements.
- **Correct—**Describes needed functionality and performance accurately.
- **Feasible—**Is technically and financially achievable.
- **Verifiable—**Is verifiable by using one of the four verification methods.

Validation and Verification

Validation and verification provide means for checking the developed mobile device-based system against the concepts and requirements that were defined in earlier steps (the down-sloping side of the Vee diagram) of the SE process. Though traceability throughout the SE process would minimize the likelihood that the system is not properly built or does not meet agency objectives or stakeholder needs, validation and verification provide documentation that this mobile device-based system is operating as intended. Verification provides a check against the established requirements to ensure the mobile device-based system that was built per the specifications as defined in the requirements document, whereas validation ensures that the mobile device-based system that was built ultimately solves the problem(s) that was/were intended to be solved by the mobile device-based system. Validation is discussed in further detail in chapter 6, and verification is discussed in further detail in chapter 7.

Validation

The initial performance measures identified in the ConOps provide a foundation for the system validation plan. Although expectations for the mobile device-based system would change over time, the performance measures outlined in the ConOps force early consideration and agreement of how mobile device-based system performance and project success would be measured. Validation confirms that the user needs are met by the installed mobile device-based system and occurs throughout the SE process. Furthermore, the validation plan ultimately establishes that the right mobile device-based system was built (i.e., right business case, right needs, right requirements, right design, and right implementation).

Verification

A plan for verifying the mobile device-based system based on the requirements would be defined. It would be critical that only verifiable requirements be included in the system requirements document. A verification method would be identified for every requirement—normally, through testing, demonstration, inspection, or analysis. The purpose of this early assignment of a method, long before the requirements are verified, would be to make sure that the authors think about how the requirement would be verified from the beginning.

The system verification plan defines testing, demonstration, inspection, and analysis processes related to each requirement. Functionally related requirements would be demonstrated in each test case. It is important to note that the verification plan would not be a test procedure. Test procedures would be provided as part of the procurement process by vendors to define what is needed to carry out a test described in the verification plan.

System Design

Once the ConOps and system requirements have been finalized, the system design could be developed. This documentation would contain the design factors and the choices made to satisfy the requirements developed in the system requirements specification document, and it would guide implementation of the system. The primary objective of the system design document would be to produce a design that meets the system requirements; defines key interfaces; and facilitates development, integration, and future maintenance and upgrades. Details could include, but would not be limited to, hardware and firmware specifications for various devices that would be deployed, configuration details for each device, and specific functions that each device might need to perform.

Key activities of the system design process would be as follows:

- Evaluate off-the-shelf components.
- Develop and evaluate alternative high-level designs.
- Analyze and allocate requirements.
- Document interfaces and identify standards.
- Create an integration plan, subsystem verification plans, and subsystem acceptance plans.
- Develop detailed component-level design specifications.

Once the detailed design has been reviewed and accepted, the mobile device-based system could be developed and procured.

Testing

Once hardware and software have been procured, they would be tested to ensure that off-the-shelf or designed components adhere to the system design specifications. Once tested, the components would be ready for integration and installation.

Integration and Verification

Software and hardware components that make up the system would be progressively combined into subsystems until the entire mobile device-based system is assembled. Verification would ensure that the completely assembled mobile device-based system could meet the system requirements specifications.

Deployment

The mobile device-based system would be installed in the operational environment and transferred from the project development team to the organization that would own and operate it. The transfer would also include support equipment, documentation, operator training, and other enabling products that would support ongoing mobile device-based system operation and maintenance. Acceptance tests would be conducted to confirm that the system performs as intended in the operational environment. A transition period and warranty would ease the transition to full system operation.

Validation

Once deployed, the system owner/operator would conduct user acceptance tests to make sure that the deployed system meets the original needs identified in the ConOps—that is, the system would fulfill its intended use.

Operations and Maintenance (O&M)

Once the mobile device-based system has been installed and accepted, the system would operate in its typical steady state. System maintenance would be routinely performed, and performance measures would be monitored. The implication of potential changes in how a mobile device-based system is managed and operated are discussed in further detail in chapter 6, ConOps.

AGILE DEVELOPMENT PROCESS

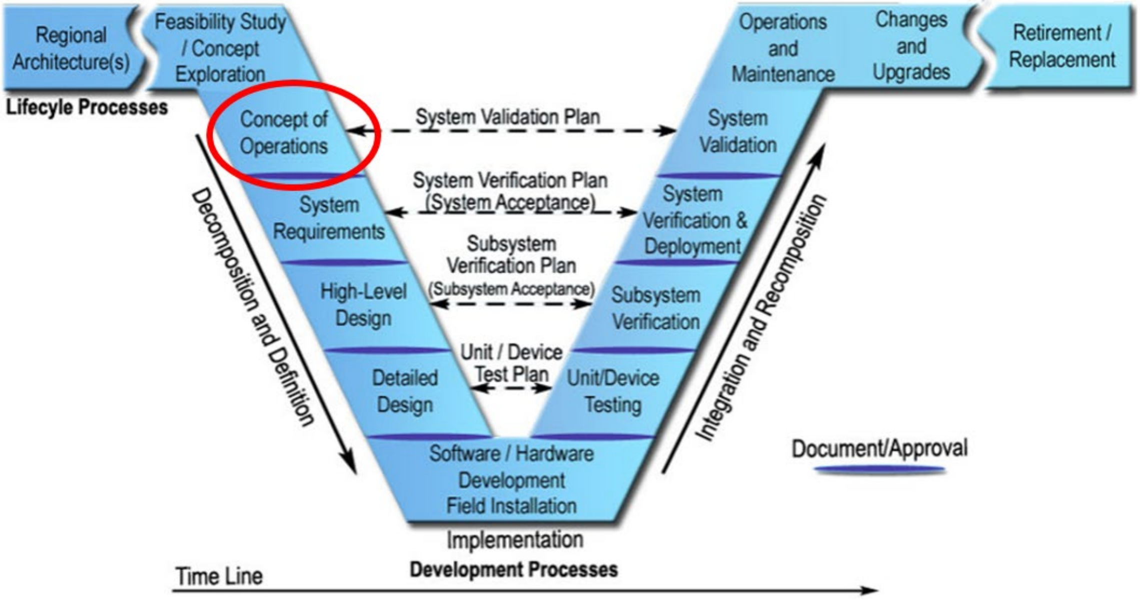
Many ITS and CV systems (e.g., research, prototype, and deployment) are traditionally designed using the Vee diagram SE process.(14) However, it is worth noting that there is an alternative process (the Agile process), which some agencies may prefer (especially for the development and integration of mobile devices with the existing system).(16) The Agile process is an incremental and iterative method of designing a final product. The Agile process, which is used primarily, but not exclusively, in software engineering projects, is adept in its ability to create and respond to change, especially when there is uncertainty that requires adaptation. One of the primary concepts used in the Agile process is "user stories." Each user story yields a contribution to the value of the overall product, once implemented.

Due to its prevalence, the remainder of the SE guidance provided in chapter 6 and chapter 7 focuses on the Vee diagram SE process.(14)

CHAPTER 6. CONOPS

CHAPTER OVERVIEW

A ConOps is the first step within an SE process that transitions from high-level planning and goal setting to design. Use of this detail-oriented process has been demonstrated to be effective in helping stakeholders and system design experts alike in capturing the necessary elements of the environment, needs, and future concept(s). For mobile device information exchange, a ConOps approach could be particularly important to document how mobile devices could play a role in a connected transportation environment. The resulting documentation would allow stakeholders—regardless of background—to understand the scope of the system, the desired operational capabilities, and the various support elements necessary. Figure 5 shows where this effort would align with the overall SE process.



Source: FHWA.

Figure 5. Diagram. ConOps in the SE process.(14)

This chapter provides an overview of the ConOps purpose, development process, and documentation. Chapter content generally follows the structure of a typical ConOps document as specified in Institute of Electrical and Electronics Engineers (IEEE) 1362-1998 and summarized in the bulleted list that follows.(17) American National Standards Institute/American Institute of Aeronautics and Astronautics ANSI/AIAA-G-043B-2018 is another industry standard that can be used for developing a ConOps, and it has a very similar outline and content as IEEE 1362-1998, which could be considered as an alternative, depending on the preferences of project development stakeholders.(18) However, the remainder of the discussion on ConOps in this document uses the IEEE 1362-1998 outline.(17) Each of the following sections of a ConOps are discussed in this document, except for the Reference Documents section, which is a standard bibliography section:

- Concept of Operation Scope (see next section).
- Reference Documents.
- Current Operating Environment (see chapter 6, Current Operating Environment subsection).
- Justification for and Nature of Changes (see chapter 6, Justification for Changes and User Needs subsection).
- Proposed Operating Environment (see chapter 6, Desired Operating Environment subsection).
- Operational Scenarios (see chapter 6, Operational Scenarios subsection).
- Summary of Impacts (see chapter 14).
- Analysis of the Proposed System (see chapter 14).

CONCEPT OF OPERATION SCOPE

The ConOps defines the purpose of the document and the scope of the project under which the system would be developed. The scope could reference the high-level goals, define how the system requirements would build off the ConOps, and describe how the system requirements would support future documentation (table 1).

Mobile devices have proven to be highly disruptive to the transportation space, but at present, most deployed applications have been developed by private companies with a strong motivation for profit-focused outcomes, with the possible exception of those applications that leverage transit data. When defining the system boundaries (i.e., the scope), the author would clarify what the agency has control of, what the agency may have some influence on, and what is outside of both control and influence and prioritize these factors accordingly. Furthermore, as the industry continues to evolve quickly, consideration of what data have proven to be from a sustainable source would be necessary.

Table 1. Scope content for a ConOps.

Subsection	Description
Identification	Identifies the document, its purpose, and its relationship to previous and subsequent documentation.
Document Overview	Lists all chapters in the document and provides a brief overview of what is included in each section.
System Overview	Provides the motivation for taking on the project, as well as any goals, objectives, vision, or mission statements for the project. If the system developed would be part of a larger system, this relationship would be defined. This section also provides a summary of the hardware, software, and functionality that would be deployed or prototyped.

CURRENT OPERATING ENVIRONMENT

The current operating environment would describe the existing systems, types of connected devices supported now or planned for future, and what would be done to support the environment. This environment would include, but would not be limited to, field infrastructure, TMS and other management systems; other technologies (API for connected devices, vehicles);

and services (e.g., updating messages, message libraries, APIs, and coordinating updates). The description would address how the existing operating environment is working; how the existing systems would work with connected mobile devices (i.e., describe, identify components/systems and capabilities); the limitations of the existing system, and the potential impacts of planned improvements. Table 2 lists the expected content of each subsection within this section. In addition to the standard ConOps language, the descriptions include some considerations as they relate specifically to the use of mobile devices.

In general, however, unless an agency is already utilizing their own mobile device data collection, the current operating environment would likely comprise traditional data collection systems, possibly supplemented by third-party data aggregators. Even if an agency supports mobile devices, it would more likely be pushing data versus receiving data. This model would need to change to truly support the goals outlined in the report, but for now, understanding what is available in today's environment is important.

Table 2. Current operating environment contents.

Subsection	Description
Background, Objectives, and Scope	Describes existing plans that contain regional transportation goals and objectives. CV or CAV strategies and Vision Zero plans are two that are more recent additions to existing ITSs as well as transit and freight plans.(19) A summary of targets and goals of the existing system would be provided.
Operations Policies and Constraints	Provides a list of regulations and agency policies that govern the existing system. This list would include local ITS/CV architectures as appropriate.
Description of the Current System or Situation	Describes the current environment in which the implementation of mobile device technology would affect travelers. This description could include a physical description of impacted locations and a list of services or devices that comprise the current system.
Modes of Operation for the Current System or Situation	Describes various modes of operation for the current system. This description would include normal operating conditions at a minimum but would also consider including nonnormal operating conditions to provide perspective on how the current system operates (or fails) when an issue arises.
User Classes and Other Involved Personnel	Describes the various users of the current system, how they interact with the system, and how the current system benefits each user class. All users that fall within the same user class share common responsibilities, skill levels, work activities, and modes of interaction with the system. Only user classes that would be affected by the implementation of the mobile device-based system would need to be included.
Support Environment	Provides a list of agencies involved in the management, operations, and/or maintenance of the current system. Agencies that would also play a role in the implementation of the mobile device-based system would need to be listed—if they do not play a supporting role in the current system, then this would be stated.

Recently, the trend has been for local infrastructure owner/operators to move away from their own data collection equipment toward that of third-party providers. These various sources of data would need to be considered.

JUSTIFICATION FOR CHANGES AND USER NEEDS

New and/or modified user needs supporting the identification of a new or modified system are summarized in this section. It summarizes the deficiencies or limitations of the current system or situation that make it unable to respond to new or changed factors. It further discusses the development of user needs to enable information sharing between connected mobile devices and traffic or transit management systems.

The user needs development process is expected to be supported by justifying changes to the existing system (table 3). The process of justifying changes would be addressed first, followed by a process for eliciting and developing user needs. The user needs would then be addressed by enhancing the existing system (discussed in the next section). There may also be system needs that could be considered to enable electronic message sharing with connected mobile devices.

A user need would be uniquely identifiable, express a major desired capability or feature that the future system should support, and be developed without an end solution in mind. A user need is strengthened by including a rationale that captures why the need is included.

Table 3. Justification for changes and user needs contents.

Subsection	Description
Justification for Changes	Provides the results of activities that indicates that the proposed system is needed to (more adequately) meet user needs. This description could include, but would not be limited to, stakeholder engagement summaries, technical working group meeting outcomes, and/or the results of data or technical analyses that represent issues faced by existing system users. Part of the challenge with the use of mobile devices is that the domain of use is still evolving. Mobile devices are disruptive, and this trend is likely to continue. Although envisioning every use of that data is impractical, a general trend is to capture what can be made available, and as technology and/or research catch up, uses may be found. In other words, plan beyond the immediate use cases.
Description of Desired Changes	Presents user needs (derived from information presented in the Justification for Changes section) for each user class. Also provides a high-level description of changes that would be made to meet the needs of users. Measures that would be used to assess system performance would be introduced. User needs would reflect the specific use cases of interest, but again, would be forward thinking, allowing for future uses of data that have not yet been conceived.
Priorities Among Changes	Prioritizes user needs presented in the previous subsection. This prioritization would be typically done by classifying each user need as essential, desirable, or optional.

DESIRED OPERATING ENVIRONMENT

This section would describe the proposed system and would include physical objects, functions performed by each object, and the messages sent between them. This section could also involve identifying constraints on the system. Various aspects of a mobile device-based system that could be discussed in this section would include, but would not be limited to, connected mobile devices, APIs, and supporting systems to meet user needs. The National ITS Architecture and the extension enabled through the *Architecture Reference for Cooperative and Intelligent Transportation* framework would be used as a basis for developing system architecture and the system description, to the extent applicable to the proposed system and the local ITS architecture.(20)

The architecture for the proposed system could be illustrated in a system diagram. The diagram would distinguish between the existing and proposed system (e.g., the communications and physical objects in the proposed system would be represented using solid lines and colored boxes, while communications and physical objects in the existing system would be represented using dashed lines and gray boxes).

The content in this section would be driven by the selected use cases. Text would establish the types of physical objects, communications, interfaces, and functions in the system. As noted earlier in the scope section of this chapter, those elements of the system that are within control and possibly influence would be shown within the system boundary, otherwise they would be indicated outside of the boundary. Even if these elements are outside of the boundary, they would still be included because their systems, which are primarily envisioned to be third-party data providers or consumers, could have a significant influence on the system.

A description of the proposed system would be provided, including the following aspects, as appropriate:

- Operational environment and its characteristics.
- Major system components and the interconnection among those components.
- Interfaces to external systems or procedures.
- Capabilities, functions, and features of the current system.
- Charts and accompanying descriptions depicting inputs, outputs, data flows, control flows, and manual and automated processes, enough to understand the current system or situation from the user’s point of view.
- Cost of system operations.
- Operational risk factors.
- Performance characteristics, such as speed, throughput, volume, frequency.
- Quality attributes, such as availability, correctness, efficiency, expandability, flexibility, interoperability, maintainability, portability, reliability, reusability, supportability, survivability, and usability.
- Provisions for safety, security, privacy, integrity, and continuity of operations in emergencies.

When describing the desired operating environment, it would be important to consider potential capability limitations and challenges that could be faced (table 4).

Table 4. Desired operating environment contents.

Subsection	Description
Background, Objectives, and Scope	Summary of targets and goals that the proposed system would provide. Ideally, the proposed system would be in alignment with regional transportation goals and objectives for the current system.
Operations Policies and Constraints	List of regulations and agency policies that would govern the proposed system. This list would include local ITS architectures and network, as appropriate.
Description of the Proposed System or Situation	Description of the environment that includes the implementation of mobile device technology. This subsection could include a physical description of affected locations, a list of services, or devices that comprise the proposed system.
Modes of Operation for the Proposed System or Situation	Description of various modes of operation for the proposed system. This subsection would include normal operating conditions at a minimum, but it would also consider including nonnormal operating conditions to provide perspective on how the proposed system would operate (or fails) when an issue arises.
User Classes and Other Involved Personnel	Description of the various users of the proposed system, how they would interact with the system, and how the proposed system would benefit each user class. All users that fall within the same user class would share common responsibilities, skill levels, and modes of interaction with the system.
Support Environment	List of agencies that would be involved in the management, operations, and/or maintenance of the proposed system.

OPERATIONAL SCENARIOS

Operational scenarios would be developed for various series of events (where the scenario would play out differently, depending on the types of events that would occur) and operating conditions (normal, degraded, failure). In the context of mobile devices, and more importantly, trip planning/taking, an almost infinite number of combinations could be produced.

When defining the scenario, the following elements would be captured. In lieu of providing examples of each of these elements, the reader can refer to the scenarios included in latter chapters of this document:

- **Identification and title**—Represents the scenario at hand. The title would be specific enough to differentiate it from other scenarios. The ID number would provide a shorthand method of referring to the scenario and would be generally useful for traceability purposes.
- **Description**—Provides a high-level overview of the scenario.
- **Objective**—Describes the outcome that the system would be enabling.

- **Overview of operational events—**Provides a description of the system functions that would take place in the scenario that would ultimately be responsible for the objectives being met.

- **Preconditions—**Provide background information regarding the state of the system and the status of actors that would occur before the events described in the scenario.

- **Description of actors—**Provides a brief description and role of each actor that would appear in the Key Actions and Flow of Events sections.

- **Key actions and flow of events—**Provide a step-by-step description of how the proposed system would operate and interact with its users and its external interfaces to accomplish a given objective. Each action would be described using a step number, the actor taking the action, the key action taken, and any applicable comments related to the described action.

- **Postconditions—**Provide information regarding the state of the system and the status of actors after the events described in the scenario have occurred.

- **Messages (information requirements)—**Provide an overview of the types of messages that would be exchanged within the system and between the system and external systems. Note: Scenarios do not typically include message content because this level of detail is usually defined in system requirements. However, the scenarios presented in chapters 8, 9, 10, and 11 of this document do address message content because of its importance to the establishment of a mobile device-based system.

- **Traceability—**Lists the user needs that would be satisfied in the scenario. Alternatively, it could describe which user needs would not be met (only if the scenario has nonnormal operating conditions).

- **Summary of inputs and outputs—**Provides an overview of inputs and outputs external to the system.

These scenarios would provide a step-by-step description of how the proposed system would be expected to operate. Scenarios would be described in a manner that would allow readers to walk through them and gain an understanding of how all the various parts of the proposed system function and interact. The scenarios would tie together all parts of the system, the users, and other entities by describing how they would interact. Scenarios could also be used to describe what the system would not do.

A scenario is a step-by-step description of how the proposed system should operate and interact with its users and external systems under a given set of circumstances.

Operational scenarios would be developed for various series of events (e.g., where the scenario plays out differently, depending on the types of events that occur) and operating conditions (e.g., normal, degraded, failure). These scenarios would provide a step-by-step description of how the proposed system would be expected to operate.

Although scenarios are traditionally developed from the perspective of various users of the system, the examples of scenarios provided in this document would contain application-level details regarding the interface between various system components (i.e., internal and external) to ensure that the reader can understand how the data flows support each use case contained in the scenario and the timing of the delivery of information that would be needed for the traveler to make decisions pertinent to their trip. Furthermore, the types of trips (e.g., home–work, home–shopping, home–recreational, etc.) are included in the example scenarios to add context.

VALIDATION

A system validation plan would be developed to assess system performance and to ensure the system addresses the needs of the stakeholders as outlined during the development of the system concept. Furthermore, the plan would ensure that the system would be effective in meeting its intended purpose. It may be advantageous to perform these tests in a closed environment to gain deployment expertise, minimize the likelihood of unintended operations, and allow revisions to be made to the system. Furthermore, as system components (including firmware) are updated, they could be tested in a closed environment to ensure the system continues to operate as intended once updates have been made.

CONCEPTS DEVELOPED IN THIS DOCUMENT

Chapter 3, User Classes, defines several classes of users that could use mobile devices throughout the course of their trip that would provide various safety, mobility, reliability, and wayfinding benefits. When developing concepts for sharing and using electronic messages with mobile device-carrying travelers, it would be important to consider the needs of local stakeholders, local transportation infrastructure, and local transportation systems as well as constraints and enablers that would need to be captured and reflected in SE documentation.

Chapters 8, 9, 10, and 11 in this document provide four concepts that focus on the ability of mobile devices to address various types of user needs. These concepts address the various issues and activities associated with the implementation of connected mobile device-based systems. This implementation includes activities that would occur before, during, and immediately after the period in which the system would be physically deployed and operated. Each developed concept would focus on the following four aspects of the system:

1. System capabilities (which include area of coverage) needed to support complete trips of travelers.

2. Capabilities of connected mobile devices to provide travelers with the information they may need when completing different type of trips.

3. Electronic messages and data elements to ensure the information needed by systems and users of connected devices would be provided.

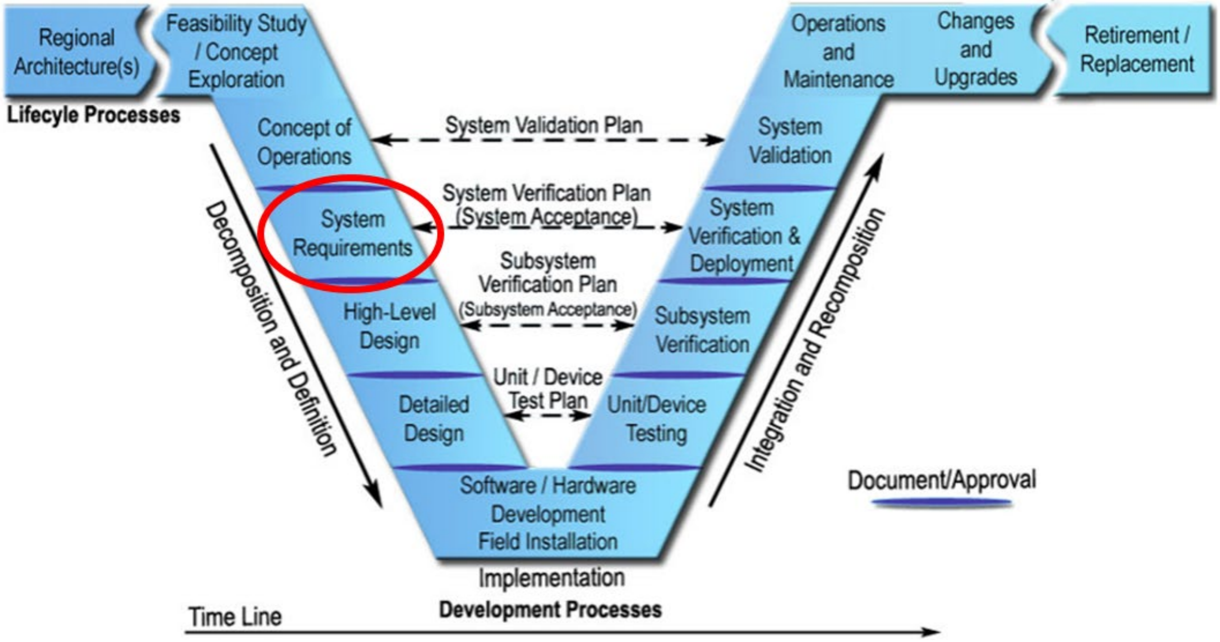
4. Support and administrative issues for agencies to consider developing and sustaining to support an environment that would enable the sharing and use of electronic messages.

Local agencies could use the concepts in chapters 8–11 as a starting point for developing SE documentation and could adapt the concepts, as necessary, to account for local needs and local conditions.

CHAPTER 7. REQUIREMENTS FOR SHARING ELECTRONIC MESSAGES WITH MOBILE DEVICES

CHAPTER OVERVIEW

The development of system requirements for a mobile device information exchange system would identify the individual tasks and functions that each component of the ecosystem would perform. Requirements would be derived from the ConOps. While the ConOps would be a narrative description of the system, the requirements would be individual statements typically listed in a hierarchical manner that would define specific functions. For mobile device information exchange, each of these requirements would ultimately provide input to the design, procurement, installation, and operation of the system. In such a system, requirements would be necessary for the mobile devices, RSE, software, hardware, and communication systems, among other components. Figure 6 shows where this effort would align with the overall SE process.



Source: FHWA.

Figure 6. Diagram. System requirements in the SE process.(14)

This chapter provides an overview of the requirements purpose, scope, and format. Chapter content generally follows the structure of the systems requirements document as specified in International Organization for Standardization (ISO)/International Electrotechnical Commission(IEC)/IEEE 29148.2018 and indicated in the following sections:(21)

- System Requirements Scope.
- References (not described in the following subsections).
- System Requirements.
- Verification Methods.
- Needs-to-Requirements Traceability.

SYSTEM REQUIREMENTS SCOPE

The systems requirements specification (SysRS) communicates the requirements of the project to the technical community that would specify and build the system. The SysRS would be a black-box description of what the project must do, but not how it would do it. The SysRS would contain descriptions of inputs, outputs, and required relationships between inputs and outputs. The first section of the SysRS would be similar in nature to the scope presented in the ConOps document and would define the purpose of the document and the scope of the project under which the system would be developed. This information would provide the reader with an expectation of what they would expect to get out of the document. The scope would reference the ConOps, describe how the SysRS would build off the ConOps, and describe how the system requirements would support future documentation.

Each system requirement is traced back to one or more user needs, which were initially defined in the ConOps.

Most applications deployed on mobile devices have been developed by private companies. When developing the SysRS, the author must be cognizant and realistic about access to these private data sources and focus on what would be attainable. As such, when defining the system boundaries (i.e., the scope), the author would be clear about what the agency has control of, what it may have some influence on, and what would be outside of both control and influence and prioritize these factors accordingly.

SysRS can be integrated into the process of planning a study or developing a project to better define how the system intends to work to meet its goals and objectives and how it would be of use to the traveler or a system management agency. A SysRS also provides a starting point for procuring equipment that is necessary for implementing the designed system.

SYSTEM REQUIREMENTS

The system can be divided into various system components, which could include, but would not be limited to, the following features:

- TMS.
- Transit management systems.
- Roadside infrastructure.
- Mobile devices.
- In-vehicle systems.
- Interfaces.
- Content and structure of electronic messages.

When forming requirements, it would be important to consider what each component must be capable of to enable the sharing and use of electronic messages as needed to meet the needs of users as defined in the ConOps. Thus, a component-by-component assessment would be undertaken to determine the requirements for a given component.

When a requirement is written for a given component depends on a function performed by another component, a reciprocating requirement would be written (focused on the function required of the other component), provided the other component being referenced would be inside of the system boundary. This reciprocating requirement would help a reader to understand specific system components or devices that need to work together.

Requirements could be categorized to differentiate between different types of requirements. Examples of various types of requirements are provided in table 5. Categorization serves to group similar types of requirements so that they can be more easily interpreted and referenced by the reader. The assignment of a requirement to a specific category is not an exact science. Discretion would be used—the requirements categories described in table 5 provide a rough outline for categorizing requirements. Furthermore, the descriptions provide various aspects of the system for stakeholders and systems engineers to consider as requirements are developed. It would not be necessary to generate a requirement within each category.

Table 5. Types of requirements.

Requirement Category	Description
Functional	Specifies actionable and qualitative behaviors (e.g., functions, tasks) of the core system of interest (e.g., mobile device, computing platform, RSE, other functional objects within the system of interest).
Data	Defines the data collected, transformed, and stored from various sources; identifies new data that would be expected to be generated; and may also specify the structure of messages that are used. Applicable standards would be referenced as necessary.
Interface	Defines how the system would interact, communicate, or exchange data with external systems (interface with a system outside of the system of interest) and how core system elements would interact with other parts of the system (interface between functional objects within the system of interest). In the case of mobile devices, caution would be used to ensure that specific technology would not be required as it continues to evolve quickly. Instead, the requirements for interface would focus on the endpoints and not the medium.
Performance	Specifies quantifiable characteristics of operations that define the extent, or how well, and under what conditions a function or task would need to be to be performed. Performance would be a very important requirement for mobile devices, because it typically relates to the reliability of outputs provided to the traveler. For certain use cases, data could be historic or required only at infrequent intervals, which would be more typical of today’s environment. However, as the demands and needs of travelers expand, access to timely and accurate data in near realtime has become necessary.

Requirement Category	Description
Security	Defines the integrity and operability of the system and its microservices, connections, and data. These features include physical security as well as cybersecurity, covering prevention, detection, identification, response, and recovery requirements. These features would be based on standards that typically define security protocols for various communications media. These features would be referenced in security requirements as appropriate.
Physical	Specifies the construction, durability, adaptability, and environmental characteristics of the system, such as installation location, device weight limits, dimension and volume limitations, temperature regulations, layout, access for maintenance, and growth and expansion characteristics. For mobile devices, this requirement would be less important because, to a certain extent, the device would be dictated by the marketplace and would not be part of the design of the system discussed herein.
Availability and recoverability	Defines the times of day, days of the year, and overall percentage of the system that can be used and when the system would not be available for use. These requirements also specify the recovery time objective of the system (which describes the timeframe permitted for a system to become operational), the recovery point objective (which specifies up to what point in time the data would be restored), and how the system would be expected to restore services (e.g., failover, backups) in an event of a failure. Availability would be a critical element of any ecosystem that depends on current data, such as those expected to be used by mobile devices.
Maintainability	Specifies the level of effort required to locate and correct an error during operation to establish a quantitative requirement for planned and unplanned support (e.g., mean and maximum times to repair or resolve issues, number of people and skill levels required, support equipment necessary, maintenance staff hours, and time and frequency of preventive maintenance). As with the physical requirements, the maintainability of the mobile devices would be dictated by the market. However, maintainability of the back-office systems that support data aggregation and dissemination and agency decisions would be relevant.
Storage and transport	Specifies the physical location and environment for the system, including designated storage facility, installation site, repair facility, and requirements for transporting equipment. Specific to this system, the context of storage for the mobile devices, as compared to that of the back office, would be dictated by the market and practical use. The back office would probably be cloud based, so concepts such as physical location would become less critical.
Disposal	Specifies the items related to the disposal of project/system components that are attributable to either failure replacements, removal, end-of-life upgrade, or retirement. This type of requirement tends to be less relevant from the agency perspective as systems move to cloud-hosted systems. The disposal of mobile devices would be dictated by the consumer.

Requirement Category	Description
Information management	Specifies the acquisition, management, and ownership of information from one or more sources, the custodianship and the distribution of that information to those who need it, and its ultimate disposition through archiving or deletion.
Lifecycle sustainment	Defines what items the project or system reviews, measures, and analyzes as part of its commitment to quality during the lifecycle of the system. The capacity to change or enhance the product and lifecycle processes could be designed into the system architecture to enable the cost-effective sustainment of the system throughout its lifecycle.
Policy and regulation	Specifies relevant and applicable organizational policies and regulations that would affect the development, operation, or performance of the system (e.g., IT and labor policies, reports to regulatory agencies, and health or safety criteria). This section would also include new policies and regulations imposed to realize the system.

VERIFICATION METHODS

Verification confirms that all interfaces have been correctly implemented and that all requirements and constraints have been satisfied. The ability to assess each requirement must be considered when assigning a verification method. A verification method would be assigned to each requirement, based on the ability of a requirement to be assessed and the rigor of which it must be assessed. Table 6 defines the four fundamental verification methods that would be used for requirements, along with a description of situations in which each method would be used. The step-by-step process by which each requirement would be assessed would not need to be specified in the System Requirements document because the process would be specified in the test plan.

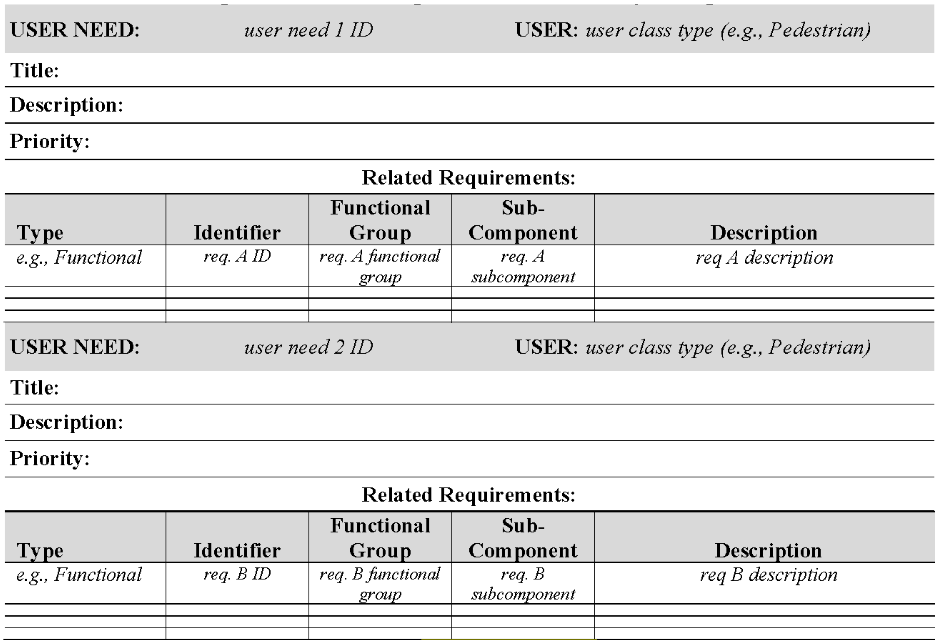
Table 6. Verification methods.

Verification Method	Description	Typical Use
Test	Direct measurement of system operation. Controlled and predefined inputs and other external elements (e.g., data, triggers) cause the system to produce the output specified by the requirement.	Tests typically include some level of instrumentation. Note: Tests would be more prevalent during early verification when component-level capabilities would be exercised and verified.
Demonstration	Observation of system operation in the expected or simulated environment without need for measurement data.	Demonstrations are more prevalent in system-level verification when the complete system is available to demonstrate end-to-end operational capabilities. For example, a requirement that an alarm would be issued under certain conditions could be verified through demonstration.

Verification Method	Description	Typical Use
Inspection	Direct observation (e.g., visual, auditory, or tactile).	Inspection is used typically for items such as construction features, workmanship, dimensions and other physical characteristics, and software language.
Analysis	Indirect and logical conclusion using mathematical analysis, models, calculations, testing equipment, and derived outputs based on validated datasets.	Analysis is frequently used when verification by test would not be feasible or would be prohibitively expensive. For example, a requirement that a website support up to 1,000 simultaneous users would normally be verified through analysis.

NEEDS-TO-REQUIREMENTS TRACEABILITY

Each requirement would be traced back to one or more user needs, which would be initially defined in the ConOps. If there is a user need that cannot be traced to a requirement, then the user would only be considered if additional requirements may need to be developed. Subrequirements associated with a given parent requirement would also be traceable to the same user need(s) as the parent requirement. Needs-to-requirements traceability would be typically presented in a tabular format by listing each user need alongside each requirement that would be associated with it. An example format for documenting this traceability is provided in figure 7. Other attributes of requirements (used to organize/group similar requirements) may be specified as well—in figure 7, for example, functional group and subcomponent are used to group similar requirements.



USER NEED: *user need 1 ID* **USER:** *user class type (e.g., Pedestrian)*

Title:

Description:

Priority:

Related Requirements:

Type	Identifier	Functional Group	Sub-Component	Description
e.g., Functional	*req. A ID*	*req. A functional group*	*req. A subcomponent*	*req A description*

USER NEED: *user need 2 ID* **USER:** *user class type (e.g., Pedestrian)*

Title:

Description:

Priority:

Related Requirements:

Type	Identifier	Functional Group	Sub-Component	Description
e.g., Functional	*req. B ID*	*req. B functional group*	*req. B subcomponent*	*req B description*

Source: FHWA.
Req. = required.

Figure 7. Screenshot. Needs-to-requirements traceability example.

Similarly, reverse traceability ensures that all requirements would have at least one user need associated with it (i.e., verifies that all requirements were included in the needs-to-requirements traceability table). One or more user needs would be associated with each requirement. Reverse traceability would be typically presented in a tabular format by listing each requirement alongside each user need that would be associated with it.

CHAPTER 8. CONCEPT 1: TRAVELER WALKING AND USING A CONNECTED MOBILE DEVICE

CHANGES CONSIDERED BUT NOT INCLUDED

This section identifies changes and new features that were considered but not included and the rationale for not including them, which could be attributable to difficulty of implementation, technology limitations, or the ability of other systems to adequately meet the needs of users. Changes considered but not included would vary from agency to agency and from region to region.

CHAPTER OVERVIEW

This chapter is the first of four chapters that develop an example concept to showcase how mobile devices and electronic messages could be used to satisfy traveler needs. This chapter focuses on addressing an example set of needs for pedestrians carrying a mobile device. Through these example concepts, the reader would begin to understand the content included in a typical ConOps. A description specific to the concept walks through existing conditions, justification for changes, desired changes, operational policies and constraints, proposed operating environment, modes of operation, user classes, support environment, and operational scenarios. These example concepts begin to shape a system that enables the exchange of electronic messages with mobile devices to satisfy the needs of different types of travelers.

EXISTING CONDITIONS

Several features at pedestrian crossings are used for pedestrian navigation at signalized intersections. At certain signalized intersections, pedestrians are required to press a pushbutton to receive a walk signal at an intersection. At most intersections with pushbutton requirements, multiple pushbuttons give pedestrians a choice of crosswalks near a single location. Some (but not all) pushbuttons provide a brief audible cue when pressed to indicate that the crossing request has been received.

Pedestrian signal heads also display the state of the pedestrian phase. The three pedestrian phases include walk, clearance (i.e., flashing do not walk), and do not walk.

- The WALK phase is indicated by a steady walking person signal indication and is typically white in color. Some older signals indicate this in text form. The pedestrian is permitted to start to cross the roadway in the direction of the signal indication.

- The pedestrian clearance phase is typically indicated by a flashing, red upraised hand. Some older signals indicate this phase in text form. During this phase, the pedestrian is expected to complete crossing the roadway, but not start to cross the roadway if still on the curb.

- The DO NOT WALK phase is indicated by a steady upraised red hand. Some older signals indicate this in text form. The pedestrian is expected to have cleared the crosswalk at this time and not begin to cross the roadway.

- At some intersections, the WALK and/or pedestrian clearance phases are supplemented with a countdown until the end of the phase. The countdown typically indicates the amount of time remaining until the DO NOT WALK phase. This countdown can be used by a pedestrian to better anticipate the amount of time left to cross the street. A buffer interval minimum of three seconds is required between the time when the DO NOT WALK phase starts and the beginning of the next phase.(10)

Some intersections do not have pedestrian signal heads. In this case, pedestrians use the traffic signal heads as a visual indication of when to cross the street. Signage is typically used to indicate intersections where pedestrian crossings are prohibited. Furthermore, truncated domes (e.g., detectible warning pavers) are used by persons who are visually impaired to assist in determining where to enter a location for crossing a street. Although truncated domes are commonplace on new sidewalk ramps, not all sidewalk ramps exhibit them.

Some intersections have directed speakers that provide audible cues that correspond to the state of the pedestrian signal head. A combination of voice, chirps, and/or rapid ticks (current standard) provide these audible cues. Not all intersections are required to be equipped with audible pedestrian cues. Audible cues are typically deployed at intersections as requested or in areas where pedestrians with visual impairments are known to cross.

Even at intersections where the pedestrian WALK phase is automatically granted for every phase, the visual walk signal is not automatically accompanied by an audible signal. Some intersections require a pedestrian to press a pushbutton to receive an audible signal. When obtaining an audible signal is among the choices, multiple pushbuttons are present, giving the pedestrian a choice of crosswalks near a single location.

JUSTIFICATION FOR CHANGES

Several aspects of the current conditions at signalized pedestrian crossings could warrant the addition of technology to enable communication to and from mobile devices. These aspects are discussed in detail in the following subsections.

Place Pedestrian Phase Call

In the process of completing a trip, a traveler may need to cross a street at one or more signalized intersections. In some cases, this process requires the pedestrian to provide an input to activate the pedestrian phase at the next available opportunity in the signal timing plan. Pedestrians typically have to press a pushbutton to complete this activation.

Pedestrians with low vision or blindness may have difficulty locating the pedestrian pushbutton due to contextual inconsistencies between intersections. Similarly, a pedestrian with a mobility impediment may not be able to access a poorly placed pushbutton (e.g., not easily accessible from a sidewalk). In another case, the pushbutton could be nonfunctional or not work properly.

Pedestrians may also have challenges determining the state of the pedestrian signal because of low vision. Many intersections may not have audible signals, which limits the ability of that intersection to communicate with the pedestrian. This situation is further complicated when a pedestrian crossing is limited to certain legs of an intersection. Transportation agencies may decide to eliminate a pedestrian crossing on certain intersection movements due to the large volume of left-turning vehicles (typically at interchange ramp intersections). The lack of a crosswalk and pedestrian phase must be communicated to a traveler with a disability. Finally, pedestrians naturally move at different speeds; therefore, the need exists for a pedestrian phase to have a flexible duration so that it can better accommodate slower-moving pedestrians.

Extend WALK Signal Phase

The pedestrian phase may not be long enough to accommodate all pedestrians. A pedestrian who is unable to complete crossing a crosswalk during the allotted pedestrian phase could be placed into a dangerous situation and could begin to move as conflicting traffic receives a green (go) indication.

Pedestrian in Crosswalk Intersection Safety

In environments where vehicles and pedestrians interact, there is a possibility for an incident involving both to occur. Pedestrians, who are classified as VRUs, are prone to injury or fatality when involved in a crash with a vehicle. Thus, drivers must be made aware of the presence of pedestrians on roadways, given their vulnerability.

Intersection Wayfinding

The Accessible Transportation Technology Research Initiative (ATTRI) program studied applications that improve mobility options for all travelers, particularly those with disabilities.(22) These applications are cross-cutting in nature and can often be integrated with existing applications to enhance the user experience. In 2016, the ATTRI program undertook research to understand the needs and barriers to mobility for travelers with disabilities that can be solved by leveraging technology in these five areas: wayfinding and navigation solutions, assistive technologies, automation and robotics, data integration, and enhanced human services transportation. Research indicates that with the notable advancement in mobile and portable computing power and the continued rise of continuously connected mobile devices, many of the technology solutions that were identified as solutions for gaps in information are very realistic for implementation within the next 3–5 yr.(23)

A traveler with low vision or blindness may have issues knowing their location while they are traveling, due to a lack of signs and waypoints that are readily accessible for persons with a visual disability. Technology-based solutions to provide real-time assistance to travelers with disabilities include the use of a virtual electronic guide dog, a wearable device to provide course corrections, and even semiautonomous technologies that detect when a traveler has departed from their expected path and automatically begin to provide real-time guidance assistance through an on-demand virtual concierge service, mobile application, or other method.

DESCRIPTION OF DESIRED CHANGES

Examples of pedestrian user needs based on the justifications described in the four previous subsections are provided in table 7, followed by descriptions of mobile device-based applications that could address these needs.

Table 7. Pedestrian user needs.

User Need ID	Title	Description
Pedestrian UN1	Approaching Crosswalk	A pedestrian needs to know when they are approaching a signalized intersection crosswalk.
Pedestrian UN2	Activate Pushbutton	A pedestrian needs to activate a pedestrian crosswalk phase.
Pedestrian UN3	Extend Crossing Time	A pedestrian needs additional time to complete crossing a crosswalk if they are still in the crosswalk and the pedestrian phase clearance time will imminently expire.
Pedestrian UN4	Pedestrian Safety Driver Awareness	A pedestrian needs their presence in a crosswalk to be known to approaching drivers.
Pedestrian UN5	Wayfinding and Navigation at Crosswalks	A pedestrian with a vision or hearing impairment needs wayfinding and navigation solutions for a complete trip between an origin and destination in the public right-of-way. Note: The traveler needs wayfinding and navigation information before starting the trip and must be updated throughout the trip to account for changing conditions, such as a pedestrian signal.

UN = user need.

Mobile Pedestrian Phase Call

Mobile devices could allow a pedestrian to request a pedestrian phase at an intersection. Such an application could also provide specialized functionality to support the needs of travelers with disabilities. Accessibility issues associated with the activation of a pedestrian phase could be addressed using mobile device technology to request the appropriate pedestrian phase. Furthermore, the mobile device could also provide audio and haptic information regarding a signal state or the lack of a crossing to travelers who are not otherwise able to readily observe the signal state or available crosswalks at an intersection.

To support this use case, the pedestrian would need information about the location of the intersection, the signal state, and the ability to provide a signal priority request to the traffic signal controller at the intersections. To support this need, the MAP would contain intersection geometry information that would allow the mobile device to position itself in relation to the intersection, and the SPaT would contain information about the state of each movement and timing details (e.g., minimum time remaining, expected phase change). A pedestrian with a mobile device would wirelessly issue an SRM, to actuate the pedestrian phase at the signal. The SRM would contain information—such as an intersection identifier, an identifier for the movement request, and the type of service requested (e.g., normal actuation, priority, preemption)—which would be received by the traffic signal that services the request. An SSM would be provided back to the mobile device to provide information regarding which signal requests would be served and the estimated timing of service. The pedestrian using the mobile device would need to be able to indicate which crosswalk they intend to use and have the ability to cancel the request at any time.

Mobile Extend Pedestrian Phase

A walking speed could be specified in the message so that the signal could adjust the phase length to accommodate slower-moving pedestrians. Alternatively, a pedestrian mobile device could continuously provide the location of the pedestrian to the intersection to ensure the signal could preemptively extend the phase until the mobile device is no longer determined to be in the crosswalk. Information regarding the pedestrian's walking speed would be provided so that longer-than-normal crossing times could be accommodated.

Pedestrian in Crosswalk Intersection Safety

Ideally, VRUs would be able to move about in a roadway environment in a safe manner. A mobile device could support the safety of the VRU in a connected environment. The mobile device could receive location, speed, and motion information from the vehicle to alert the VRU when a vehicle is near the VRU, could issue an advisory when a vehicle is moving in the direction of the VRU, and could issue a warning when the vehicle may be at risk of colliding with the VRU unless immediate action is taken.

Conversely, the mobile device would broadcast the location and motion information of the VRU so that similar notifications, advisories, and warnings could be issued to a driver of an approaching vehicle. This would improve the vehicle operator's awareness of VRUs to reduce the likelihood of a collision.

Intersection Wayfinding

Technologies involving text-to-speech or speech-to-text mobile wayfinding and navigation applications and enhanced assistance technologies, such as on-demand assistance or virtual assistants, are frequently identified as potential solutions. Technologies that would reduce the level of information needed by travelers with disabilities, such as autonomous vehicles with preprogrammed door-to-door service, are also frequently cited.

Like all travelers, disabled travelers need additional travel options. Information systems integrated into a single database across multiple agencies that could be accessed by a single piece of technology unique to the traveler would enable personalized services and provide travel options that account for disabled travelers' individual mobility needs. For example, if payment and information systems were integrated with fixed-route transit services across both public and private providers, a traveler could be informed of alternative travel routes that are suitable for their mobility needs. These options could be provided automatically, based on the travelers' current location and transaction with the payment system. Their individual mobility needs could also be conveyed.

Wayfinding and navigation technologies show significant potential to improve mobility. Information before and during a trip was consistently cited as the greatest need, and wayfinding and navigation technologies could help address this need.(24) For instance, electronic orientation aids use RFID tags and mobile devices to determine a person's exact location, which would be used to assist vision-impaired individuals in navigating a route to a destination. The strength of the application would be its ability to annotate the route a user wants to take and invite trusted sources (i.e., individuals or organizations) to enhance urban navigation decisions by blind or vision-impaired travelers.

Priorities Among Changes

This section prioritizes the user-proposed functionality presented in the previous subsection. This prioritization is typically done by classifying each possible change as essential, desirable, or optional. The classification method used would be determined by each deploying agency. Functions related to safety or other high-priority needs are essential, whereas desirable functions are considered to provide enhanced functionality but are not necessary for the system to meet user needs. Optional needs are generally limited to needs that are discretionary in nature. Prioritizing user needs would be a subjective practice and would vary from agency to agency and from region to region.

Assumptions and Constraints

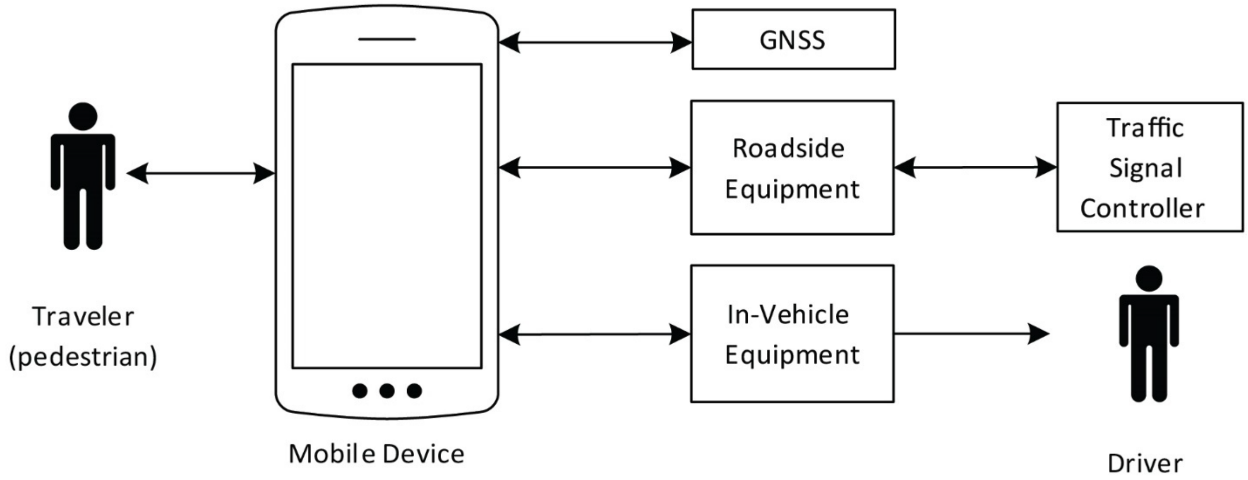
This section lists assumptions and constraints that would (or could) limit how the system can be designed and implemented. The following examples describe common assumptions and constraints that could affect the design of the proposed system:

- Communication, technology, hardware, or software availability.
- Off-the-shelf technology procurement (as opposed to the development of a new device).
- Operational policies and constraints.
- Existing laws and regulations (e.g., governing the operations of motor vehicles, pedestrians, and bicyclers on the roadways).

PROPOSED OPERATING ENVIRONMENT

For this concept, the proposed operating environment includes the mobile device, RSE, a traffic signal controller, and in-vehicle equipment.

Figure 8 illustrates a systems diagram for this concept. The interfaces, hardware, messages, facilities, and external systems that comprise this concept are discussed in detail in the proceeding subsections.



Source: FHWA.

Figure 8. Diagram. Mobile device pedestrian system.

Interfaces

The following interfaces would be required to bring functionality to this concept:

- A mobile device must be able to receive a BSM that would be broadcast from in-vehicle equipment.
- In-vehicle equipment must be able to receive a PSM broadcast from a mobile device.
- A mobile device must be able to send an SRM that would be received by RSE.
- The RSE must be able to make a priority request to the traffic signal controller and receive signal status information and phase information from the traffic signal controller.
- The RSE must be able to send SPaT, MAP, and SSMs to the mobile device.
- The RSE, mobile device, and in-vehicle equipment must interface with GNSS to receive location and time information. GNSS data allow time synchronization between devices and a mobile device and in-vehicle equipment to enable the device users to position themselves in the context of the roadway environment.
- The RSE must interface with a continuously operating reference station (CORS) to receive localized Radio Technical Commission for Maritime Services (RTCM) data that would be used to populate RTCM messages. The RSU would forward this RTCM data to the mobile device and in-vehicle equipment to correct for errors in positioning.

All the messages exchanges using these proposed interfaces would occur within the vicinity of a signalized intersection.

Hardware

The following hardware would be required:

- **Mobile device—**A mobile device would be a self-contained apparatus that wirelessly sends and receives messages, receives data from its onboard sensors, has a processor to execute functions, and has an HMI that allows it to receive input from and provide output to the pedestrian (i.e., audio/visual/haptic). The mobile device would position itself in the roadway environment to provide wayfinding guidance, would enable the virtual pedestrian pushbutton, and would broadcast PSM (this PSM would enable safety applications on receiving devices). Using its positioning capability and information regarding intersection geometry, the mobile device would determine when the pedestrian is approaching a crosswalk. If the pedestrian's route is known, the mobile device could automatically broadcast an SRM to place a call for the crosswalk that is part of the pedestrian's planned route. If the pedestrian's route is not known, the mobile device could prompt the pedestrian to query whether they plan to cross the street, and if so, verify which crosswalk they intend to use before broadcasting the SRM. As the pedestrian approaches the intersection and uses the crosswalk, the mobile device would provide information to the pedestrian (e.g., when and where to wait, when to walk, the state of the pedestrian signal, and the amount of time left to cross). This information would be intended primarily to benefit pedestrians with disabilities who may have difficulty perceiving visual and audio cues provided for the pedestrian signal at an intersection.

- **RSE—**The RSE would be capable of wireless communications with a mobile device (method not specified), would contain a processor to execute functions, would be backhaul connected to a TMC, and would be locally connected to a traffic signal controller. The RSE would receive SRMs from mobile devices and determine whether the type of priority being requested is valid; that is, is the mobile device authorized to make the request specified in the SRM? This may require the RSE to contact the TMC. If authorized, the RSE would place a call for the requested pedestrian phase on the traffic signal controller. The RSE would receive SPaT data and signal status data from the traffic signal controller and would forward this information to the mobile device in the form of SPaT and an SSM.

    - The RSE would receive intersection geometry data from the TMC to generate and constantly broadcast the MAP. The RSE would also receive position-correction data to populate and broadcast the RTCM messages. These messages would be used by mobile devices and in-vehicle devices for positioning purposes.
    - When receiving a PSM, the RSE would use the positioning data to determine whether any pedestrians are remaining in the crosswalk as the pedestrian phase clears. If so, the RSE would place a call to interrupt phase progression to the traffic signal controller. This feature provides additional time for the pedestrian to finish crossing before advancing to the next phase.

- **Traffic signal controller—**The traffic signal controller would be capable of receiving a priority request made by the RSE, processing the request, placing a call on the requested phase, and outputting SPaT data and signal status data that could be received by RSE.

- **In-vehicle equipment—**Like the mobile device, in-vehicle equipment would wirelessly send and receive messages, would receive controller area network bus (CANbus) data, and would have a processor to execute functions and an HMI that would allow it to receive input from and provide output to the driver (i.e., audio/visual). The in-vehicle equipment would receive PSMs from the mobile device. The in-vehicle equipment would use the data in this message, along with information regarding location and motion of the vehicle, to determine whether the vehicle is approaching the pedestrian and would notify the driver in safety-critical situations.

Messages

The following messages would be required to enable this concept:

- **BSM—**The BSM would convey safety information about a given vehicle. Broadcast from a vehicle, core BSM data would comprise required data elements including, but not limited to, vehicle size, position (latitude/longitude), speed, heading, acceleration, and brake system status. These data would be used to support safety-critical applications on the mobile device that rely on frequent transmission of BSM data.

- **PSM—**The PSM would be the mobile device equivalent of the vehicle-based BSM. The PSM would provide safety information about a given VRU. PSM data, which would be broadcast from a mobile device, would comprise required data elements including, but not limited to, position (latitude/longitude), speed, and heading. These data would be used to support safety-critical applications on in-vehicle devices that rely on frequent transmissions of PSM data.

- **SRM—**The SRM would contain data that are typically used to request signal preemption or signal priority from a signalized intersection. In this case, the SRM would allow a mobile device to place a call for a pedestrian phase. These data would include the desired phase/movement and the priority type (phase call). In addition, the SRM would include the estimated time of arrival and duration required to cross (or crossing speed) to ensure that the intersection could accommodate pedestrian crossing speeds.

- **SSM—**The SSM would contain data regarding the state of phase calls and would allow a mobile device to confirm that the pedestrian phase call requested in the SRM would be serviced by the intersection. Data contained in this message would be populated using the output from the traffic signal controller.

- **SPaT—**The SPaT message would be used to communicate the signal state of the pedestrian phase at a given intersection. SPaT would contain the signal indication for every phase of the intersection, phase timing information, crosswalk status, and a movement number, which would allow the data to be paired with the physical layout of the intersection described in the MAP, described in the next bullet.

- **MAP—**The MAP would contain the intersection geometry, the layout of all approaches/receiving lanes, sidewalks, and crosswalks. Phase numbers would be defined for each approach lane, sidewalk, and crosswalk. These phase numbers would be used to pair SPaT data with the appropriate approach lane/crosswalk. MAP data would be used to position a mobile device with respect to sidewalk/crosswalk geometries identified in the MAP. The data for this message type would be manually acquired though surveys, and these data must be converted into the MAP format.

Facilities and External Systems

The following external systems would be required to enable this concept:

- **TMC—**The TMC would be backhaul connected with the RSE. Traffic management staff would input MAP to the TMC. The TMC could send MAP data to the RSE, which would forward the MAP to mobile devices via communications equipment colocated at the intersection.

- **Multimodal trip planner (MMTP)—**The MMTP would receive the MMTP trip request message and would determine one or more potential options between the specified origin and destination that are within the constraints of the traveler's specified preferences. For the MMTP to provide effective itineraries, it would need access to real-time data from external systems including, but not limited to, roadway traffic conditions, real-time transit data, bikeshare station availability, locations of shared-mobility devices, and ridesharing/ridesourcing availability information. The MMTP would provide a response containing route options to the mobile device in the MMTP trip options information message.

MODES OF OPERATION

Mobile devices are intended to complement pedestrians and the interactions between pedestrians and drivers of vehicles in the roadway environment. Pedestrians and drivers would continue to follow the rules of the road and respond to traffic control devices, as they currently do, but they would be provided with additional information and notifications through their respective mobile devices. This information and the notifications would improve the mobile device users' safety, mobility, and ability to make informed decisions. Mobile devices are not intended to add to or override regulations that govern the movement of pedestrians and interactions between pedestrians and vehicles. Thus, if the mobile device-based system experiences nonnormal modes of operations, it would still be up to pedestrians and drivers to exercise normal judgment in accordance with existing roadway usage regulations.

Normal operations indicate the system is functioning as intended, generating outputs when necessary, and not generating outputs when unnecessary. Mobile device users would be expected to adhere to existing regulations associated with traffic control devices (e.g., traffic signals, signage, and lane markings), with the added benefit of information and notifications that complement these regulations. Events that could result in nonnormal operations may include, but are not limited to, the following situations:

- **Loss of connectivity with supporting systems—**The mobile device would rely on communication between the mobile device and other systems or communications between other systems that would allow the system to function as intended to meet user needs.

- **Attenuation of wireless signal to mobile device (for any communications medium)—** Mobile devices use wireless forms of communication to exchange data with external systems. These wireless forms of communication are subject to attenuation, which is the degradation in the strength of a wireless signal due to the location of obstructing objects between sending and receiving devices. Attenuation can result from foliage, the body of vehicles, or various types of fabric (when held in a pocket or backpack). The extent of the attenuation could affect the ability of the mobile device to receive the information it needs to meet user needs in a timely manner.

- **Slower than typical rate of data transfer—**Wired and wireless network bandwidth limitations could result in data transfer rates that are less than typical performance, which may not allow time-sensitive data to be received before being needed to support user needs.

- **Loss of power—**An unpowered mobile device would be unable to send/receive messages, process data, or provide information or notifications to travelers. This would affect the ability of the system to influence the current conditions.

- **Inaccurate GNSS data—**GNSS data would be used by mobile devices to provide position, speed, and heading. Inaccurate GNSS data would have the largest implications for determining when and at what time information or a notification would be displayed to the traveler holding the mobile device. Similar implications could be expected for other users of devices that rely on precise traveler position information from the mobile device. For example, vehicle onboard equipment would require precise pedestrian positioning information to issue a pedestrian safety-related notification to the driver of a vehicle. Inaccurate positioning information could result in the system providing an output at the wrong time or not providing an output when one is needed, which would reduce the system's perceived effectiveness and credibility.

- **Time synchronization—**When not synchronized, data originating from two devices may not be paired properly, resulting in false-positive and false-negative notification outputs, which would reduce the system's effectiveness and credibility. Unsynchronized data would be an issue particularly when the data are being used for safety-related applications.

- **Processing limitations—**If the amount of data that must be processed by the mobile device is greater than its processing capability, alerts/warnings may not be provided in time for the traveler to appropriately react.

These potential events that could result in nonnormal operating conditions are for illustrative purposes only and would be examined in detail on a case-by-case basis if such a system is considered for deployment. Thus, although it would be important to consider how the system would behave and which such events would occur when developing the conceptual design of mobile device-based systems, the operational scenarios developed in chapter 8, Operational Scenarios, only consider normal operating conditions.

USER CLASSES AND INVOLVED PERSONNEL

The two primary user classes are the traveler (pedestrian) and driver. The traveler user class comprises pedestrians who carry a mobile device on their person. The traveler uses sidewalks and crosswalks to complete their trip. Safely using the crosswalk at a signalized intersection may involve the traveler receiving information about the pedestrian signal state. Some intersections require the traveler to use a pedestrian pushbutton to place a request on the traffic signal controller to call the desired pedestrian walk phase.

The driver operates a vehicle in a roadway environment. When navigating through intersections, the driver would assess crosswalks for pedestrian activity before making a permitted right or left turn. The driver would be expected to yield to pedestrians in the crosswalk.

SUPPORT ENVIRONMENT

The local transportation agency/TMC would be responsible for the following actions:

- Operating and maintaining ITS/communications hardware on the roadside.
- Controlling traffic signals.
- Handling roadside communications.
- Managing intersection geometry data.
- Maintaining roadway signage inventory.

The Internet Service Provider would provide the following options:

- Cellular service (3G/4G/5G) to mobile devices.
- Connectivity between two systems so that data can be exchanged between them to support needs of travelers.
- Private networks used to establish communications to privately managed field devices.

OPERATIONAL SCENARIOS

The operational scenarios in this section intentionally contain details that would be typically beyond the scope of what would be necessary for ConOps, such as including the functions carried out by each component, detailing the sending and receiving of messages, and identifying the content of those messages. This level of detail would be typically found in subsequent SE documentation. However, in this concept, these additional details are included to provide the reader with additional context about how such a system could work and how messages can be used to enable the use case to underscore the theme of sharing electronic messages with mobile devices to satisfy the needs of different types of travelers.

Use Case 1—Scenario 1

Use Case 1—Scenario 1 describes the virtual pedestrian pushbutton for Concept 1: Traveler Walking and Using a Connected Mobile Device. This scenario is identified and titled "UC1-S1: Virtual Pedestrian Pushbutton" with the following characteristics:

- **Short description—**A traveler (pedestrian) would use a mobile device to place a call on a pedestrian phase at a signalized intersection. Notifications from the mobile device would provide added wayfinding assistance, especially for travelers with disabilities.

- **Scenario objective—**To demonstrate the ability of a mobile device to provide the following options:

  - Mobile pedestrian phase call.
  - Mobile extend pedestrian phase.
  - Pedestrian in crosswalk intersection safety.
  - Intersection wayfinding.

- **Operational event(s)—**The functioning-related events would take place in the following order:

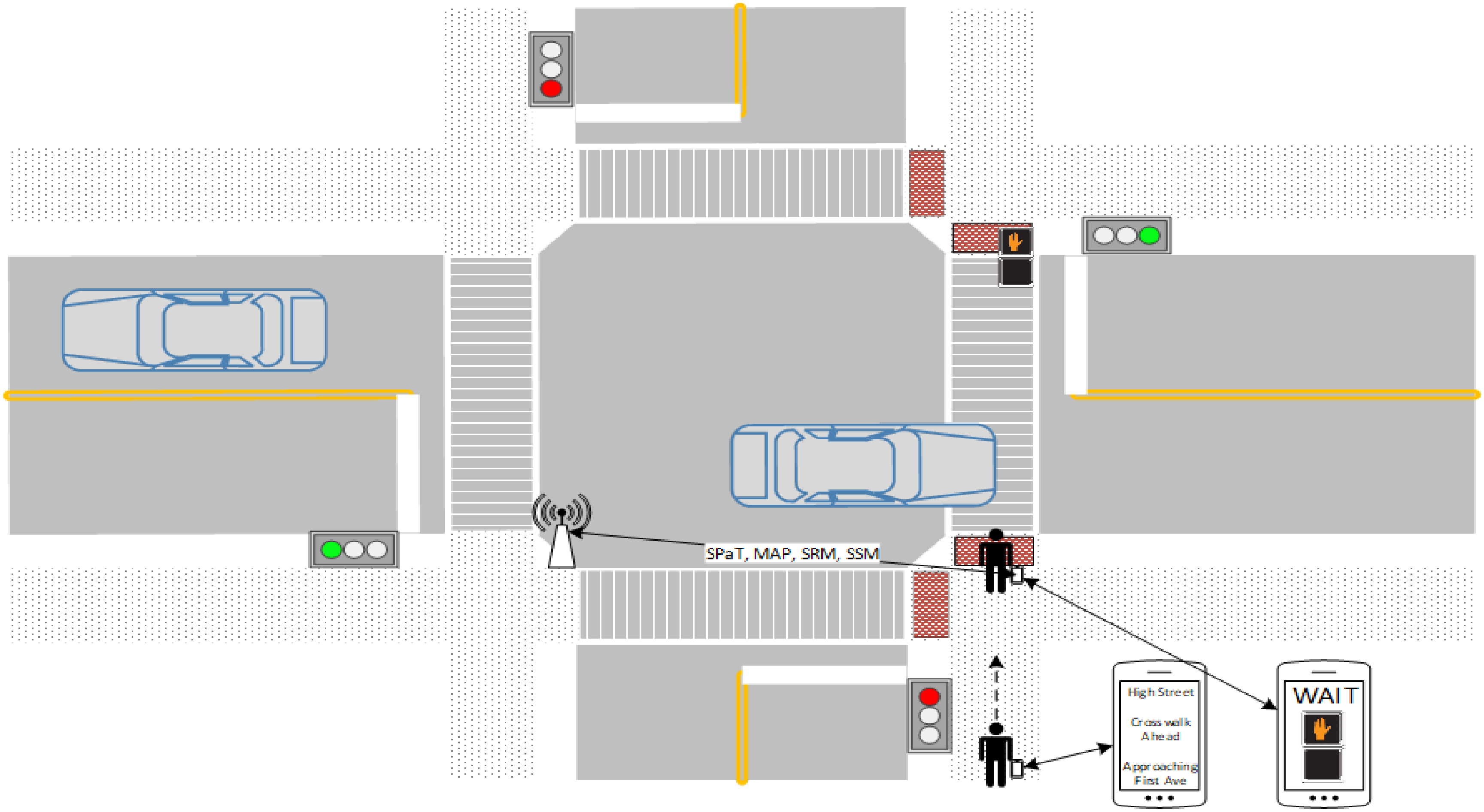
  - Messages would be exchanged between the mobile device and RSE to enable the traveler to place a call on a pedestrian phase.
  - The RSE would receive data from the mobile device to determine whether the crosswalk is occupied and would extend the phase if the crosswalk is occupied as the pedestrian clearance phase ends.
  - The mobile device would receive messages from RSE to enable wayfinding and provide information regarding the pedestrian signal status to the traveler.

- **Preconditions—**The traveler would walk toward an intersection with a pedestrian crosswalk that would be along a route (planned usage of a mobile device) that the pedestrian would be following.

- **Traveler actor role—**The traveler would effectively receive information regarding the pedestrian signal status and safely traverse the crosswalk.

- **Driver actor role—**The driver would safely navigate through the intersection, yielding to pedestrians, as indicated by the signal.

The scenario then describes key actions and the flow of events of four sources: mobile devices, pedestrian signals, RSE, and travelers. Figure 9 illustrates steps 1 through 9 as described in table 8. Figure 10 illustrates steps 10 through 18 as described in table 9. Figure 11 illustrates steps 19 through 23 as described in table 10. Figure 12 illustrates steps 24 through 30 as described in table 11. Table 12 describes the remaining steps 31 through 34.



Source: FHWA.

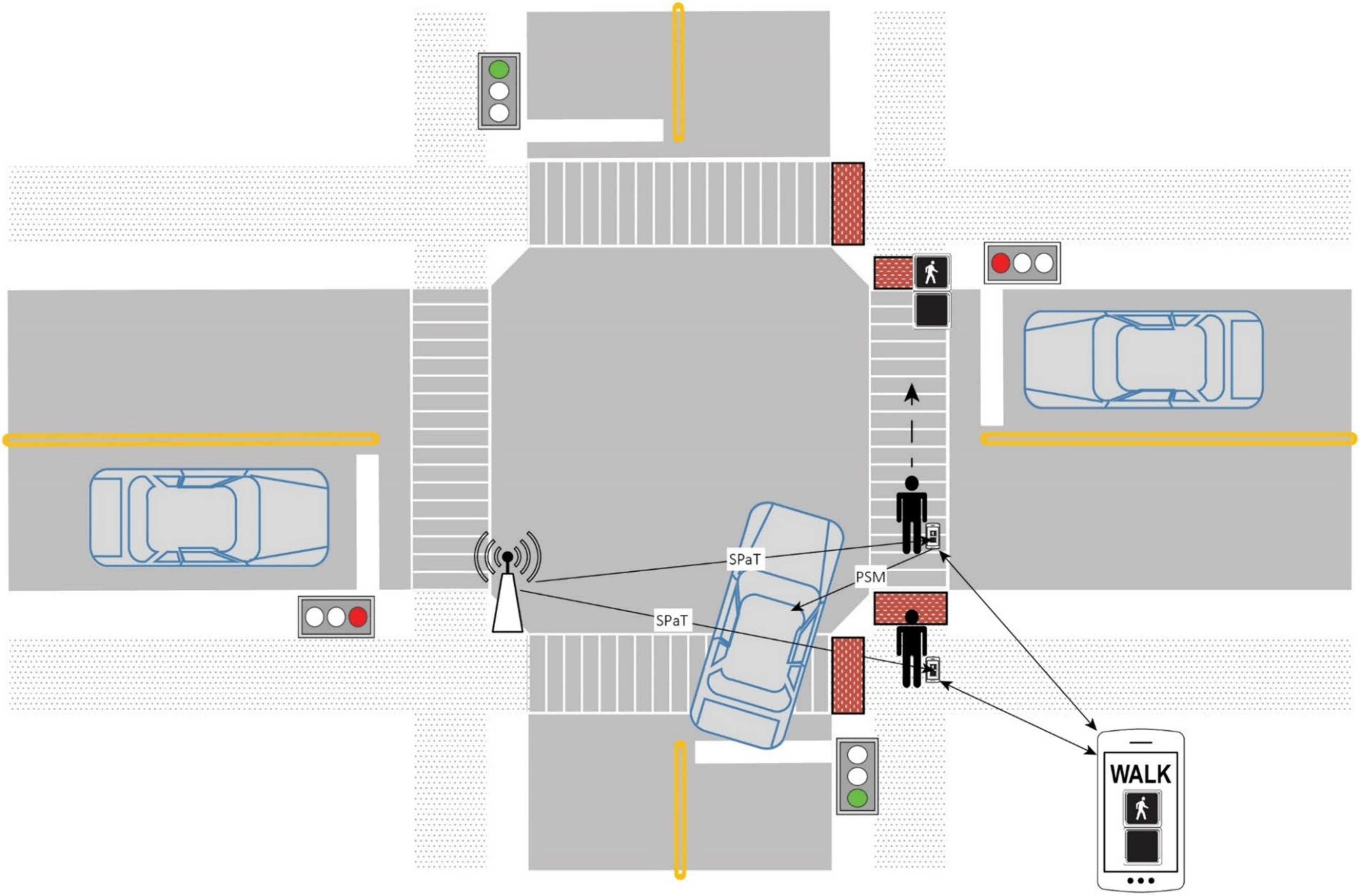
Figure 9. Diagram. Use Case 1—Scenario 1, steps 1–9.

Table 8. Use Case 1—Scenario 1 details for each source, steps 1–9, key action, and associated comments.

Source	Step	Key Action	Comments
Mobile device	1	Receives MAP from a nearby intersection.	Contains intersection geometry information about both vehicle lanes, crosswalks, and crosswalk approaches (i.e., sidewalks).
Mobile device	2	Compares the pedestrian's position against the intersection geometry information to determine whether the pedestrian is approaching a crosswalk.	Compares pedestrian-planned path against crosswalk to determine which crosswalk they are approaching.
Mobile device	3	Receives SPaT from the nearby intersection.	Time to next phase is unknown. Regarding the pedestrian phase, SPaT contains the following information: • Intersection number: 1248. • Phase ID: 12 (crosswalk east leg). • Description: High St. at First Ave. • Current state: red (solid red DON'T WALK). • Minimum end time: 20 s. • Time to next phase: indeterminite.
Mobile device	4	Sends an SRM to the intersection.	Enables a virtual pedestrian pushbutton. Other types of service that could be requested include preemption and priority, but these services would typically be available only to authorized system users. The SRM content includes: • Temp request ID: 123456. • Intersection number: 1248. • Phase ID requested: 12. • Service requested: normal detection.
Pedestrian signal	5	Indicates stop (solid red DON'T WALK) for the crosswalk that the traveler intends to use as the traveler reaches the corner.	N/A

Source	Step	Key Action	Comments
Mobile device	6	Provides an audible notification to alert the traveler that they are approaching a crosswalk as the traveler approaches the signalized intersection: "Approaching High St. Crosswalk at First Ave. Wait to Cross." Provides a visual indication that the pedestrian signal state indicates stop (solid red DON'T WALK).	Pedestrian intends to cross First Ave.
RSE	7	Receives the SRM, which places a pedestrian phase actuation on the local traffic signal controller.	Traffic signal controller successfully accepts the actuation.
RSE	8	Sends an SSM to the mobile device.	The mobile device optionally displays confirmation to the traveler. SSM content: • Temp Request ID: 123456. • Status: accepted.
Traveler	9	Waits at the corner of the intersection.	N/A

N/A = not applicable.



Source: FHWA.

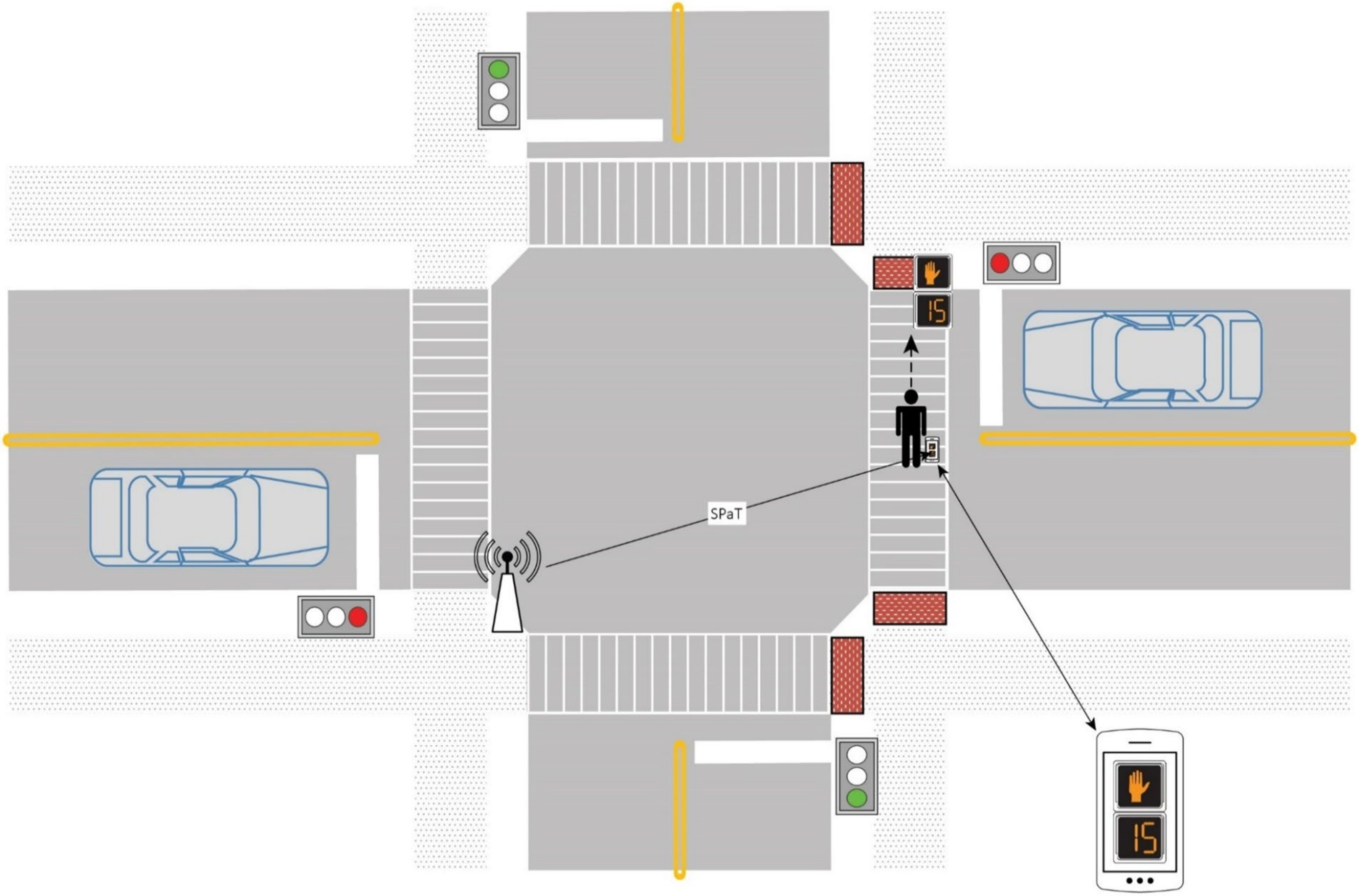
Figure 10. Diagram. Use Case 1—Scenario 1, steps 10–18.

Table 9. Use Case 1—Scenario 1 details for each source, steps 10–18, key action, and associated comments.

Source	Step	Key Action	Comments
Pedestrian signal	10	Changes to indicate walk (solid white WALK).	N/A
Mobile device	11	Receives SPaT from the nearby intersection.	Regarding the pedestrian phase, the message contains the following information: • Intersection number: 1248. • Phase ID: 12. • Description: High St. at First Ave. • Current state: green (solid white WALK). • Current state minimum end time: 20 s. • Time to next phase: 20 s.
Mobile device	12	Provides an audible notification to the traveler that the pedestrian signal has changed: “Cross Parsons Ave.” Provides an output (audio and visual) to the traveler that indicates that the pedestrian signal state indicates walk (solid white WALK).	N/A
Traveler	13	Begins to cross the crosswalk.	N/A
Mobile device	14	Continues to provide a constant output that the pedestrian signal state is green (solid white WALK).	N/A

Source	Step	Key Action	Comments
Mobile device	15	Sends a PSM containing the location of the pedestrian to nearby vehicles as the pedestrian traverses the crosswalk.	Crosswalk ID corresponds to Crosswalk ID in the intersection geometry message. The PSM content includes the following information: • Temp ID: 18459349. • Location: o Lat: 39.980873. o Long: −83.004160. • Heading: 0. • Crosswalk ID: 42.
In-vehicle device	16	Receives the PSM.	N/A
In-vehicle device	17	Alerts the driver who intends to turn across the path of the pedestrian that there is a pedestrian in the crosswalk: "Yield to pedestrian in crosswalk."	N/A
Driver	18	Waits for the pedestrian to clear.	N/A

Lat = latitude; Long = longitude; Temp = temporary.

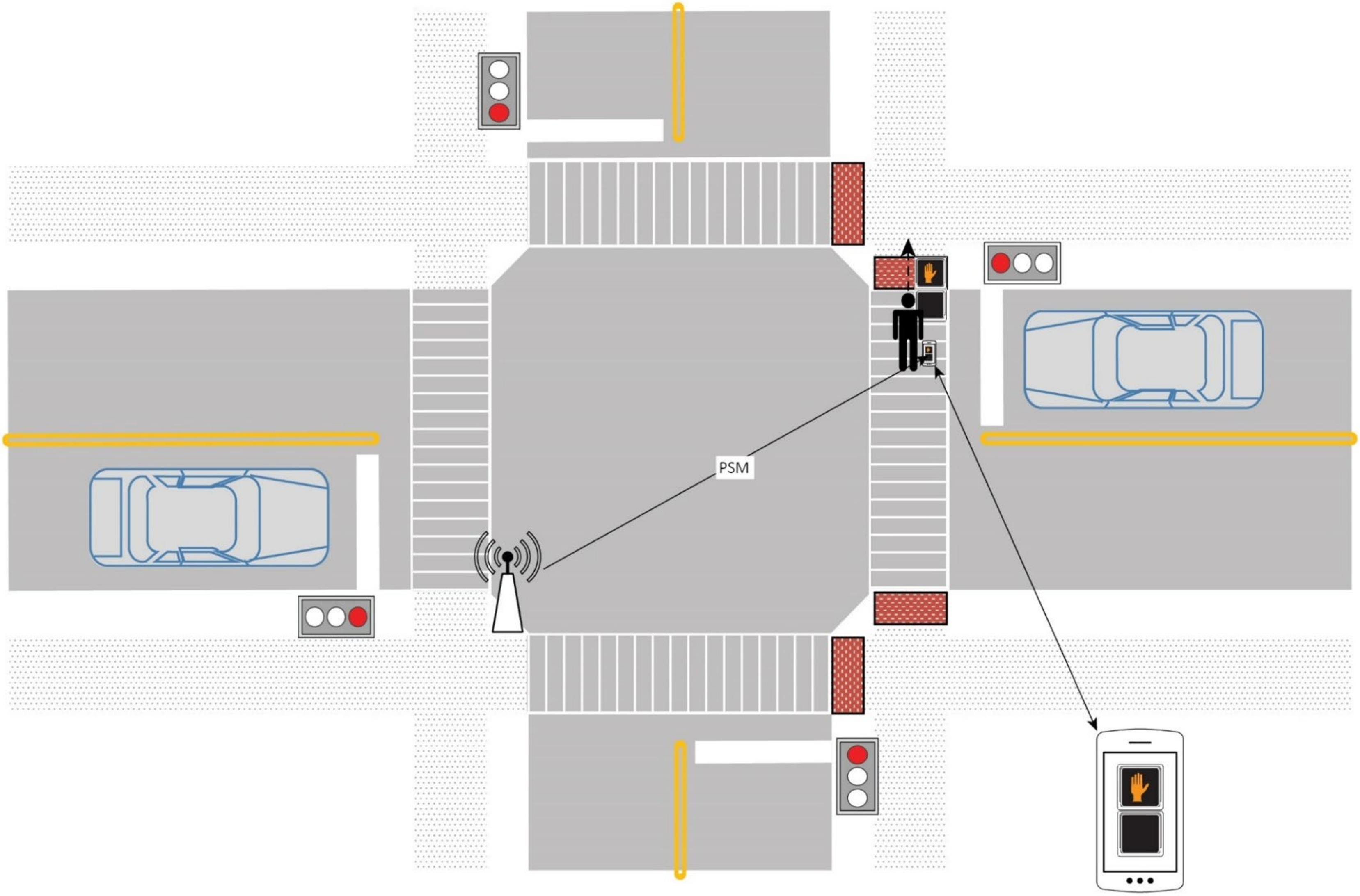


Source: FHWA.

Figure 11. Diagram. Use Case 1—Scenario 1, steps 19–23.

Table 10. Use Case 1—Scenario 1 details for each source, steps 19–23, key action, and associated comments.

Source	Step	Key Action	Comments
Traveler	19	Clears the half of the roadway containing the receiving lane that the driver intends to use.	N/A
Driver	20	Completes their turning maneuver. The traveler continues crossing the second half of the roadway.	N/A
Pedestrian signal	21	Changes to the clearance phase (flashing red DON'T WALK—could be accompanied with a countdown timer).	N/A
Mobile device	22	Receives SPaT from the nearby intersection.	Regarding the pedestrian phase, the message contains the following information: • Intersection number: 1248. • Phase ID: 12. • Description: High St. at First Ave. • Current state: yellow (flashing red DON'T WALK). • Current state minimum end time: 15 s. • Time to next phase: 15 s.
Mobile device	23	Provides an audible notification to the traveler that the pedestrian signal has changed and provides a countdown: "Clear Crosswalk. 15, 14, 13, …" Provides a constant visual output that the pedestrian signal state is clearance (flashing red DON'T WALK) and provides a countdown to the traveler to indicate when the pedestrian phase ends.	N/A



Source: FHWA.

Figure 12. Diagram. Use Case 1—Scenario 1, steps 24–30.

Table 11. Use Case 1—Scenario 1, steps 24–30.

Source	Step	Key Action	Comments
Pedestrian signal	24	Reaches the point where it would normally transition to the stop phase (solid red DON'T WALK).	The traveler is still in the crosswalk and needs more time.
Mobile device	25	Receives SPaT from the nearby intersection.	Regarding the pedestrian phase, the message contains the following information: • Intersection number: 1248. • Phase ID: 12. • Description: High St. at First Ave. • Current state: yellow (flashing red DON'T WALK). • Current state minimum end time: 0.1 s. • Time to next phase: 0.1 s.
Pedestrian signal	26	Provides an additional 1 s of time for the pedestrian clearance phase.	N/A
Mobile device	27	Receives SPaT from the nearby intersection.	Regarding the pedestrian phase, the message contains the following information: • Intersection number: 1248. • Phase ID: 12. • Description: High St. at First Ave. • Current state: yellow (flashing red DON'T WALK). • Current state minimum end time: 1 s. • Time to next phase: 1 s.

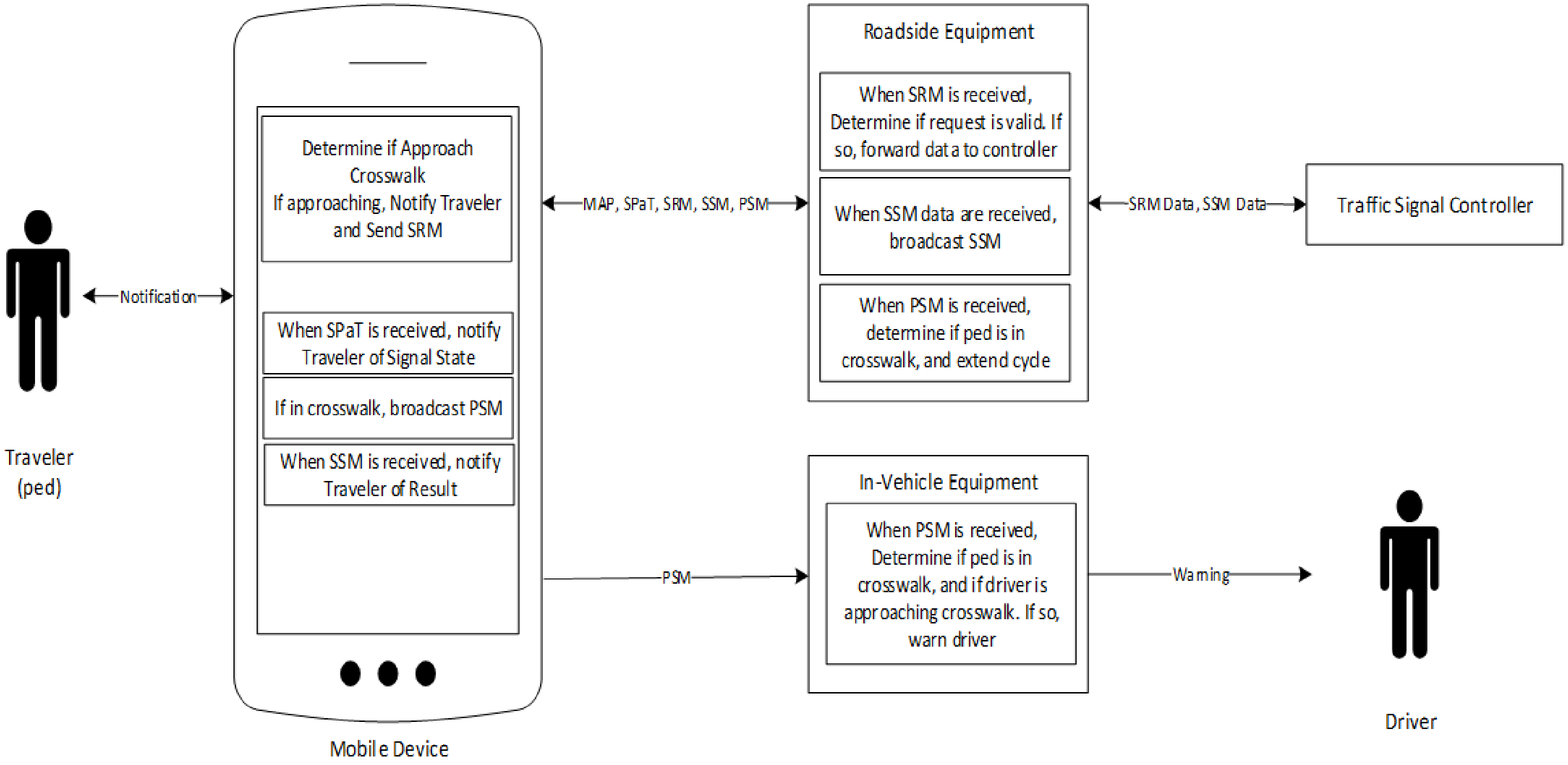
Source	Step	Key Action	Comments
Mobile device	28	Provides a more urgent output that the pedestrian signal state is in clearance (flashing red DON'T WALK) and that the traveler must complete crossing immediately: "Clear Crosswalk immediately."	The previous four steps are repeated until the pedestrian clears the crosswalk. Note: Traffic management agencies could limit the amount of time allowed for pedestrian signal priority.
Traveler	29	Finishes crossing the intersection.	N/A
Pedestrian signal	30	Changes to the stop phase (solid red DON'T WALK).	N/A

The remaining steps in this scenario not illustrated in figures 9–12 are documented in table 12.

Table 12. Use case 1—Scenario 1, steps 31–34.

Source	Step	Key Action	Comments
Mobile device	31	Receives SPaT from the nearby intersection.	Regarding the pedestrian phase, the message contains the following information: • Intersection number: 1248. • Phase ID: 12. • Description: High St. at First Ave. • Current state: red (solid red DON'T WALK). • Current state minimum end time: 30 s. • Time to next phase: indeterminite
Traveler	32	Walks away from the intersection toward final destination.	N/A
Mobile device	33	Stops outputting information about the pedestrian signal state at the intersection.	N/A
Traveler	34	Completes the trip at the final destination.	N/A

To complete this scenario, six characteristics are included, along with a system diagram capturing the four sources included in the scenario, as shown in figure 13.



Source: FHWA.

Figure 13. Diagram. Use Case 1—Scenario 1, data flows between four sources.

The following characteristics complete the documentation for Use Case 1—Scenario 1:

- **Postconditions—**Additional crossing time would be provided, and the traveler would safely cross the crosswalk.

- **Messages—**The message types would include MAPs, SPaTs, SRMs, SSMs, and PSMs.

- **Traceability—**The following user needs would apply to this scenario:

    - Pedestrian UN1—Approaching Crosswalk.
    - Pedestrian UN2—Activate Pushbutton.
    - Pedestrian UN3—Extend Crossing Time.
    - Pedestrian UN4—Pedestrian Safety Driver Awareness.
    - Pedestrian UN5—Wayfinding and Navigation at Crosswalks.

- **Mobile device inputs summary—**Inputs would include time and location (from GNSS), MAPs (from RSE), SPaT messages (from RSE), and SSMs (from RSE).

- **Mobile device—**SRMs and PSMs.

- **Outputs summary—**Outputs would include audio/visual/haptic notifications to the traveler who is approaching the crosswalk, pedestrian signal status alerts, and time remaining to cross warnings.

CHAPTER 9. CONCEPT 2: TRAVELER RIDING ON A BICYCLE AND USING A CONNECTED MOBILE DEVICE

CHAPTER OVERVIEW

This chapter is the second of four chapters that develop an example concept to showcase how mobile devices and electronic messages can be used to satisfy traveler needs. The concept in this chapter focuses on addressing an example set of needs for bicyclists carrying a mobile device. Through these example concepts, the reader can begin to understand the content included in a typical ConOps. A description specific to the concept is provided and walks through existing conditions, justification for changes, description of desired changes, operational policies and constraints, description of proposed operating environment, modes of operation, user classes, support environment, and operational scenarios. These example concepts begin to shape a system that enables the exchange of electronic messages with mobile devices to satisfy the needs of different types of travelers.

EXISTING CONDITIONS

Currently, many intersections have in-pavement loop detectors, video detection systems, and radar detection systems that are used to determine the presence of vehicles at an intersection approach. Some systems may not be calibrated properly to detect bicyclists as they approach these intersections. Loop detection systems may use pavement markings alongside signage to indicate to bicyclists where to stop to trip a loop detector.(10)

Bicyclists approaching a signalized roadway crossing (rectangular rapid flashing beacon, pedestrian hybrid beacon, or traffic signal) from a bike path may have to use a pushbutton to activate the pedestrian/bicyclist crossing phase at the intersection (figure 14). The rectangular beacon rapidly flashes when the pushbutton is pressed, which warns motorists of activity at the crossing location (figure 15). The rapid flashing continues for a predetermined period after the pushbutton has been pressed before going dark again. The pedestrian hybrid beacon transitions from a dark state to a yellow-flashing caution state when the pushbutton is pressed. After a predetermined period, the signal progresses to a solid yellow clearance phase, followed by a red phase. At this point, the pedestrians and bicyclists cross. The signal then changes to a flashing red—stop before proceeding—for a predetermined period before going dark again. The traditional signal transitions through a typical signal cycle when the pushbutton is pressed.

Source: FHWA.

Figure 14. Photograph. Cyclist waiting at signalized intersection.

Source: FHWA.

Figure 15. Photograph. Pedestrian/bicycle crossing with pushbutton-activated warning lights.

JUSTIFICATION FOR CHANGES

An aspect of the current conditions at signalized intersections could warrant the addition of technology to enable communication to and from mobile devices. This aspect is discussed in detail in the following subsection.

Bicyclist Intersection Detection

Bicyclists riding on the roadway may not be easily detected by traditional means (e.g., in-pavement loop detector or video detection), because these devices are typically calibrated to detect vehicles (which are much larger). In a scenario where a bicyclist cannot be detected at an intersection, and the signal is not programmed to recall to the phase for the maneuver for which the cyclist intends to make, the bicyclist could pass through the intersection while the signal is red or leave the roadway to access the pedestrian pushbutton. In some cases, bicyclists riding on the sidewalk to access this pushbutton could be illegal.

In many urban areas, bicyclists are required to ride in the roadway. Detection systems at actuated signalized intersections are typically designed to detect the presence of vehicles and could have difficulty determining when a bicyclist is waiting at a signal. A bicyclist could dismount the bicycle to push a pedestrian pushbutton, but this is not always practical (e.g., when making a left turn from a left turn lane) or convenient. Furthermore, having to stop to press the pushbutton could discourage bicyclists from using the pushbutton, which could result in the cyclist crossing the street without warning oncoming drivers or crossing against the signal indications.

DESCRIPTION OF DESIRED CHANGES

Examples of bicyclist user needs are provided in table 13.

Table 13. Bicyclist user needs.

User Need ID	Title	Description
Bicyclist UN1	Activate Detector	A bicyclist needs to activate a phase that they intend to utilize at a signalized intersection.
Bicyclist UN2	Bicyclist Roadway Safety Driver Awareness	A bicyclist needs their presence in the roadway to be known to approaching drivers.

The following mobile device-based applications could address bicyclist user needs.

Mobile Bicycle Phase Call

A mobile device application could support many of these user needs, including allowing a bicyclist to request a movement though an intersection. To support this use case, the mobile device would need information about the location of the intersection and the signal state and would need to have the ability to provide a signal priority request to the traffic signal controller at the intersections. The MAP would contain intersection geometry information that would allow the mobile device to position itself in relation to the intersection, and SPaT would contain information about the state of each movement and timing details (minimum time remaining, expected phase change, etc.).

A bicyclist with a wireless mobile device would issue an SRM to actuate the pedestrian phase at the signal. However, this option would be predicated on the mobile device having the bicyclist's route itinerary information. This option could be accomplished without prompting the bicyclist, which could result in a distraction. The SRM would contain information, such as an intersection identifier, an identifier for the movement request, and the type of service requested (e.g., normal actuation, priority, preemption), which would be received by the traffic signal that services the request. An SSM would be provided back to the mobile device to provide information regarding which signal requests would be served and the estimated timing of service. The bicyclist using the mobile device would need to be able to indicate which movement they intend to make and would need to be able to cancel the request at any time.

Bicycle Intersection Movement Assist

This use case supports bicyclist safety at intersections by making the location of the bicyclist available to vehicle systems and by making the location of vehicles available to the bicyclist's mobile device. The mobile device would constantly broadcast a PSM while in a location where the bicyclist is vulnerable (i.e., operating in a mixed environment with other vehicles). Similarly, vehicles constantly broadcast BSMs. The in-vehicle device would receive the PSM, and along with its internal location and motion information, would determine whether the vehicle is on a collision course with VRUs at an intersection. Similarly, the mobile device would receive BSMs and along with its internal location and motion information, would determine whether the bicyclist is on a collision course with a vehicle at an intersection. If either device detects a potential collision, a warning would be issued to the driver and bicyclist to ensure they are aware of the potentially unsafe situation.

Bicycle Overtake Lateral Clearance Safety

This use case supports bicyclist safety biking on shared-use streets by making the location of the bicyclist available to vehicle systems and by making the location of vehicles available to the bicyclist's mobile device. As with Bicycle Intersection Movement Assist, this use case depends on the mobile device broadcastings and the vehicle broadcasting BSMs. The in-vehicle device would receive PSMs that could be used to identify its location and motion information to determine whether it is passing a bicycle and if there is enough lateral clearance. If either device determines sufficient lateral distance is not going to be available, a warning would be issued to the driver and bicyclist to ensure they are aware of the situation.

Priorities Among Changes

This section prioritizes user-proposed functionality presented in the previous subsection. This prioritization would be typically done by classifying each possible change as essential, desirable, or optional. The classification method used would be determined by each deploying agency. Functions related to safety or other high-priority needs would be considered essential, whereas desirable functions would be considered to provide enhanced functionality but would not be necessary for the system to meet user needs. Optional needs would be generally limited to needs that would be discretionary in nature. Prioritizing user needs would be a subjective practice and would vary from agency to agency and from region to region.

Changes Considered But Not Included

This section identifies changes and new features considered but not included and the rationale for not including them. Not including certain features could be due to implementation difficulties, technology limitations, or other systems' ability to adequately meet the needs of users. Consideration of changes that are considered but not included would vary from agency to agency and from region to region.

Assumptions and Constraints

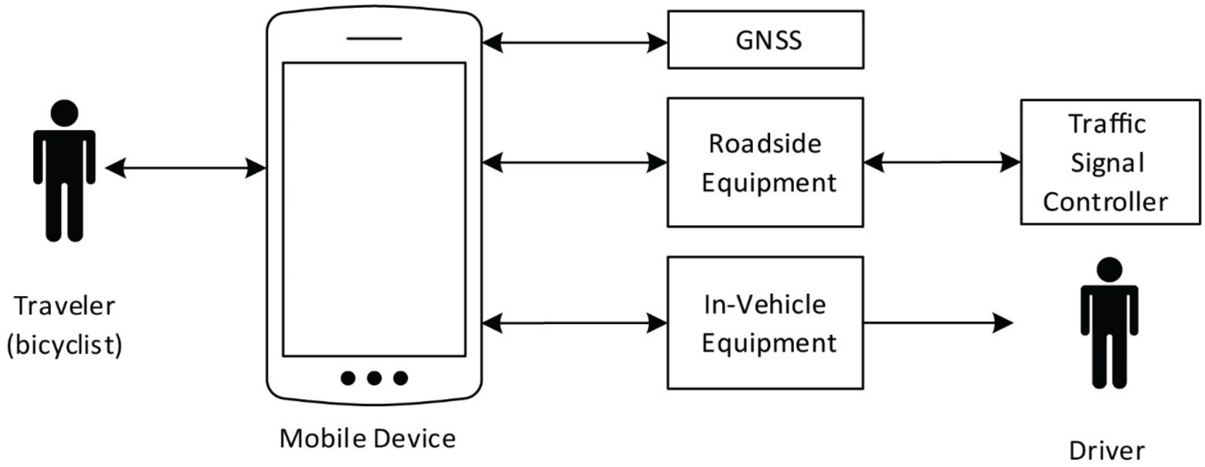
This section lists assumptions and constraints that could limit how the system could be designed and implemented. The following examples of common assumptions and constraints could affect the design of the proposed system:

- Communication, technology, hardware, or software availability.
- Off-the-shelf technology procurement (as opposed to the development of a new device).
- Operational policies and constraints.
- Existing laws and regulations (e.g., governing the operations of motor vehicles, pedestrians, and bicyclers on roadways).

PROPOSED OPERATING ENVIRONMENT

This concept includes the mobile device, RSE, a traffic signal controller, and in-vehicle equipment.

Figure 16 illustrates a systems diagram for this concept. The interfaces, hardware, messages, and facilities and external systems that comprise this figure are discussed in detail in the proceeding subsections.



Source: FHWA.

Figure 16. Diagram. Mobile device bicyclist system.

Interfaces

The following interfaces would be required to support this concept:

- A mobile device would be able to receive a BSM that would be broadcast from in-vehicle equipment. In-vehicle equipment would be able to receive a PSM broadcast from a mobile device. A mobile device would be able to send an SRM that would be received by the RSE.

- The RSE would be able to make a priority request to the traffic signal controller and receive signal status information and phase information from the traffic signal controller. The RSE would be able to send SPaT, MAPs, and SSMs to the mobile device.

- The RSE, mobile devices, and in-vehicle equipment must interface with GNSS to receive location and time information. GNSS data allow time synchronization between devices, mobile devices, and in-vehicle equipment to position themselves in the context of the roadway environment. The RSE would interface with a CORS to receive localized RTCM data that would be used to populate RTCM messages. The RSU would forward this RTCM data to a mobile device and in-vehicle equipment to correct for errors in positioning.

- All the messages exchanges described in this section would occur within the vicinity of a signalized intersection.

Hardware

The following hardware would be needed to enable this concept:

- **Mobile device**—The mobile device would be a self-contained apparatus that wirelessly sends and receives messages, receives data from its onboard sensors, has a processor to execute functions, and has an HMI that allows it to receive input from and provide output to the bicyclist (audio/visual/haptic). The mobile device would position itself in the roadway environment to enable a call for a phase and broadcast PSMs (this enables safety applications on receiving devices). Using its positioning capability and information regarding intersection geometry, the mobile device would determine when the bicyclist is approaching an intersection. If the bicyclist's route is known, the mobile device may automatically broadcast an SRM to place a call for the movement that is part of the bicyclist's planned route. If the bicyclist's route is not known, the mobile device can determine which lane the bicyclist is in and make a call for the corresponding movement in the SRM. As the bicyclist approaches the intersection, the mobile device would provide confirmation to the pedestrian that the call was successfully placed.

- **RSE**—The RSE would be capable of wireless communications with a mobile device (method not specified), would contain a processor to execute functions, would be backhaul connected to a TMC, and would be locally connected to a traffic signal controller. The RSE would receive SRMs from mobile devices and would determine whether the type of priority being requested is valid (i.e., is the mobile device authorized to make the request specified in the SRM?). This may involve the RSE contacting the TMC. If authorized, the RSE would place a call for the requested phase on the traffic signal controller. The RSE would receive SPaT data and signal status data from the traffic signal controller and would forward this information to the mobile device in the form of SPaT and SSM:

  - RSE would receive intersection geometry data from the TMC to generate and constantly broadcast the MAP.
  - RSE would also receive RTCM data to populate and broadcast the RTCM messages.
  - Mobile devices and in-vehicle devices would use these messages for positioning purposes.

- **Traffic signal controller—**The traffic signal controller would be capable of receiving a priority request made by the RSE, processing the request, placing a call on the requested phase, and outputting SPaT data and signal status data that can be received by the RSE.

- **In-vehicle equipment—**Like the mobile device, in-vehicle equipment would wirelessly send and receive messages, receive (CANbus) data, and would have a processor to execute functions and an HMI that would allow it to receive input from and provide output to the driver (audio/visual). The in-vehicle equipment would receive PSMs from the mobile device. The in-vehicle equipment would use the data in these messages, along with information regarding location and motion of the vehicle, to determine whether the vehicle is approaching the bicyclist, and it would notify the driver in safety-critical situations.

Messages

The following types of messages would enable this concept:

- **BSM—**The BSM would convey safety information about a given vehicle. Broadcast from a vehicle, core BSM data could include vehicle size, position (latitude/longitude), speed, heading, acceleration, and brake system status. These data could support safety applications on the mobile device that rely on frequent transmission of BSM data.

- **PSM—**The PSM would be the mobile device equivalent of the vehicle-based BSM. It would provide safety information about a given VRU. Broadcast from a mobile device, PSM data could include position (latitude/longitude), speed, and heading. These data would be used to support safety-critical applications on in-vehicle devices that rely on frequent transmission of PSM data.

- **SRM—**The SRM would contain data that is typically used to request signal preemption or signal priority from a signalized intersection. In this case, the SRM would allow a mobile device to place a call for a phase for a bicyclist. These data would include the desired phase/movement and the priority type (phase call).

- **SSM—**The SSM would contain data regarding the state of phase calls, and it would allow a mobile device to confirm that the bicycle phase call requested in the SRM would be serviced by the intersection. Data contained in this message could be populated by using the output from the traffic signal controller.

- **SPaT—**The SPaT message would be used to communicate the signal state at a given intersection. SPaT would contain the signal indication for every phase of the intersection, phase timing information, and a movement number, which would allow the data to be paired with the physical layout of the intersection described in the MAP.

- **MAP—**The MAP would contain the intersection geometry, the layout of all approaches/receiving lanes, sidewalks, and crosswalks. Phase numbers would be defined for each approach lane, sidewalk, and crosswalk. This phase number would be used to pair SPaT data with the appropriate approach for the bicyclist. MAP data would be used to position a mobile device with respect to lane geometries that are identified in the MAP. The data for this message would be manually acquired though surveys. These data would be converted into the MAP format.

Facilities and External Systems

TMC

The TMC would be backhaul connected with the RSE. Traffic management staff would input MAP to the TMC. The TMC could send MAP data to the RSE, which would forward the MAP to mobile devices via communications equipment colocated at the intersection.

MODES OF OPERATION

Mobile devices are intended to complement existing regulations that govern the movement of bicyclists and the interactions between bicyclists and drivers of vehicles in the roadway environment. Bicyclists and drivers would continue to follow the rules of the road and respond to traffic control devices, as they currently do, but they would be provided with additional information and notifications through their respective mobile devices. This information and notifications are expected to improve the mobile device users' safety, mobility, and ability to make informed decisions. Mobile devices are not intended to add to or override regulations that govern the movement of bicyclists and interactions between bicyclists and vehicles. Thus, if the mobile device-based system experiences nonnormal modes of operations, it would still be up to bicyclists and drivers to exercise normal judgment in accordance with existing roadway usage regulations.

Various issues that could result in nonnormal operations are provided in general context in chapter 8, Modes of Operation.

USER CLASSES AND INVOLVED PERSONNEL

The two primary user classes are the traveler (bicyclist) and driver. The traveler user class comprises bicyclists who carry a mobile device on their person. The traveler uses paved off-road (multipurpose) trails and the street network to complete their trip. For the traveler to request a phase at an intersection, the traveler must be detected or able to place a call for service at the signal. Some multipurpose trail intersections (with roadways) require the traveler to use a pushbutton to place a request for the traffic signal controller to call the pedestrian phase or activate a pedestrian beacon. Finally, when riding on the roadway, a traveler must be aware of the movements of other vehicles that could result in a safety issue for the traveler.

A driver operates a vehicle in a roadway environment. When navigating through environments with bicycles, the driver could leave enough space between the vehicle and bicyclist when making an overtaking maneuver, notice bicyclists at an intersection (to yield, as appropriate when navigating the intersection), and be aware of bicyclists when opening the driver's side doors after parallel parking.

SUPPORT ENVIRONMENT

The local transportation agency/TMC would be responsible for the following actions:

- Operating and maintaining ITS/communications hardware on the roadside.
- Controlling traffic signals.
- Handling roadside communications.
- Managing intersection geometry data.

OPERATIONAL SCENARIOS

The operational scenarios in this section intentionally contain details that are typically beyond the scope of what would be necessary for a ConOps, such as including the functions carried out by each component, detailing the sending and receiving of messages, and revealing the content of those messages. This level of detail is typically found in subsequent SE documentation. However, in this concept, this additional detail is included to provide the reader with additional context about how such a system could work and how messages could be used to enable the use case, to underscore the theme of sharing electronic messages with mobile devices to satisfy the needs of different types of travelers.

Use Case 2—Scenario 1 and Scenario 2

Use Case 2—Scenario 1: Virtual Bicyclist Detection and Scenario 2: Bicycle Street Safety describe a traveling bicyclist using a connected mobile device. Scenario 1 is identified and titled "UC2-S1: Virtual Bicyclist Detection" with the following characteristics:

- **Short description—**A traveler (bicyclist) would use a mobile device to place a call for a phase at a signalized intersection that services the approach used by the bicyclist. A traveler (bicyclist) would use a mobile device to enable a rapid flashing beacon as they approach the crossing area.

- **Scenario objective—**To demonstrate the ability of mobile device to provide a mobile bicycle phase call.

- **Operational event(s)—**The functioning-related events would take place in the following order:
    - As the bicyclist approaches the intersection, the mobile device would send a message to infrastructure-based equipment to indicate that the bicyclist intends to pass through the intersection.
    - The phase requested by the bicyclist's mobile device would be served (as allowed by the signal timing plan) and the bicyclist would pass through the intersection (even though no other vehicles are activating the signal with their presence).

- **Preconditions—**The traveler (bicyclist) would use a mobile device to plan a trip from home to a grocery store. The trip would consist of cycling through a neighborhood and crossing an arterial at a signalized intersection to get from the neighborhood streets to the grocery store. In the past, the bicyclist has had limited success in activating the signal with their presence. The ITS detection equipment does not reliably detect the presence of bicyclists. Bicyclists, at times, may need to wait for a vehicle to activate the detection, move onto the sidewalk to press the pedestrian pushbutton, or cross during a red signal after waiting for a few minutes.

- **Traveler actor role—**The bicyclist would have the ability to move through intersection in a timely and safe manner.

- **Driver actor role—**The driver would safely navigate through the intersection, yielding to bicyclists, as indicated by the signal.

The scenario then describes key actions and the flow of events of four sources: mobile devices, pedestrian signals, RSE, and travelers. Table 14 describes steps 1 through 15, which would occur when the RSU places a call requesting a phase, and table 15 describes steps 1 through 20, which would occur when the RSU places a call and initiates an action as described.

Table 14. Use Case 2—Scenario 1 details for each source, steps 1–15, key action and associated comments.

Source	Step	Key Action	Comments
Traveler	1	Approaches intersection.	N/A
Mobile device	2	Receives a SPaT and a MAP.	Indicates intersection geometry and the current signal state. The SPaT contains the following content: • Intersection number: 1314. • Phase ID: 7. • Description: Whittier Ave. at High St. • Current state: red. • Minimum end time: 20 s. • Next time: indeterminite.
Mobile device	3	Positions itself (and the traveler) within the intersection geometry.	Determines the intersection ID that it would be approaching.
Mobile device	4	Broadcasts an SRM indicating approach time and anticipated movement.	System estimates the approach time based on current time, bicycle speed, and distance to intersection. Note: The anticipated movement would be determined by the mobile device—the route (from trip planner, see preconditions) through the intersection would be compared with the intersection movements indicated in the intersection geometry message to determine which movement would be made by the bicyclist. Alternatively, the anticipated movement could be determined based on the approach lane where the mobile device is positioned. The SRM contains the following content: • Temp request ID: 123456. • Intersection number: 1314. • Phase ID requested: 7. • Service requested: normal.

Source	Step	Key Action	Comments
RSU	5	Receives an SRM broadcast from mobile device.	Releases communication that would not necessarily have to come directly from mobile device to the RSU.
RSU	6	Checks that the approach would be for the intersection where the RSU is assigned and that the movement being requested would be valid.	Determines the request would be made for the intersection and that the movement would be valid.
RSU	7	Places a call for the requested phase to the traffic signal controller	N/A
Traffic signal controller	8	Provides an indication that it has received the call for the requested phase.	N/A
RSU	9	Broadcasts an SSM indicating that the requested movement would be valid and that the traffic signal controller would service the phase for the requested movement.	The SSM contains the following content: • Temp request ID: 123456. • Status: accepted.
Mobile device	10	Receives SSM indicating the requested movement would be valid and that the phase for the requested movement would be serviced.	N/A
Mobile device	11	Provides an audio/visual notification to the traveler to confirm that the phase they need would be in the process of being serviced (optional).	Could also provide intermittent countdown until the phase is be served.
Traveler	12	Receives notification as they approach the stop bar at the intersection (optional).	N/A
Traveler	13	Waits at stop bar.	N/A
General	14	Signal turns green.	N/A
Traveler	15	Proceeds through intersection.	N/A

A secondary flow of actions occurs in this scenario at step 7. Table 15 details the steps after the traffic signal controller initiates flashing (strobe) warning lights at intersection.

Table 15. Use Case 2—Scenario 1 details for each source, steps 1–20, key action, and associated comments.

Source	Step	Key Action	Comments
Traveler	1	Approaches intersection.	N/A
Mobile device	2	Receives a SPaT and a MAP.	Indicates intersection geometry and the current signal state. The SPaT message contains the following content: • Intersection number: 1314. • Phase ID: 7. • Description: Whittier Ave. at High St. • Current state: red. • Minute end time: 20 s. • Next time: indeterminite.
Mobile device	3	Positions itself (and the traveler) within the intersection geometry.	Determines the intersection ID that it would be approaching.

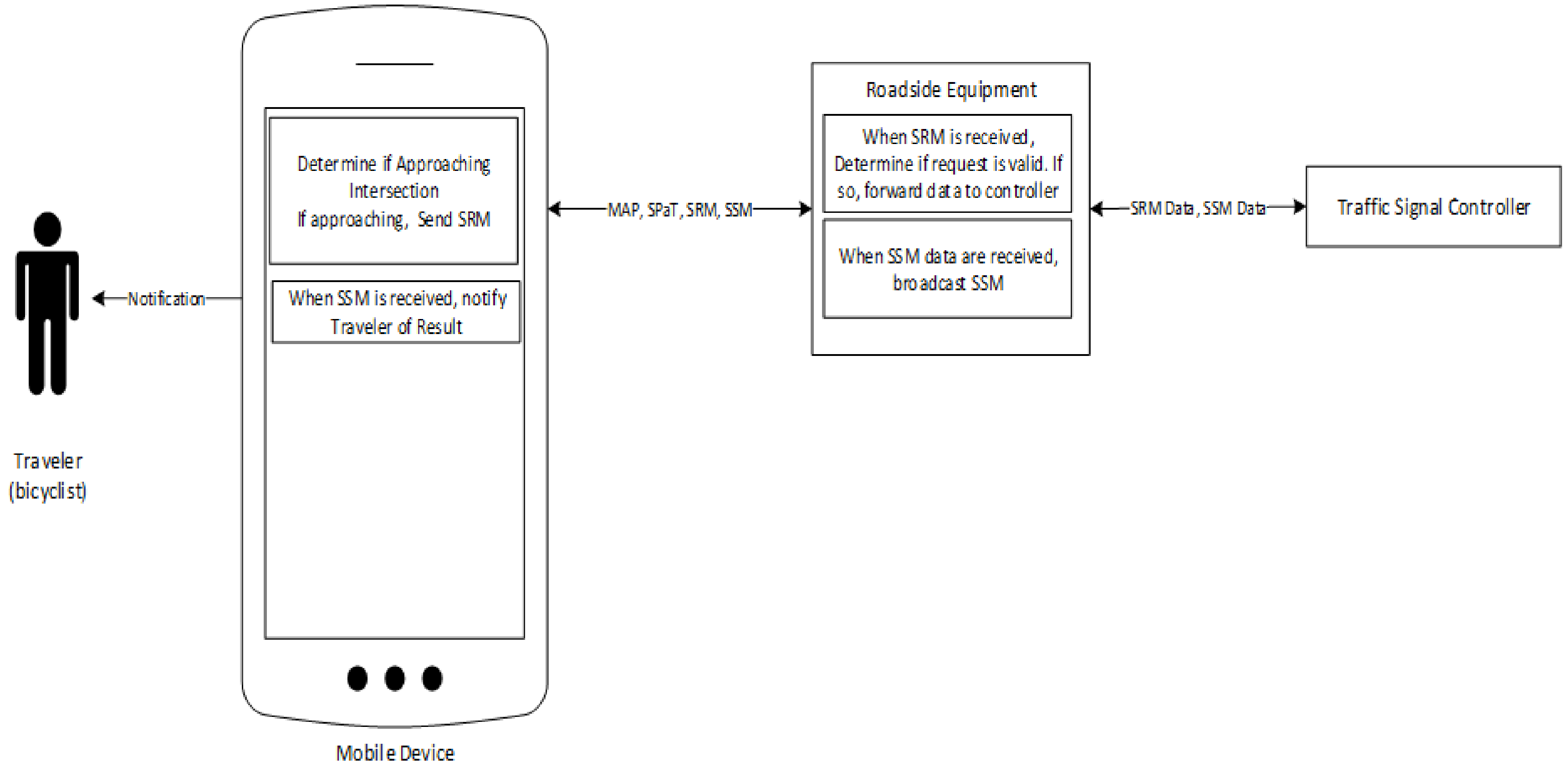
Source	Step	Key Action	Comments
Mobile device	4	Broadcasts an SRM indicating approach time and anticipated movement.	Estimates the approach time based on current time, bicycle speed, and distance to intersection. Note: The anticipated movement would be determined by the mobile device—the route (from trip planner, see preconditions) through the intersection would be compared with the intersection movements indicated in the intersection geometry message to determine which movement would be made by the bicyclist. Alternatively, the anticipated movement could be determined based on the approach lane where the mobile device is positioned. The SRM contains the following content: • Temp request ID: 123456. • Intersection number: 1314. • Phase ID requested: 7. • Service requested: normal.
RSU	5	Receives an SRM broadcast from mobile device.	Communication would not necessarily have to be directly from mobile device to the RSU.
RSU	6	Checks that the approach would be for the intersection where the RSU would be located and that the movement being requested would be valid.	Determines the request would be made for the intersection and that the movement would be valid.
RSU	7	Places a call for the requested phase to the pedestrian signal controller.	N/A
Traffic signal controller	8	Initiates flashing (strobe) warning lights at intersection.	N/A

Source	Step	Key Action	Comments
RSU	9	Broadcasts an SSM indicating that the requested movement would be valid and that the signal controller has accepted the request. SPaT indicates that the flashing warning lights are active.	The SSM contains the following content: • Temp request ID: 123456. • Status: accepted. The SPaT message contains the following content: • Intersection number: 1314. • Phase ID: 7. • Description: Whittier Ave. at High St. • Current state: flashing. • Minute end time: 20 s. • Next time: indeterminite.
Mobile device	10	Receives messages indicating the flashing warning lights are active.	N/A
Mobile device	11	Provides an audio/visual confirmation to the traveler that flashing warning lights are active (optional).	Notification would be continuous while warning lights are on and while traveler is approaching and crossing.
Traveler	12	Receives notification as they approach the bike/pedestrian crossing (optional).	N/A
OBU	13	Receives messages indicating the flashing warning lights are active.	N/A
OBU	14	Provides an audio/visual confirmation to the driver that flashing warning lights are active.	Determines that it would be approaching the crossing while flashing warning lights are active.
Driver	15	Receives notification as they approach the bike/pedestrian crossing.	Notification would be continuous while warning lights are on.
Traveler	16	Slows down, checks conflicting traffic to ensure no vehicles would encroach the crosswalk while crossing.	N/A
Traveler	17	Proceeds through intersection.	N/A

Source	Step	Key Action	Comments
RSU	18	Determines that the traveler has passed through the intersection.	Determines that no other cyclists/pedestrians are crossing or approaching the crosswalk.
General	19	Turns warning lights off.	N/A
OBU	20	Ceases issuing notification to driver.	N/A

OBU = on-board unit.

To complete this scenario, six characteristics are included, along with a system diagram capturing the four sources included in the scenario, as shown in figure 17.



Source: FHWA.

Figure 17. Diagram. Use Case 2—Scenario 1, four sources.

The following characteristics complete Use Case 2—Scenario 1:

- **Postconditions**—The bicyclist would be detected and would proceed through the intersection when the signal changes after determining that all conflicting traffic has stopped.

- **Messages**— The message types would include MAPs, SPaTs, SRMs, and SSMs.

- **Traceability**—The Bicyclist UN1—Activate Detector applies to this scenario.

- **Mobile device inputs summary**—Inputs would include time and location (from GNSS), MAPs (from RSE), SPaT (from RSE), and SSMs (from RSE).

- **Mobile device**—The mobile device would send SRMs (to RSE).

- **Outputs summary**—Outputs would include audio/visual notifications (optionally, to bicyclists) to confirm the phase would be serviced and to confirm that flashing warning lights are active.

Use Case 2—Scenario 2

Use Case 2—Scenario 2: Bicycle Street Safety describes a traveling bicyclist using a connected mobile device. Scenario 2 is identified and titled "UC2-S2: Bicycle Street Safety" with the following characteristics:

- **Short description**—A traveler (bicyclist) would carry a mobile device that would receive vehicle safety data, and the bicyclist would be made aware of potential safety issues as they complete their trip. Drivers in CVs that receive safety data from the mobile device would be made aware of potential bicycle-related safety issues as they complete their trip.

- **Scenario objective**—To demonstrate the ability of a mobile device to provide the following capabilities:

    - Bicycle intersection movement assist.
    - Bicycle overtake lateral clearance safety.

- **Operational event(s)**—The functioning-related events would take place in the following order:

    - In-vehicle device receives safety messages broadcast from mobile device.
    - Mobile device receives safety messages broadcast from the in-vehicle device.

- **Preconditions—**The traveler (bicyclist) would take a trip from work to home. The trip would take place during rush hour in an urban environment on arterials with many intersecting cross streets and on local streets, where many vehicles parallel park to access residences and local businesses. Motor vehicle traffic would typically be able to move at a pace that would be faster than the traveler. Local regulation allows bicyclists to take the full lane and has provisions that allow drivers to pass bicyclists (i.e., no oncoming traffic, 3-ft lateral clearance).

- **Traveler actor role—**The traveler would carry a mobile device while operating a bicycle on the roadway network in an environment with drivers.

- **Driver 1 actor role—**The driver would operate a vehicle containing an in-vehicle device on a shared roadway in an environment with bicyclists.

- **Driver 2 actor role—**The driver would operate a vehicle containing an in-vehicle device approaching an intersection with a roadway in an environment with bicyclists.

The scenario then describes key actions and the flow of events of six sources: traveler, driver 1, mobile devices, in-vehicle device 1, driver 2, and in-vehicle device 2. Table 16 describes steps 1 through 38 in this scenario.

Table 16. Use Case 2—Scenario 2, steps 1–38.

Source	Step	Key Action	Comments
Traveler	1	Proceeds forward in a shared lane.	N/A
Driver 1	2	Approaches the bicyclist from behind.	Driver’s vehicle is moving faster than the bicycle.
Mobile device	3	Broadcasts a PSM.	Provides location and movement information about the bicycle. Note: It would be an inherent attribute of the message that the traveler would be a VRU. The mobile device would be assumed to be located on the person of the traveler and could communicate normally. Messages broadcast by the mobile device could be received by other local devices. The PSM contains the following contents: • Temp ID: 18459349. • Location: o Lat: 39.947081. o Long: −82.994952. • Heading: 348. • Speed: 10 mph.

Source	Step	Key Action	Comments
In-vehicle device 1	4	Broadcasts a BSM.	Provides location and movement information about vehicle 1. Note: It would be an inherent attribute of the message that the driver would be in a vehicle (i.e., not a VRU). Messages broadcast by the in-vehicle device can be received by other local devices. The BSM contains the following contents: • Temp ID: 18459349. • Location: o Lat: 39.946905. o Long: −82.994938. • Heading: 348. • Speed: 30 mph.
In-vehicle device 1	5	Uses the PSM received from the mobile device to determine whether the vehicle is approaching a bicyclist.	Determines that the vehicle would be approaching the bicyclist.
In-vehicle device 1	6	Provides notification that a driver is approaching a bicyclist.	Issues a notification when the distance between the vehicle and the bicycle decreases beyond a threshold that may be variable as a function of the speed difference between the vehicle and the bicycle.
Driver 1	7	Receives a notification that they are approaching a bicyclist.	N/A
Driver 1	8	Checks traffic in adjacent lane to determine whether it is safe to pass.	No conflicting traffic.
Driver 1	9	Begins to move over to the left to overtake the bicyclist.	Crosses double solid yellow lines if local traffic regulations allow. According to local traffic regulations, the vehicle would not provide sufficient lateral clearance, which would be 3 ft in most cases.

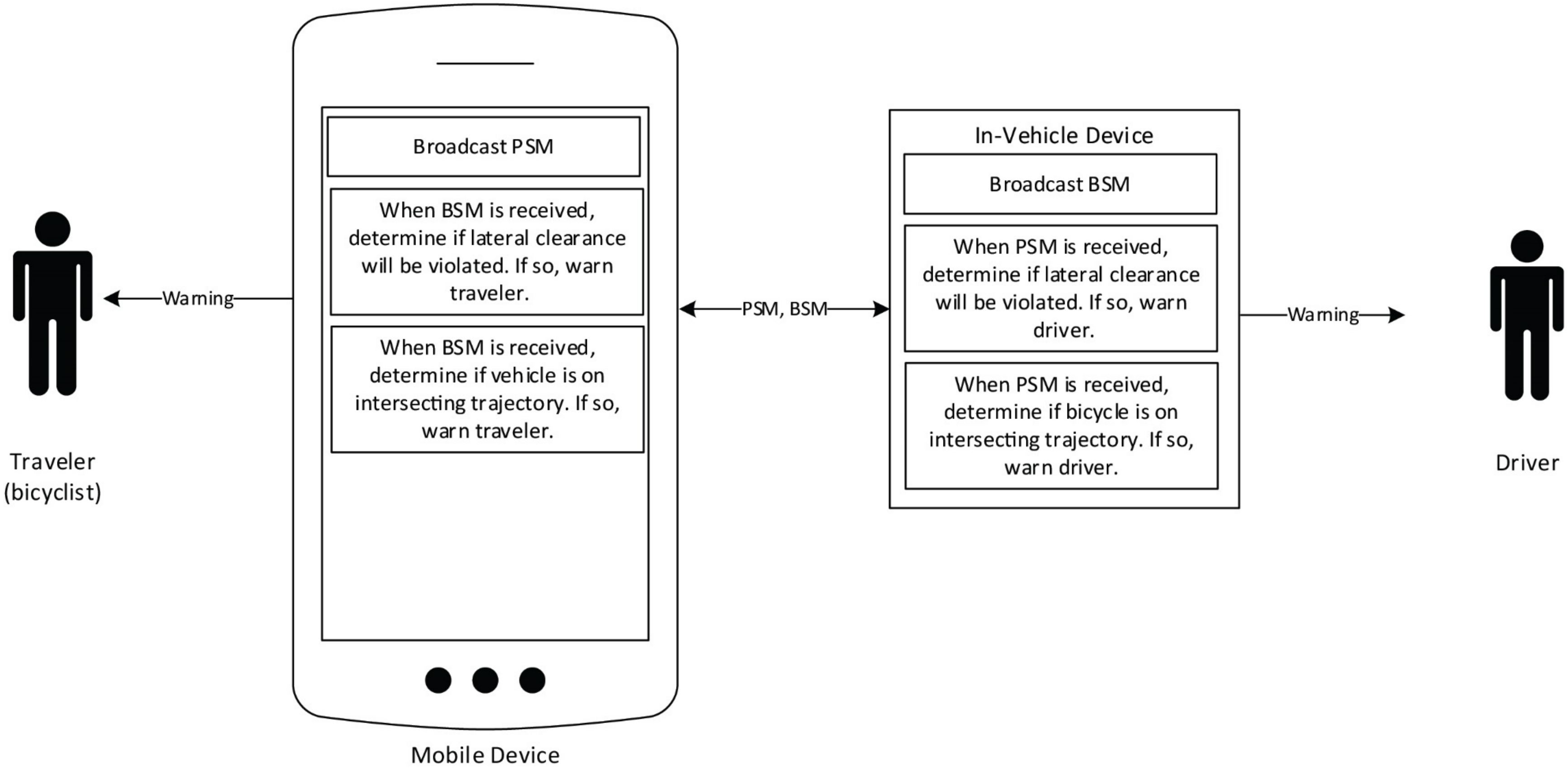
Source	Step	Key Action	Comments
Mobile device	10	Uses the BSMs received from the in-vehicle device to determine that there is a vehicle about to overtake the cyclist.	Determines that a vehicle is attempting a passing maneuver as the distance between the vehicle and the bicycle decreases beyond a threshold that may be variable as a function of the speed difference between the vehicle and the bicycle.
Mobile device	11	Provides audio notification that the bicyclist will be overtaken by a passing vehicle.	Issues a notification when the distance between the vehicle and the bicycle decreases beyond a threshold that may be variable as a function of the speed difference between the vehicle and bicycle. Note: In an alternative scenario, this notification may not be issued if the lateral distance between the bicycle and vehicle would be greater than a given threshold.
Traveler	12	Continues proceeding forward in the shared lane.	Becomes aware of movements of passing vehicles. This notification discourages the bicyclist from making movements without checking the movements of surrounding vehicles.
In-vehicle device 1	13	Uses information received from the mobile device to determine the lateral clearance between the vehicle and the cyclist.	Determines whether the lateral clearance is expected to be less than 3 ft. Note: Other applications on the in-vehicle device could notify the driver of conflicting traffic movements (forward collision warning or lane change warning), but that is outside the scope of this concept.
In-vehicle device 1	14	Provides notification that not enough lateral distance is being provided.	Issues notification when the distance between the vehicle and the bicycle decreases beyond a threshold that may be variable as a function of the speed difference between the vehicle and the bicycle. Note: In an alternative scenario, this notification may not be issued if the lateral distance between the bicycle and the vehicle would be greater than a given threshold.
Driver 1	15	Receives a notification that not enough lateral clearance is being provided before overtaking the bicyclist.	Becomes aware of the lack of sufficient lateral clearance. This notification gives the driver an opportunity to provide additional lateral clearance for passing the bicyclist.

Source	Step	Key Action	Comments
Driver 1	16	Moves farther to the left as they overtake the bicyclist.	N/A
In-vehicle device 1	17	Ceases issuing notification to the driver.	Ceases issuing notifications as the lateral clearance increases above a sufficient threshold. Note: The in-vehicle device would continue to process incoming safety messages received from the mobile device (carried by the traveler) and would continuously evaluate the position of the vehicle with respect to the cyclist to determine whether a notification needs to be issued again.
Mobile device	18	Ceases issuing notification to the traveler.	Ceases issuing notifications as the vehicle overtakes the bicycle.
Driver 1	19	Moves back to the right into the shared lane of travel.	N/A
Traveler	20	Continues proceeding forward in the shared lane.	N/A
Traveler	21	Approaches a two-way stop intersection.	Approaches on the through approach of the intersection.
Mobile device	22	Continues to broadcast the PSM.	The PSM contains the following content: • Temp ID: 18459349. • Location: o Lat: 39.949144. o Long: −82.995356. • Heading: 348. • Speed: 10 mph.
Driver 2	23	Approaches a two-way stop intersection.	Approaches the ame intersection as the travelers, but from a Stop approach. Intends to make a through maneuver.

Source	Step	Key Action	Comments
In-vehicle device 2	24	Broadcasts a BSM.	The BSM contains the following contents: • Temp ID: 18459349. • Location: o Lat: 39.949241. o Long: −82.995281. • Heading: 258. • Speed: 0 mph.
Driver 2	25	Stops and checks for cross traffic.	Does not notice any cross traffic.
Driver 2	26	Begins to travel through the intersection.	Fails to see the traveler approaching from the uncontrolled approach from the left.
Mobile device	27	Uses information received from the in-vehicle device to determine potential collision courses between the vehicle and the cyclist.	Determines that there would be a sufficient probability of collision.
Mobile device	28	Provides a potential crash notification with a vehicle.	Issues a notification when the distance between the vehicle and the bicycle decreases beyond a threshold that may be variable as a function of the speed difference between the vehicle and the bicycle.
Traveler	29	Receives a potential crash notification.	Becomes aware of an imminent crash situation. Notices vehicle moving forward.
Traveler	30	Slows down to avoid a potential crash situation.	N/A
In-vehicle device 2	31	Uses information received from the mobile device to determine potential collision courses between the vehicle and the cyclist.	Determines that there would be a sufficient probability of collision.
In-vehicle device 2	32	Provides a potential crash notification with a bicyclist.	Issues a notification when the distance between the vehicle and the bicycle decreases beyond a threshold that may be variable as a function of the speed difference between the vehicle and the bicycle.

Source	Step	Key Action	Comments
Driver 2	33	Receives a potential crash notification with a bicyclist.	Becomes aware of an imminent crash situation.
Driver 2	34	Comes to an abrupt stop.	N/A
Mobile device	35	Ceases potential crash notification.	N/A
In-vehicle device 2	36	Ceases potential crash notification.	N/A.
Traveler	37	Continues proceeding forward through the intersection.	N/A
Driver 2	38	Checks for cross traffic and proceeds through the intersection.	Uses the in-vehicle device, which continues processing incoming safety messages received from mobile devices (carried by other VRUs) and continuously evaluates the position of the vehicle with respect to other cyclists to determine whether a notification needs to be issued again.

To complete this scenario, six characteristics are included, along with a system diagram capturing the four sources included in the scenario, as shown in figure 18.



Source: FHWA.

Figure 18. Diagram. Use Case 2—Scenario 2, four sources.

The following six characteristics complete Scenario 2:

- **Postconditions—**Driver 1 and driver 2 would be aware of the presence of the bicyclist in the roadway environment, and they would modify their behavior to ensure the bicyclist is identified. The bicyclist would be aware of presence of vehicles in various safety-critical situations.

- **Messages—**The message types would include PSMs and BSMs.

- **Traceability—**The Bicyclist UN2—Bicyclist Roadway Safety Driver Awareness applies to this scenario.

- **Mobile device inputs summary—**Inputs would include time and location (from GNSS) and BSMs from in-vehicle device 1 and in-vehicle device 2.

- **Mobile device—**The mobile device would send PSMs to in-vehicle device 1 and in-vehicle device 2.

- **Outputs summary—**Outputs would include audio/visual notifications to the traveler about overtaking by a passing vehicle and potential crashes.

CHAPTER 10. CONCEPT 3: TRAVELER USING PUBLIC TRANSIT WHILE USING A CONNECTED MOBILE DEVICE

CHAPTER OVERVIEW

This chapter is the third of four chapters that develop an example concept to showcase how mobile devices and electronic messages could be used to satisfy traveler needs. The concept in this chapter focuses on addressing an example set of needs for public transit users carrying a mobile device. Through these example concepts, the reader can begin to understand the content included in a typical ConOps. A description specific to the concept is provided and walks through existing conditions, justification for changes, description of desired changes, operational policies and constraints, description of proposed operating environment, modes of operation, user classes, support environment, and operational scenarios. These example concepts begin to shape a system that enables the exchange of electronic messages with mobile devices to satisfy the needs of different types of travelers.

EXISTING CONDITIONS

Travelers have access to trip planning applications to determine a route and itinerary that most closely matches their preferences. Existing conditions for travelers include the following options and actions:

- Trip planning applications (desktop- and mobile-based) typically use real-time data, but do not continuously check for changing conditions once the trip has been started. Trip planners cannot account for travelers who are en route (already on a transit vehicle). Trip planners assume the traveler has not started their trip.

- Transit agencies provide real-time information online and/or through a smartphone application. Planned routes could utilize this information. Arrival information could be provided at stations and bus stops, but not always.

- Transit buses typically display the route number and heading on exterior signs on the front and the side of the bus. An audio notification could also be provided as the bus or train stops at each stop. Regarding bus systems, drivers visually detect pedestrians at a stop to know whether a traveler intends to get on at the stop.

- The bus or train provides information regarding the next stop information to the traveler in both audio and visual formats. This system could be electronic and automated, or the information could be provided via static maps and driver announcements.

- Passengers are required to pull a cord (or similar) to notify drivers to stop at next stop.

- Passengers pay when boarding or by using a ticket machine at train station or near a bus stop (typically high frequency or bus rapid transit), depending on the system. Commuter rail systems also allow payment to be made onboard, typically at a higher fare than if the passengers were buying the ticket before getting on the train.

- Passengers add funds at a payment terminal or through an online portal. Once funds have been added, the traveler taps a fare payment card to gain access to a bus or train (fare gate). Some systems also require the traveler to tap the farecard when exiting the system. This is usually required when the system uses a distance-based or zone-based fare system. Some systems can have an integrated fare payment that allows free or discounted transfers to another system.

JUSTIFICATION FOR CHANGES

Several aspects of the current conditions of traveling on public transit could warrant the addition of technology to enable communication to and from mobile devices. These aspects are discussed in detail in the following subsections.

En route Adjustment for a Transit Trip (Alternative Route)

A transit trip planned by using an MMTP may not go as scheduled because traffic conditions continuously change, and transit vehicles might travel ahead of or behind schedule. Such unexpected changes could particularly affect a transit trip if transfers are involved. In a situation in which the first leg of a trip is running ahead of the schedule, it could be more advantageous for the traveler to use a different route for the second leg of the trip to ensure they could reach their destination faster. Similarly, if the first leg of a trip is running behind schedule, the traveler might miss the connecting second leg. In this case, it could be advantageous for the traveler to be provided with an alternate route to get to their destination, especially if there are long headways between arrivals on the connecting route. Furthermore, a traveler who is interested in receiving transit trip adjustments might need to provide their location and speed to a Transit Management Center to receive the benefit of en route adjustments.

En route Mode Adjustment for a Transit Trip (Alternative Mode)

If a traveler intends to take transit to the final destination but the changing system conditions could result in severe delays for the traveler, the traveler might take alternative modes of travel.

Adjust Transit Operations (Connection Protection and Variable Service Adjustment)

Travelers on a multileg transit trip depend on reliable connections to arrive at their destination in a timely manner. Making a connection would be especially important to a traveler when the connecting line provides low-frequency (high-headway) service. If the traveler misses the connection, waiting for the next transit vehicle to service the stop would result in the traveler arriving at their destination much later than intended.

In addition, transit agencies might experience unexpected high demand along certain routes. When unexpected demand occurs, buses or trains could become overcrowded, resulting in delays (increased dwell times for boarding/alighting) and bus/train bunching.

Driver Notification of Passenger Waiting at Stop

Transit stops with passengers waiting at them are typically served by transit vehicles that operate at those stops. Transit vehicle operators generally look for the presence of a traveler waiting at a stop along the route to determine whether to service the stop to allow the traveler to board. It may be difficult for a transit vehicle operator to determine whether a person is waiting if the potential passengers or the stop itself is occluded by other objects on the roadside or if the potential passengers are sitting away from the roadway. Drivers are more likely to stop for passengers if they are standing alert at a bus stop. Similarly, during night hours, it might be difficult to see a traveler waiting at a bus stop if it is not well lit.

Traveler Notification When Transit Vehicle Approaching

Travelers might not be able to readily read the heading sign on an approaching transit vehicle or might not be able to hear audible external announcements provided by the transit vehicle or the operator (if the transit vehicle is not capable of providing external announcements).

Driver Notification of Stop Request

Traditionally, pull cords or pushbuttons are available for use by travelers to indicate whether the bus may service the next stop so that the traveler can get off the bus. Passengers who are unable to locate the pull cord might have difficulty getting the bus to stop so they can alight at the proper location. Similarly, travelers who are unfamiliar with the transit system may not know when their stop is approaching and know when to use the pull cord (if required to stop). Ideally, there would be an alternative method to accommodates passengers performing tasks needed to request a bus to stop.

Passenger Notification to Alight

When onboard a transit vehicle, travelers might not be able to readily read information or hear audio notifications about the next stop. Also, travelers who are not familiar with the transit system might have difficulty determining what stop they need to get off a transit vehicle to get to their destination.

Transit Fare Payment (Pay When Boarding/Pay at Fare Gate)

Smartphones are becoming an increasingly popular method for travelers to pay for a fare to gain access to transit or other shared services. Certain transit systems allow a traveler to purchase a trip through an application specific to the transit system(s) in the region before arriving at the transit vehicle. Travelers activate the trip just before entering the transit vehicle, and the mobile device screen shows a proof of payment, which is displayed to the transit vehicle operator, kiosk, turnstile, or enforcement agent when boarding. Completing a trip that uses multiple modes of travel (or that uses multiple transit agencies or first-mile/last-mile options) can be more burdensome if each system has its own payment system.

Some systems do not allow for smartphone-based payments, requiring the traveler to pay onboard (typically limited to cash) or to use a fare payment machine before boarding. (In some systems, fare payment machines might not be located at all transit stops, which places the burden of making a cashless payment on the traveler.)

DESCRIPTION OF DESIRED CHANGES

Examples of transit user needs are provided in table 17.

Table 17. Transit user needs.

User Need ID	Title	Description
Transit UN1	Continuous Efficient Route Check	A transit user needs an alternative route or mode options that could be used by the traveler while en route to the destination.
Transit UN2	Trip Planning Service Access	A transit user needs access to a multimodal trip planning service.
Transit UN3	Approaching Transit Vehicle Information	A transit user needs to know information about approaching transit vehicles while waiting at a transit stop.
Transit UN4	Board/Alight Notification	A transit user needs to notify the transit vehicle operator when they intend to enter/exit from the transit vehicle.
Transit UN5	Connection Protection	A transit user needs to notify a transit manager (or a transit management system) when they intend to make a scheduled connection.
Transit UN6	Transit Fare	A transit user needs to know the fare to take a trip using transit.
Transit UN7	Transit Payment	A transit user needs a method to pay for a trip taken using transit.
Transit UN8	Transit Wayfinding and Navigation	A transit user with disabilities needs wayfinding and navigation solutions for a complete trip between an origin and destination in the public right-of-way. Note: The traveler needs wayfinding and navigation information before starting the trip and must be updated throughout the trip to account for changing conditions, such as arrival times of a transit vehicle.

The mobile device-based applications described in the following subsections could address transit user needs.

En route Adjustment for a Transit Trip (Alternative Route or Alternative Mode)

As the traveler completes the trip, the mobile device could check to see whether other modes are available to continue to the final destination and avoid delays on the transit leg of the trip. For a mode adjustment to be feasible for the traveler, the traveler could consider alternative modes (within a certain given walking distance of the traveler’s current location). Furthermore, it would be expected that preference selections made by travelers who are not physically capable of using one or several of these modes would preclude an MMTP from returning trips that contain these alternative modes. Allowing the traveler to program their abilities and preferences into an MMTP (e.g., willingness to park and ride, preference of walking up to 1 mi over a 10-min wait at a transfer, inability to use a scooter-share or bikeshare) could allow the system to adjust to these preferences when displaying and prioritizing travel mode and route options.

A mobile device could access real-time scooter-share and/or bikeshare data to periodically provide updated optimal route options and trip time estimates to the traveler. If close enough to the destination, walking to compete the trip may also be a feasible option. The traveler can use this information to better make decisions about using transit and other options to proceed to their destination.

Adjust Transit Operations (Connection Protection and Variable Service Adjustment)

Connection protection seeks to protect transfers between both transit (e.g., bus, subway, and commuter rail) and nontransit (e.g., shared ride) modes, and to facilitate coordination between multiple agencies to accomplish this protection. For a traveler to benefit from connection protection, they would provide information to the transit agency that specifies they intend to make a transfer at a specific location/time to a specific line. This transfer alert could be accomplished by sharing the itinerary with the transit agency. Once the transit agency receives this transfer request, they can hold the transferring vehicle if it arrives at the transfer location early, or if the transit vehicle arrives behind schedule. The transit operations must be flexible to allow transit vehicles to wait for a transferring traveler. The agency may put a limit on the amount of time it holds one of its vehicles at a location.

A transit agency may require certain conditions to be met to allow connection protection to be provided for travelers. There could be a threshold on the number of travelers needing to make the transfer or for the connecting route to be of low capacity or low frequency in service. A transit agency may also be more willing to allow connection protection to occur if the connecting transit vehicle waits at the beginning of its route.

A mobile device could be used to facilitate the communication of traveler information to the transit agency. The traveler could use a mobile device-based trip planner to get a trip itinerary. The mobile device could be used to communicate a traveler’s anticipated transfer location to the transit agency. Alternatively, if the traveler’s proposed route information were available to the transit agency, and the transit agency could confirm that the traveler is adhering to the provided itinerary, the transit agency could provide connection protection when necessary and as operations allow. A response could be provided to the traveler through the mobile device to indicate they are likely to make the connection. It may also be useful to the traveler to be provided with information on the amount of time needed to make the connection.

If a transit agency has advance information about greater-than-usual demand (e.g., during peak travel periods or after a special event), extra buses could be added to certain routes to better accommodate demand along the route. As travelers use a mobile device to plan a transit trip, they could provide the transit agency with their itineraries. The transit agency would aggregate the itineraries received from all travelers to forecast demand to use certain transit lines in the system. Transit vehicles could then be added to transit lines where demand is expected to exceed a given threshold to increase the frequency of bus arrivals (until demand falls below the threshold). This itinerary aggregation and subsequent forecast would reduce the time travelers wait for buses, assist in preventing delays and bus bunching, and improve the overall user experience along the affected line.

Driver Notification of Passenger Waiting at Stop

To enhance transit vehicle operators' awareness of when they need to service a stop to pick up a passenger, the traveler's mobile device would notify the operator of the approaching transit vehicle that the traveler is waiting at the stop. The notification could include the location of the stop, the intended route, and direction of travel. This notification process would ensure that the traveler boards the correct bus.

Traveler Notification when Transit Vehicle Approaching

The basic premise behind this use case is to notify a traveler when a bus is approaching, along with information about the bus and its route. When coupled with a multimodal trip planning application, the mobile device could provide additional details to the traveler to indicate whether the approaching bus is the bus as indicated by the planned itinerary. A mobile device could provide an alternate means of providing this information to the traveler that would be consistent and could be readily comprehended by the traveler. The approaching transit vehicle could send the route number and heading and a specified stop number, so the traveler (or mobile device) could determine whether they want to board the approaching bus. This increase in the traveler's awareness of the approaching bus would give the traveler more time to prepare to board the bus, which could result in decreasing the amount of time it takes to board and improving schedule adherence.

Driver Notification of Stop Request

This use case would allow a traveler to use a mobile device to alert to the transit driver that they need to get off the bus at a certain stop. The mobile device would send the stop location to the driver at any point throughout the trip. The transit vehicle operator would then be notified as they approach the stop that they need to service the stop. When used along with a multimodal trip planning application, the mobile device could place an automated call to the driver without added input from the traveler. This notification option would provide wayfinding and navigation assistance to travelers who are unfamiliar with the route they are traveling.

Passenger Notification to Alight

This use case would notify the traveler when they are expected to get off a transit vehicle. The successful execution of this use case would be predicated on the traveler using an MMTP where the destination stops would be known to the mobile device. This use case would primarily benefit travelers who are unfamiliar with using public transit (or who are unfamiliar with the system they are on) or travelers who are unable to readily read or listen to onboard information regarding the next stop.

Transit Fare Payment (Pay When Boarding/Pay at Fare Gate)

The integration of fare payment systems (i.e., a single method for paying fares on multiple systems) would add convenience for a traveler when utilizing multiple systems on the same trip. A mobile device could provide a common interface for paying for a trip. However, enabling this feature would also depend on the availability of a common payment platform and a service provider's (e.g., transit, ride hailing/sharing, carsharing) ability to accept payments using the common interface.

A common payment service typically involves a traveler carrying a device, such as a mobile device, that is compatible with the common payment system. The traveler would also provide account information in the device to enable a transaction to occur. As with many applications that are currently available on smartphones, this account information could be credit card information. However, to promote equity among users who do not have access to a credit card, the application would also accept payment from a common payment account that provides other options (e.g., cash) for the traveler to load funds into the account that could be used to pay for a trip. The traveler's payment information could be used to complete a one-time payment for a single trip, or to purchase a monthly or yearly pass to access systems (e.g., transit or bikeshare systems) that have a monthly or yearly access option.

Priorities Among Changes

This section prioritizes user-proposed functionality presented in the previous subsection. This prioritization would be typically done by classifying each possible change as essential, desirable, or optional. The classification method used would be determined by each deploying agency. Functions related to safety or other high-priority needs are considered essential, whereas desirable functions are considered to provide enhanced functionality but are not necessary for the system to meet user needs. Optional needs are generally limited to needs that are discretionary in nature. Prioritizing user needs would be a subjective practice and would vary from agency to agency and from region to region.

Changes Considered But Not Included

This section identifies changes and new features considered but not included, and the rationale for not including them. Not including certain features could be due to implementation difficulties, technology limitations, or other systems' ability to adequately meet the needs of users. Changes that are considered but not included would vary from agency to agency and from region to region.

Assumptions and Constraints

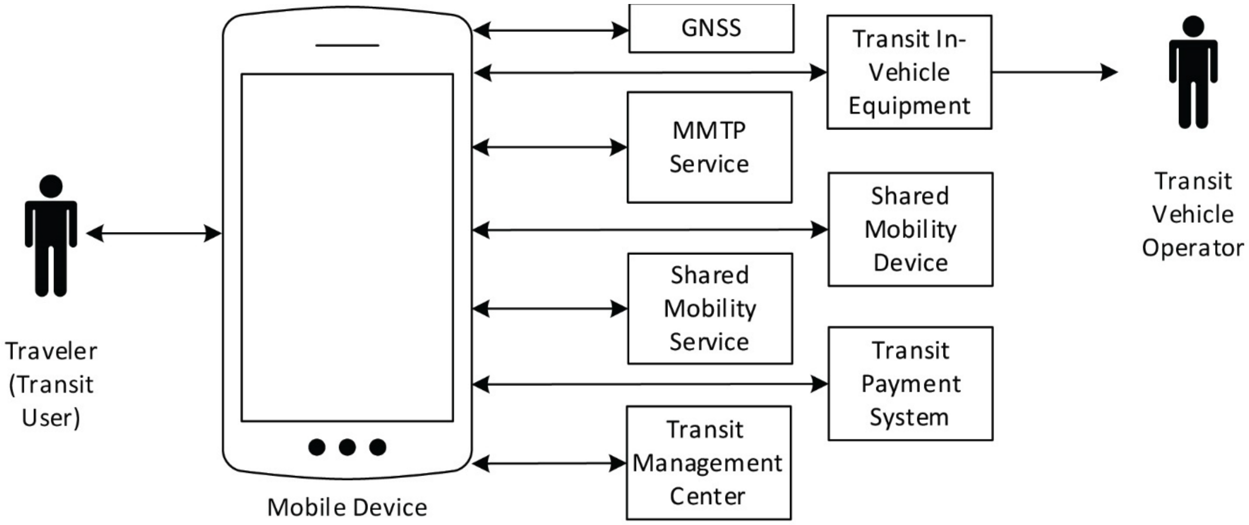
This section lists assumptions and constraints that would (or could) limit how the system can be designed and implemented. The following examples describe common assumptions and constraints that could affect the design of the proposed system:

- Communication, technology, hardware, or software availability.
- Off-the-shelf technology procurement (as opposed to the development of a new device).
- Operational policies and constraints.
- Existing laws and regulations (e.g., governing the operations of motor vehicles, pedestrians, and bicyclers on the roadways).

PROPOSED OPERATING ENVIRONMENT

As discussed in previous chapters, sharing and using electronic messages with connected mobile devices can be described as systems that work together. This concept includes the mobile device, GNSS, the transit in-vehicle equipment, an MMTP service, a shared-mobility device/service, a transit payment system, and a transit management center.

Figure 19 illustrates a systems diagram for this concept. The interfaces, hardware, messages, and facilities and external systems that comprise this figure are discussed in detail in the proceeding subsections.



Source: FHWA.

Figure 19. Diagram. Mobile device transit user system.

Interfaces

The following interfaces would be required to bring functionality to this concept:

- The transit in-vehicle equipment would provide a transit vehicle approaching message to the mobile device. This message would be received by the mobile device as a transit vehicle approaches the traveler's location and while the traveler is inside the transit vehicle.

- The mobile device would send a pickup request message and a stop request message to the transit in-vehicle equipment. The transit vehicle would receive this message as the transit vehicle approaches the traveler's location and while the traveler is inside the transit vehicle.

- The mobile device would send an MMTP trip request message to the MMTP service. The mobile device would send a reservation request message to the shared-mobility service. The mobile device would receive an MMTP trip options message from the MMTP service. Connectivity between the mobile device and the MMTP service, and between the mobile device and the shared-mobility service, would occur pretrip and while en route throughout the course of the traveler's trip.

- The mobile device would send a shared-use device unlock request message and a shared-use device end trip message to the shared-mobility device. The mobile device would receive the shared-use device unlock response message from the shared-mobility device. These messages exchanges would occur when the mobile device is near the shared-mobility device.

- The mobile device would exchange payment messages with payment systems for all services utilized by the traveler. (For this use case, the payment systems would include those used by both transit and shared-mobility systems.) Payment registration would be completed before the traveler uses the transit service or shared-mobility service, whereas the payment user ID would be exchanged as the traveler enters and/or exits the transit vehicle and when the traveler unlocks a shared-mobility device.

Hardware

The following hardware would be needed to enable this concept:

- The mobile device would be a self-contained apparatus that wirelessly sends and receives messages, receives data from its onboard sensors, and has a processor to execute functions and an HMI, which would allow it to receive input from and provide output to the pedestrian (audio/visual/haptic). The mobile device would position itself in the roadway environment to provide the traveler with local transit information. The mobile device would have access to an MMTP. The mobile device would accept MMTP inputs from the traveler, submit the request to the MMTP, receive trip planning results from the MMTP, and provide the results back to the traveler. Once the traveler selects a trip to take, the mobile device would forward the selected trip to all agencies that serve various legs of the trip. While en route, the mobile device would constantly exchange information with the MMTP to check for alternative trip options.

- As the traveler waits at the transit stop, the mobile device would receive transit vehicle approaching messages from incoming transit vehicles and would provide this information to the traveler waiting at the stop. If the traveler is in the process of taking a trip (selected a trip), the mobile device would also indicate whether the traveler should board the bus. As the transit vehicle approaches the stop where the traveler is waiting, the mobile device would send a pickup request message containing information about the transit vehicle that the traveler wants to board.

- The mobile device would be used to facilitate payment. A payment information message would be sent to the transit vehicle system (when the traveler is boarding or alighting a transit vehicle, as necessary) or the shared-mobility device (when a traveler unlocks or ends a trip on a shared-mobility device).

- While the traveler is on the transit vehicle, the mobile device would send a stop request message to the transit in-vehicle equipment as the transit vehicle approaches the traveler's stop. The mobile device would also notify the traveler that they are approaching their destination stop.

- The transit in-vehicle equipment would constantly broadcast a transit vehicle approaching message containing the information regarding the next stop. A pickup request message would notify the transit vehicle operator that a passenger is waiting at the stop specified in the message. Similarly, a stop request message would notify the transit vehicle operator that a passenger intends to alight at the stop specified in the message. The transit in-vehicle equipment would also receive payment information messages and would forward the information to the transit vehicle payment system.

Messages

Transit Vehicle Approaching Message

The transit vehicle approaching message would provide information to a mobile device about an approaching transit vehicle. The mobile device could use information about the approaching transit vehicle and the pedestrian's current location to determine whether the information about the approaching transit vehicle should be displayed to the pedestrian. The message contents could include the transit system operator's name or ID, the route number, the final destination, a route shape identifier, the next stops along the route, and the ID number of the coach. This message would help travelers better identify buses approaching a given bus stop.

Pickup Request Message

The pickup request message would allow a mobile device-carrying traveler waiting on a transit vehicle to notify the transit vehicle operator that they are waiting to board the transit vehicle at the passenger's given location. The contents of the message could include the transit system operator's name or ID, the route number, the final destination, and the pickup stop ID number. This type of message would be useful for transit services where stops are not serviced unless a passenger is waiting at the stop, especially under conditions in which the passenger might not be easily visible (e.g., when physical objects on the roadside are occluding the traveler from the transit vehicle operator's view or during nighttime hours). This message would be sent to an onboard transit vehicle device after the mobile device has received a transit vehicle approaching message from a transit vehicle that the pedestrian intends to take.

Stop Request Message

The stop request message would allow traveler with a mobile device to alert the transit vehicle operator about the stop where the traveler wants to get off the transit vehicle. This type of message would be useful for transit service where stops are not serviced unless requested by a passenger. At a minimum, the content in this message could include the stop identifier or could simply specify the next stop (in case the mobile device does not have access to transit stop identification information).

Payment Account Registration Message

The payment account registration message would be sent from a mobile device to an agency's payment system to register payment information and associate that payment information with a traveler. This message would contain the traveler's payment account information (e.g., card/account number, name, billing address), agency payment identifier, and an account activation period. This message would be sent only when the mobile device does not have an active registration with the payment system for a given agency providing a service the traveler intends to use.

Payment Account Confirmation Message

The payment account confirmation message would be sent to the mobile device once an agency's payment system has determined whether a valid method of payment has been provided (the registration was successful or not). Information in this message could include the payment status, an account ID, and a date of expiration for the account activation period. This account ID could be used in future transactions between the mobile device and the payment service with which the mobile device is registered until the end of the activation period (at which time, the payment account must be reactivated).

Payment User ID Message

The payment user ID message would be sent from a mobile device to pay for services once a payment account has been registered. This message could contain the intended payment system ID along with the travelers account ID. No payment information would be exchanged.

Payment User Confirmation Message

The payment user confirmation message would be sent in response to the payment user ID message, and it would contain the payment system ID, the account ID, and the payment confirmation status.

MMTP Trip Request Message

The MMTP trip request message would provide a standardized format for sending a query from a mobile device to an MMTP service. At a minimum, it would contain the origin and destination locations and traveler preferences (mode, departure/arrival time, cost, etc.), and it would indicate whether the traveler is in a vehicle. This message would allow the MMTP to provide accurate route choices based on whether the traveler is already onboard a vehicle (or other mode of transport).

MMTP Trip Options Message

The MMTP trip options message would be sent in response to the MMTP request message and would contain route options that satisfy the query and preferences specified by the traveler in the MMTP trip request message. Each route in this message would be broken into legs, whereby a single leg would be one segment of a trip taken in a single vehicle or on foot, without needing to make a transfer. The message would contain a polyline overview of the route, the route total duration, and the total cost. For each leg of the trip, the mode, starting location (latitude/longitude, descriptive name, stop ID), end location, service provider, route number, vehicle number, cost, duration, and waiting duration would be provided at a minimum.

Reservation Request Message

The reservation request message would be sent from a mobile device to a shared-mobility service to reserve a shared-mobility device, which would be identified in the message.

Shared-Mobility Device End Trip Message

The shared-mobility device end trip message would be sent from the mobile device to the shared-mobility device to end a trip on the shared-mobility device.

Facilities and External Systems

Transit Payment System

The transit payment system would receive payment information from the transit in-vehicle system and would charge the traveler's account according to the services used. Payment information would be used as an identifying feature to enable and track transfers within the system. The transit payment system would track payment information received for the same account (from the same mobile device). After the trip is complete, the payment system would determine the total cost of the trip (accounts for free/discounted transfers or upcharges for use of higher tier services) and would charge the account accordingly.

MMTP

The MMTP would receive the MMTP trip request message and would determine one or more potential options between the specified origins and destinations that are within the constraints of the traveler's specified preferences. For the MMTP to provide effective itineraries, it would need access to real-time data from external systems, including but not limited to, roadway traffic conditions, real-time transit data, bikeshare station availability, the locations of shared-mobility devices, and rideshare/ridesourcing availability information. The MMTP would provide a response containing route options to the mobile device in the MMTP trip options information message.

Shared-Mobility Service

The shared-mobility service would provide management services for a system of shared-mobility devices. The service would communicate with each shared-mobility device to obtain its location and to determine whether a user trying to unlock the device is registered, when a user has unlocked and started using the shared-mobility device, and when a user has ended a trip for the purpose of determining the trip cost. It would then use payment information (provided by the traveler) to charge the traveler's account for the trip taken. Although most shared-mobility service systems that exist do not allow reservations to be placed on a shared-mobility device, this function could easily be integrated.

Shared-Mobility Device

The shared-mobility device would typically be a powered device that would be located throughout the city and would be wirelessly connected with the shared-mobility service. The shared-mobility service may send a reservation request to the shared-mobility device so that only a traveler holding the reservation credentials could unlock the shared-mobility device for use. It would also receive the shared-user device unlock request message. If there is not a reservation on the shared-mobility device, then it would unlock for the traveler to use. However, if there is a reservation, the shared-mobility device would determine whether the reservation details in the unlock request message match the reservation from the shared-mobility service before unlocking the mobile device for the traveler to use. The shared-mobility device would send an unlock response message to the mobile device that provides details regarding whether the shared-mobility device was successfully unlocked.

MODES OF OPERATION

Mobile devices are intended to complement existing methods of providing transit information, accessing an MMTP, wayfinding, and payment for utilizing a transit service or a shared-mobility service. Information and notifications provided to the traveler are expected to improve the mobile device users' mobility, wayfinding, and ability to make informed decisions. Mobile devices are not intended override existing methods of receiving information or payment. If the mobile device-based system experiences nonnormal modes of operations, the mobile device user would have to rely on existing methods of receiving transit information, accessing an MMTP, wayfinding, and making payments.

Various issues that could result in nonnormal operations are provided in general context in chapter 8, Modes of Operation.

USER CLASSES AND INVOLVED PERSONNEL

The traveler user class can be categorized as both a transit user and a shared-mobility device user. Using transit, the traveler waits at a given location for a transit vehicle to arrive and boards the transit vehicle when it arrives. For these actions to occur successfully, the traveler should receive information regarding the transit vehicle that is approaching and stopping to ensure they are boarding the correct transit vehicle, especially when there is more than one transit route servicing the stop where the traveler is waiting.

The traveler must pay for use of the transit service. At a bus stop, the traveler typically pays in cash when boarding or taps a preloaded farecard against a terminal when boarding. Alternatively, the traveler could use a farecard to pass through fare gates to gain access to a paid-fare zone. Fare gates, which are typically found at bus terminals or train stations, eliminate the need for payment, and when the traveler enters the transit vehicle, fare gates increase boarding efficiency. Proof-of-payment type systems do not have a fare gate but require the traveler to pay for a trip or activate a trip before boarding. The traveler is then provided with a proof of payment, which is validated from time-to-time by fare enforcement officials.

After boarding, the traveler rides on the transit vehicle approaching their destination (or end of the trip leg). The traveler is responsible for knowing the stop where they plan to alight the vehicle. Whereas certain services (e.g., subway, trolley) may stop at every stop, other services (e.g., bus, light rail, streetcar) require the traveler to notify the transit vehicle operator when they plan to alight the transit vehicle. In this case, the traveler would use a pull cord (or stop button or press the yellow strip) to request getting off at the next stop.

The traveler uses a shared-mobility device to access areas that are not easily accessible by transit, when traveling in an area where driving would be difficult or expensive and when other personal modes of transport are not practical (i.e., too long to walk or other personal mobility options are not available). These services require a traveler to be within the proximity where the shared-mobility device is present or to view real-time availability data to determine where to find the nearest shared-mobility device. The traveler cannot be guaranteed that a device that is shown as available would still be found at the indicated location because another traveler could reach the device first. If another traveler does reach the device first, the traveler must find (and navigate to) a different shared-mobility device to use. Dockless systems require the traveler to use a smartphone to unlock the device, whereas dock-based systems (e.g., bikeshare) typically require a credit card (short-term use) or fob (long-term membership) for access. A trip taken on a dockless system may end at any location within the service boundary; the traveler uses the smartphone to lock the device. The traveler then receives a fee for the trip, which they are responsible for paying. (Long-term bikeshare members may not be charged because they typically receive a free-use period.) Most shared-mobility systems require the traveler to keep credit card information on file (or carry credit on an account) to ensure that payment for the trip is automatically made once the trip ends.

The transit vehicle operator is responsible for stopping at all stops where passengers are waiting and for stopping when a passenger makes a stop request. As each passenger boards, the transit vehicle operator collects a fare from the passenger or verifies that the passenger has already paid (i.e., has a valid pass). When implementing connection protection, the transit vehicle operator would also be responsible for performing a holdover when they reach the stop where connection protection would be granted. Ideally, the transit vehicle operator would be in a position where they can see the arrival of the connecting transit vehicle, but they would verify that all transferring passengers were able to make the transfer before continuing along the route.

SUPPORT ENVIRONMENT

The transit agency would be responsible for the following actions:

- Operating and maintaining the transit service.
- Making real-time transit data publicly available so that the information can be used on a mobile device to provide real-time transit data to travelers and for trip planning purposes.

- Making real-time transit fare data available (most fare structures are static, but some vary depending on time of day, e.g., peak fares).
- Collecting fares and verifying proof of payment when a traveler enters a bus or passes through a fare gate. This step includes managing transfers that occur within the transit network (e.g., from train to bus or from one bus to another).
- Implementing connection protection under a given set of circumstances (i.e., a bus is running late, and a rider has indicated they intend to make a transfer to another bus line).

The personal mobility service provider (bikeshare, scooter-share) would be responsible for the following actions:

- Operating and maintaining devices that can be used for personal mobility.
- Making real-time data regarding the location of available bikes or scooters available. This step includes data on docking stations (if required) and any applicable service areas' boundaries.
- Making real-time cost data available so that data can be used for trip planning purposes.
- Collecting fees for use of service.

The ridesource/rideshare provider would be responsible for the following actions:

- Matching travelers with nearby drivers to service a trip requested by the travelers.
- Allowing a driver (actively servicing a traveler) to pick up another traveler (i.e., enable ridesharing).
- Maintaining real-time data regarding the availability of drivers.
- Making real-time cost data available so that data can be used for trip planning services. Cost may fluctuate based on number of drivers available to service current demand for service.
- Collecting payment for completed trips.

OPERATIONAL SCENARIOS

The operational scenarios in this section intentionally contain details that are typically beyond the scope of what would be necessary for a ConOps, such as including the functions carried out by each component, detailing the sending and receiving of messages, and revealing the content of those messages. This level of detail would be typically found in subsequent SE documentation. However, in this concept, this additional detail is included to provide the reader additional context about how such a system could work, and how messages could be used to enable the use case, to underscore the theme of sharing electronic messages with mobile devices to satisfy the needs of different types of travelers.

Use Case 3 captures the traveler using public transit while using a connected mobile device and has the following four scenarios:

- Transit System Navigation and Virtual Transit Vehicle Operator Notification.
- Transit En Route Adjustment (Same Mode).
- Transit Connection Protection.
- Transit En route Adjustment (Alternative Mode).

Use Case 3—Scenario 1

Use Case 3—Scenario 1 describes a traveler using public transit while using a connected mobile device. This scenario is identified and titled "UC3-S1: Transit System Navigation and Virtual Transit Vehicle Operator Notification" with the following characteristics:

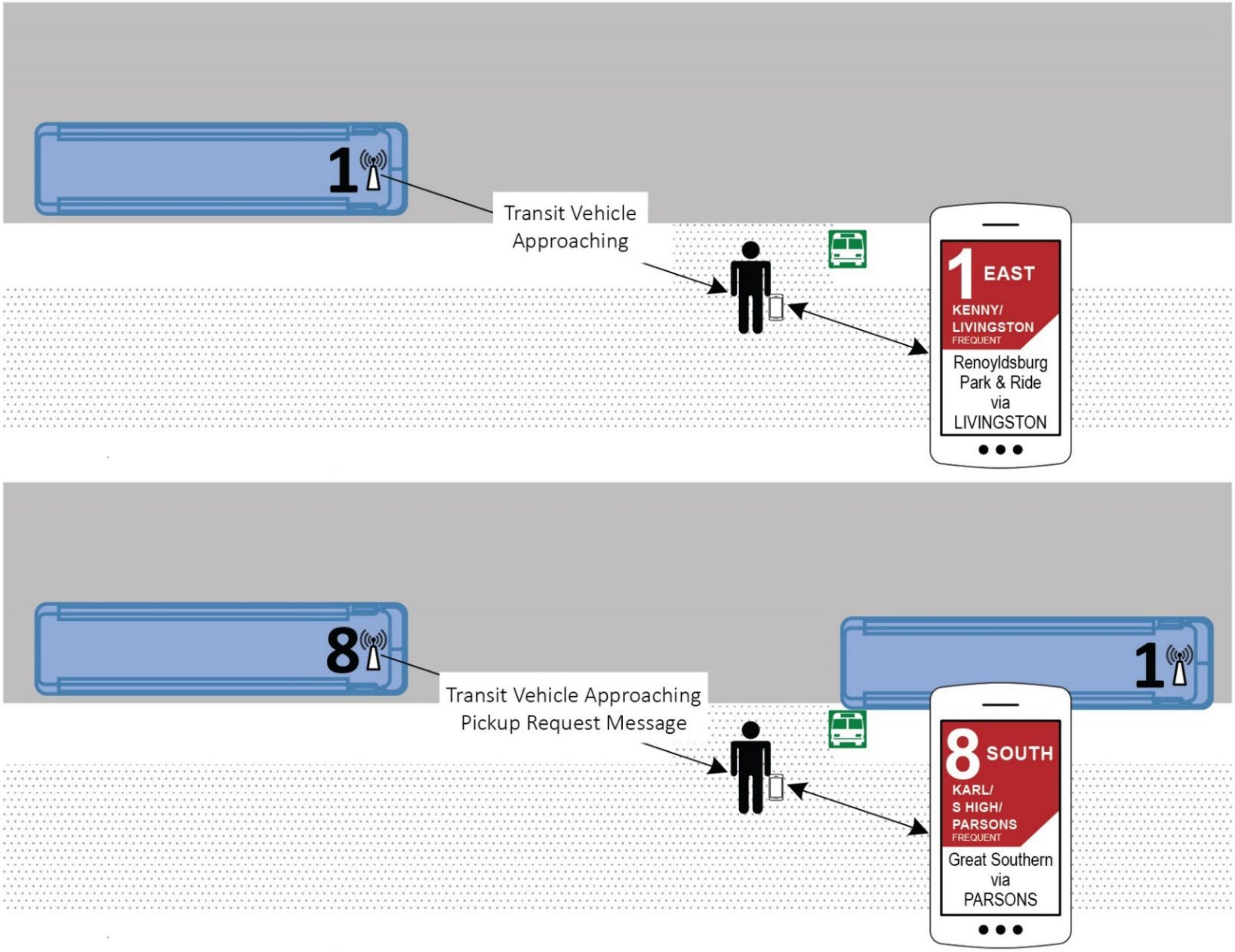
- **Short description**—A traveler (transit user) would use a mobile device to navigate a transit system with which they are not familiar.
- **Scenario objective**—To demonstrate the ability of the mobile device to provide the following options:
  - Driver notification of passenger waiting at stop.
  - Traveler notification when transit vehicle approaching.
  - Driver notification of stop request.
  - Passenger notification to alight.
  - Transit fare payment.
- **Operational event(s)**— The functioning-related events would take place in the following order:
  - Approaching transit vehicles would send information about their route to the mobile device.
  - The mobile device would determine whether the approaching transit vehicle is the one the traveler intends to take (according to the planned trip itinerary) and would notify the traveler via the mobile device when the transit vehicle is at the stop.
  - The mobile device would send a notification that there is a traveler waiting at the stop to the transit vehicle that the traveler intends to take as it approaches.
  - The mobile device would facilitate payment for the transit trip.
  - The mobile device would send the location that the traveler intends to disembark to the transit vehicle.
  - The transit vehicle would provide a relevant notification to the transit vehicle operator (and to the traveler) as it approaches the stop.
  - The mobile device would notify the traveler via the mobile device when the transit vehicle is approaching the destination (alighting) stop.
- **Preconditions**—The traveler (transit user) would use a mobile device to plan a trip from home to downtown. The trip would consist of a transit segment, but the traveler would be not familiar with the transit system. The traveler's mobile device would have received a trip itinerary from an MMTP. The mobile device would use this trip itinerary to provide the traveler with step-by-step instructions for wayfinding purposes. The traveler would have limited vision, which would make it difficult for the traveler to know when a bus is approaching or to easily determine the status of a pedestrian crossing at a traffic signal.
- **Traveler actor role**—The traveler would successfully and safely navigate the planned itinerary.

- **Mobile device actor role—**The mobile device would provide relevant wayfinding information to the traveler (based on the location of the mobile device in the transportation environment) and send and receive messages that enable the traveler's needs to be met.

- **Transit vehicle in-vehicle device actor role—**The in-vehicle device would release a transit vehicle approaching message and alert the transit vehicle operator when a stop must be serviced.

- **Transit vehicle operator actor role—**The transit vehicle operator would service transit vehicle stops and monitor their surroundings for safety.

The scenario then describes key actions and the flow of events of six sources: traveler, transit vehicle 2, mobile device, transit vehicle 1, transit vehicle 1 in-vehicle device, and transit payment system. Figure 20 and table 18 describe steps 1 through 12 of this scenario and table 19 further describes steps 13 through 24 as detailed in figure 21.



Source: FHWA.

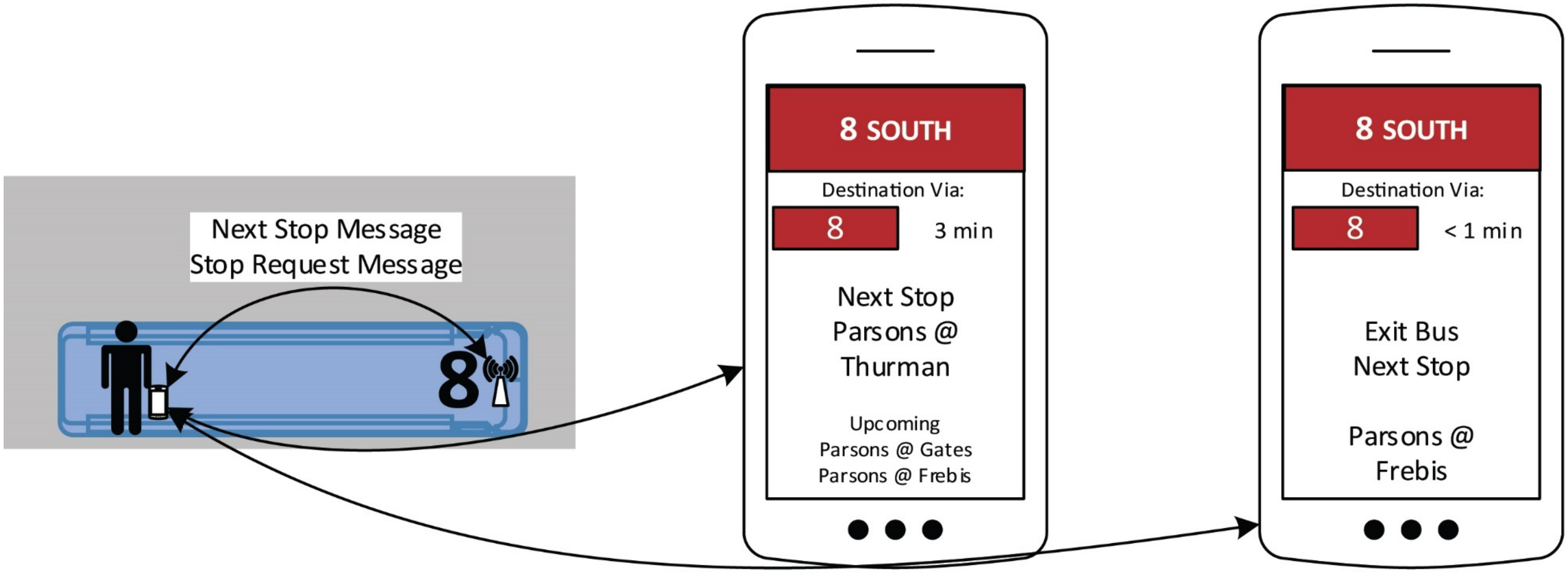
Figure 20. Diagram. Use Case 3—Scenario 1, data flows of steps 1–12.

Table 18. Use Case 3—Scenario 1, steps 1–12.

Source	Step	Key Action	Comments
Traveler	1	Navigates from home to the location of the bus stop. The traveler waits for the bus to arrive. The bus stop serves two routes (Route 1 and Route 8).	Traveler needs to take Route 1 to get to the grocery store (planned destination).
Transit vehicle 2	2	Route 1 bus approaches the stop where the traveler is waiting.	N/A
Transit vehicle 2	3	Sends a transit vehicle approaching message as it travels along its route.	Route shape ID and next stops correspond to GTFS (General Transit Feed Specification) Realtime data.(6) The traveler waits at stop ID 7890. This transit vehicle does not service the traveler's intended stop (ID 7899). The transit vehicle approaching message contains the following content: • Operator: local transit authority. • Route number: 1. • Route heading: via Livingston. • Final destination: Reynoldsburg Park and Ride. • Polyline (of route). • Next stops: o Stop ID: 7890. o Stop ID: 7891. o Stop ID: … o Stop ID: 8888. • Service provider ID: 12. • Vehicle ID: 1234.

Source	Step	Key Action	Comments
Mobile device	4	Provides an output (audio and visual) to the traveler that indicates that the approaching bus is not the correct bus: "Local transit authority—Route 1 toward Reynoldsburg Park and Ride is approaching. Continue waiting to stay on planned itinerary."	N/A
Transit vehicle 2	5	Continues, and the traveler continues to wait at the stop.	N/A
Transit vehicle 1	6	Approaches the stop.	N/A
Transit vehicle 1	7	Sends a transit vehicle approaching message as it travels along its route.	Route shape ID and next stops correspond to GTFS Realtime data.(6) The traveler waits at stop ID 7890. The traveler needs to get off the bus at stop ID 7899. The transit vehicle approaching message contains the following content: • Operator: local transit authority. • Route number: 8. • Route heading: via Parsons. • Final destination: Great Southern. • Polyline (of route). • Next stops: o Stop ID: 7890. o Stop ID: 8891. o Stop ID: 8892. o Stop ID: 9999. • Service provider ID: 12. • Vehicle ID: 2345.

Source	Step	Key Action	Comments
Mobile device	8	Provides an output (audio and visual) to the traveler that indicates that the Route 1 bus is approaching: “Local transit authority—Route 8 toward Great Southern is approaching. Board to stay on planned itinerary.”	N/A
Mobile device	9	Sends a pickup request message to the bus.	The pickup request message contains the following content: • Service provider ID: 12. • Vehicle ID: 2345. • Stop ID: 7890. • Require kneel: no. • Require ramp: no.
Transit vehicle 1 in-vehicle device	10	Provides an output to the bus driver to indicate that the next stop must be serviced: “Pickup passenger at stop 7890.”	Note: This step would likely be optional because transit system policies typically require a bus driver to stop at any bus stop where a passenger is waiting. The output would simply provide added awareness to the bus driver.
Transit vehicle 1	11	Stops at the bus stop.	N/A
Traveler	12	Traveler boards the bus.	N/A



Source: FHWA.

Figure 21. Diagram. Use Case 3—Scenario 1, data flows of steps 13–24.

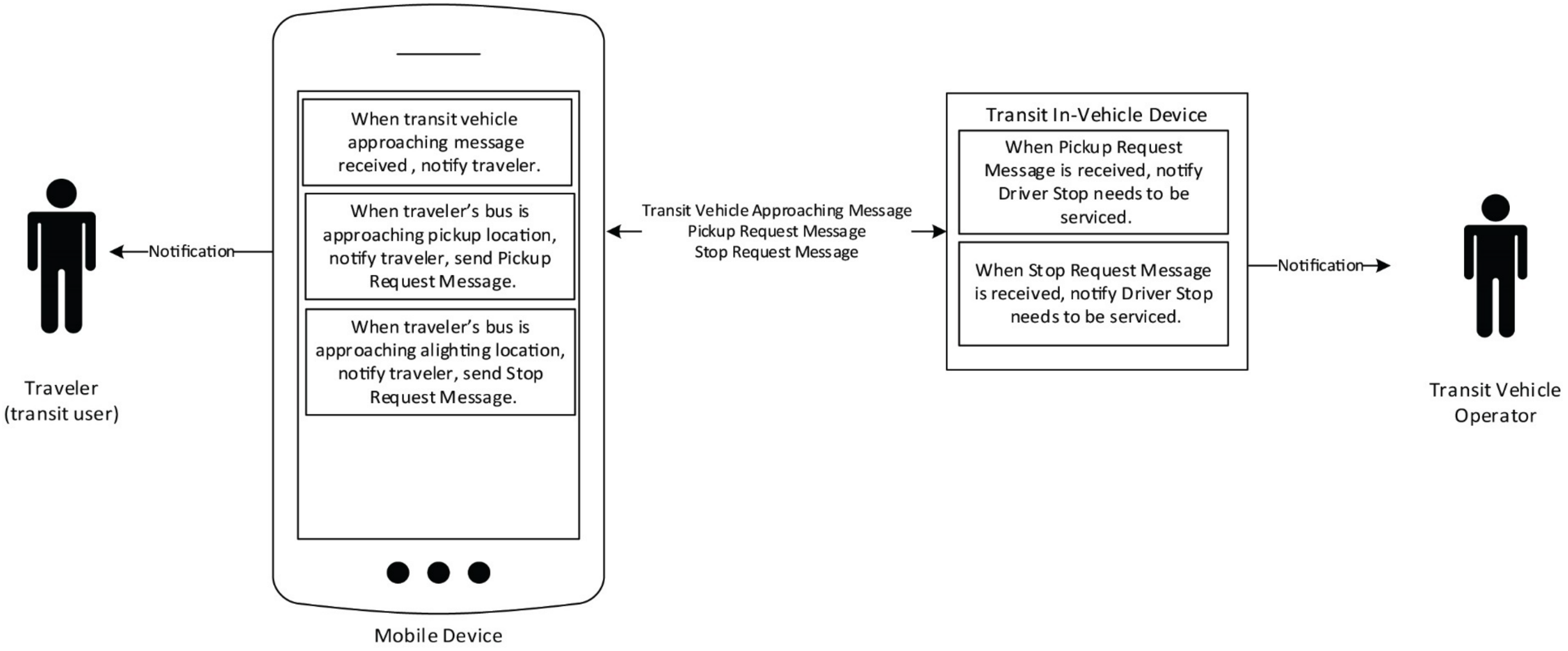
Table 19. Use Case 3—Scenario 1, steps 13–24.

Source	Step	Key Action	Comments
Traveler	13	Places mobile device near payment terminal.	Traveler has not used the transit payment system before.
Mobile device	14	Sends payment account registration message to transit payment system.	The payment account registration message contains the following content: • Payment account information: o Account number: 1234567890123456. o Name: John Doe. o Payment billing address: 123 Main St. • Payee ID: 111222333 (corresponds to transit payment system). • Account activation period: 7 d. Note: The traveler would have previously entered payment information into the mobile device when it was initialized. If multiple payment options have been entered, the mobile device may prompt the traveler which payment method to use.
Transit payment system	15	Receives payment account registration message.	The transit payment system stores payment account information until the end of the account activation period.
Transit payment system	16	Authorizes payment method.	Payment method is authorized.

Source	Step	Key Action	Comments
Transit payment system	17	Sends payment account registration confirmation to mobile device.	The payment account registration confirmation message contains the following content: • Payee ID: 111222333 (corresponds to transit payment system). • Payment status: authorized. • Account ID: 1A2B3C4D5E. • Account activation period: 7 d. Payee ID and account ID would be used in the payment user ID message for all trips taken using the transit agency during the account activation period (7 d). This activation period limits the number of times account information needs to be exchanged.
Mobile device	18	Sends a stop request message to the transit vehicle 1 in-vehicle device.	This message may be communicated from the mobile device to the bus directly or via a transit management center. The stop request message contains the following content: • Service provider ID: 12. • Route ID: 8. • Stop ID: 8898. • Require kneel: No. • Require ramp: No.
Transit vehicle 1	19	Continues along its route. The mobile device provides an indication of how close the traveler is to their destination stop.	N/A
Mobile device	20	Provides an output (audio and visual) to the traveler that indicates that they are approaching their stop: "Prepare to exit bus to stay on planned itinerary."	N/A

Source	Step	Key Action	Comments
Transit vehicle 1 in-vehicle device	21	Provides an output to the bus driver to indicate that a passenger needs to get off the bus at the next stop: "Drop off passenger at stop 8898."	The bus driver is notified as the bus passes the stop immediately before the traveler's planned stop.
Transit vehicle 1	22	Stops at the designated stop.	N/A
Mobile device	23	Provides an output (audio and visual) that confirms that the traveler should get off at this stop: "Exit bus here to stay on planned itinerary."	N/A
Traveler	24	Exits transit vehicle 1 and proceeds onward toward destination.	N/A

To complete this scenario, six characteristics are included, along with a system diagram capturing the four sources included in the scenario, as shown in figure 22.



Source: FHWA.

Figure 22. Diagram. Use Case 3—Scenario 1, four sources.

The following characteristics complete Use Case 3—Scenario 1:

- **Postconditions—**The mobile device would improve the traveler's ability for wayfinding (approaching transit vehicle information, information regarding when to board/exit transit vehicle, and signal information). The transit vehicle operator would become more aware of the traveler waiting at the stop and the traveler's intent to board the transit vehicle.

- **Messages—**The message types would include transit vehicle approaching messages, pickup request messages, stop request messages, and PSMs.

- **Traceability—**The following user needs would apply to this scenario:

    - Transit UN3—Approaching Transit Vehicle Information.
    - Transit UN4—Board/Alight Notification.
    - Transit UN8—Transit Wayfinding and Navigation.

- **Mobile device inputs summary—**Inputs would include time and location (from GNSS) and transit vehicle approaching messages (from transit vehicle in-vehicle equipment).

- **Mobile device—**The mobile device would send pickup request messages (to transit vehicle in-vehicle equipment) and stop request messages (to transit vehicle in-vehicle equipment).

- **Outputs summary—**Outputs would include audio/visual/haptic notifications to the traveler, such as "bus approaching" or "exit bus at next stop."

Use Case 3—Scenario 2

Use Case 3—Scenario 2 describes a traveler using public transit while using a connected mobile device. This scenario is identified and titled "UC3-S2: Transit En route Adjustment (Same Mode)" with the following characteristics:

- **Short description—**A traveler (transit user) uses a mobile device to find a better route to navigate to their destination after the first leg of a two-leg transit trip is delayed.

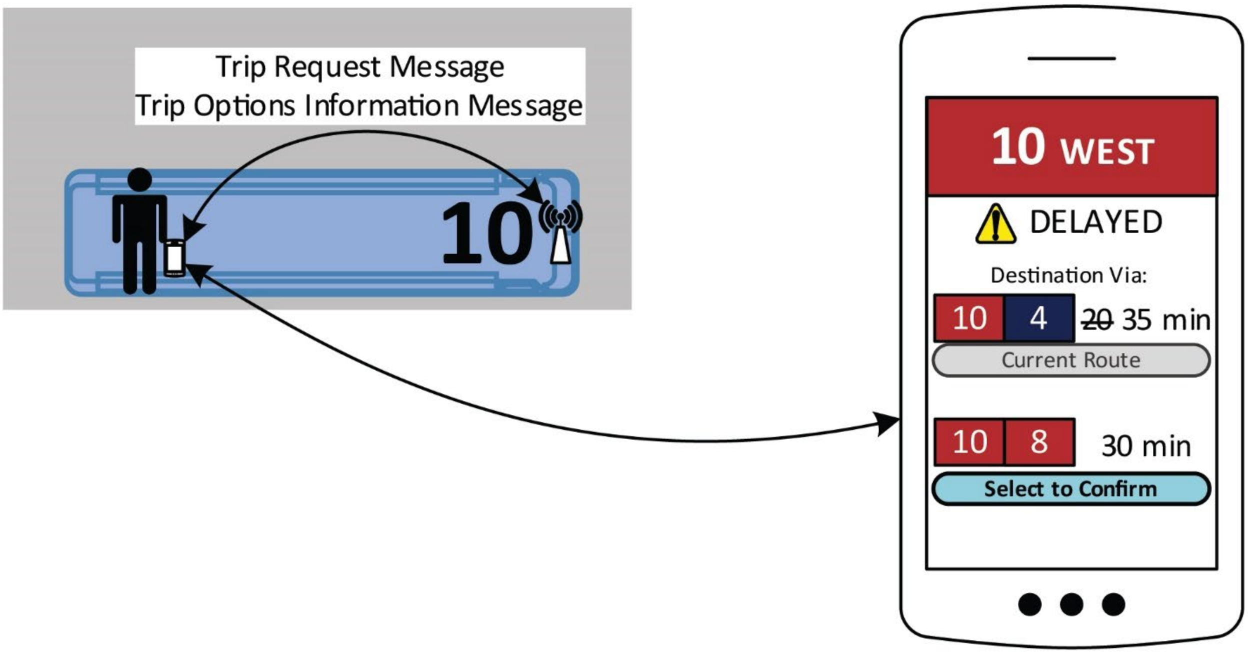
- **Scenario objective—**To demonstrate the ability of the mobile device to provide an en route adjustment (alternative route).

- **Operational event(s)—**The functioning-related events would take place in the following order:

    - The mobile device would periodically assess progress along the planned route (using an MMTP) to determine whether there is a more efficient route.
    - The mobile device would send a notification to the traveler when a more efficient route becomes available.

- **Preconditions**—A traveler (transit user) would use a mobile device to plan a trip from home to downtown. The trip would consist of two legs—both legs are different routes on the same transit system, but unforeseen congestion would cause a delay on the first leg. The trip would take place in a region where the transit network runs many parallel routes to accommodate regional needs. The traveler would indicate (i.e., provide input to the mobile device) that they prefer to use only transit to complete their trip.
- **Traveler actor role**—The traveler would navigate the planned itinerary safely and successfully.
- **Mobile device actor role**—The mobile device would provide relevant wayfinding information to the traveler (based on the location of the mobile device in the transportation environment) and send and receive messages that enable the traveler's needs to be met.
- **Transit vehicle in-vehicle device actor role**—The in-vehicle device would release a transit vehicle approaching message and alert the transit vehicle operator when a stop must be serviced.
- **Transit vehicle operator actor role**—The transit vehicle operator would service the transit vehicle stops and monitor their surroundings for safety.

The scenario then describes key actions and the flow of events of four sources: traveler, transit vehicle, mobile device, and MMTP service. Figure 23 and table 20 describe steps 1 through 16 of this scenario.



Source: FHWA.

Figure 23. Diagram. Use Case 3—Scenario 2, steps 1–16.

Table 20. Use Case 3—Scenario 2, steps 1–16.

Source	Step	Key Action	Comments
Traveler	1	Boards transit vehicle 1.	The traveler has an itinerary connecting to another bus line. The itinerary, based on real-time transit data, anticipates a 5-min window for the traveler to make the connection.
Transit vehicle	2	Encounters unexpected congestion along the route.	This congestion adds 10 min to the transit vehicle's typical travel time.
Mobile device	3	Continuously evaluates the traveler's progress along the selected itinerary.	As the bus sits in traffic, the mobile device compares the position of the bus against the anticipated position in the selected itinerary.
Mobile device	4	Determines that the traveler would miss the connection as planned in the selected itinerary.	Once the bus falls 5 min behind schedule of the planned itinerary, the mobile device determines that the connection cannot be reliably made.
Mobile device	5	Begins to assess alternative routes to get to the selected destination.	Utilizes the MMTP service.
Mobile device	6	Sends MMTP trip request to MMTP service.	The MMTP trip request message contains the following content: • Trip ID: 2468. • Origin (lat/long or address). • In vehicle: yes: o Service provider ID: 12. o Vehicle ID: 2346. • Destination (lat/long or address). • Preferences. • Mode: bus.
MMTP service	7	Receives trip request.	N/A
MMTP service	8	Evaluates potential options based on traveler preferences.	The MMTP service provides traveler preferences, including mode, travel time, trip cost, and maximum walking distance.

Source	Step	Key Action	Comments
MMTP service	9	Sends MMTP trip options information back to the mobile device.	The MMTP trip options information message contains the following content for trip ID 2468: • Route ID: 1 (selected route). o Polyline (of route). o Total duration: 35 min. o Total cost: $2.00. o Leg: 1: • Mode: transit. • Start location: ▪ Lat/long: 39.9601, −83.0170. ▪ Descriptive name: N/A. ▪ Stop ID: N/A. • End location: ▪ Lat/long: 39.9619, −83.0027. ▪ Descriptive name: Broad St. at Front St. ▪ Stop ID: 7890. • Service provider ID:12. • Route ID: 10. • Vehicle ID: 2346. • Cost: $2.00. • Travel duration: 3 min; wait duration: N/A.

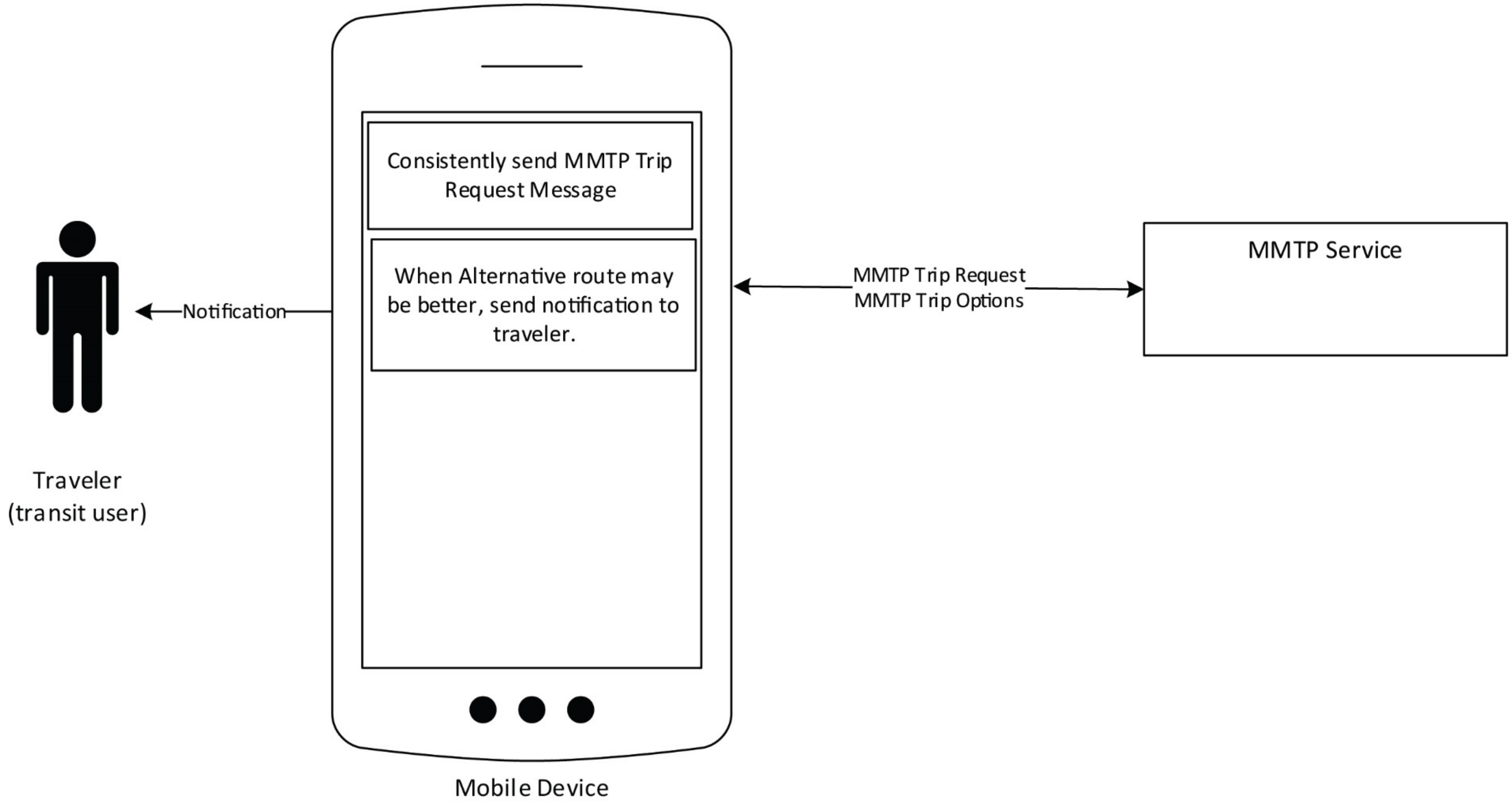
Source	Step	Key Action	Comments
MMTP service	9	Sends MMTP trip options information back to the mobile device.	• Route ID: 1 (selected route). o Leg: 2: • Mode: walk (transfer). • Start location: ▪ Lat/long: 39.9619, −83.0027. ▪ Descriptive name: Broad St. at Front St. ▪ Stop ID: N/A. • End location: ▪ Lat/long: 39.96177, −83.0024. ▪ Descriptive name: Front St. at Broad St. ▪ Stop ID: N/A. • Distance: 0.1 mi. • Travel duration: 1 min. • Wait duration: 15 min. o Leg: 3: • Mode: transit. • Start location: ▪ Lat/long: 39.96177, −83.0024. ▪ Descriptive name: Front St. at Broad St. ▪ Stop ID: 8000. • End location: ▪ Lat/long: 39.96186, −83.0012 ▪ Descriptive name: Parsons Ave. at Gates St. ▪ Stop ID: 8210. • Service provider ID: 12. • Route ID: 4. • Vehicle ID: 2400. • Cost: $2.00. • Distance: 3 mi. • Travel duration: 16 min; wait duration: N/A.

<table>
<tr><th>Source</th><th>Step</th><th>Key Action</th><th>Comments</th></tr>
<tr><td>MMTP service</td><td>9</td><td>Sends MMTP trip options information back to the mobile device.</td><td>• Route ID: 2 (new route).
○ Polyline (of route).
○ Total duration: 30 min.
○ Total cost: $2.00.
○ Leg: 1:
• Mode: transit.
• Start location:
▪ Lat/long: 39.9601, −83.0170.
▪ Descriptive name: N/A.
▪ Stop ID: N/A.
• End location:
▪ Lat/long: 39.9624, −82.9975.
▪ Descriptive name: Broad St. at Third St.
▪ Stop ID: 7892.
• Service provider ID:12.
• Route ID: 10.
• Vehicle ID: 2346.
• Cost: $2.00.
• Travel duration: 5 min.
• Wait duration: N/A.</td></tr>
</table>

Source	Step	Key Action	Comments
MMTP service	9	Sends MMTP trip options information back to the mobile device.	• Route ID: 2 (new route). o Leg: 2: • Mode: walk (transfer). • Start location: ▪ Lat/long: 39.9624, −82.9975. ▪ Descriptive name: Broad St at Third St. ▪ Stop ID: N/A. • End location: ▪ Lat/long: 39.96208, −82.9980. ▪ Descriptive name: Third St. at Broad St. ▪ Stop ID: N/A. • Distance: 0.1 mi. • Travel duration: 2 min. • Wait duration: 4 min. o Leg: 3: • Mode: transit. • Start location: ▪ Lat/long: 39.96208, −82.9980. ▪ Descriptive name: Third St. at Broad St. ▪ Stop ID: 8100. • End location. ▪ Lat/long: 39.96186, −83.0012 ▪ Descriptive name: Parsons Ave. at Gates St. ▪ Stop ID: 8210. • Service provider ID: 12. • Route ID: 4. • Vehicle ID: 2500. • Cost: $2.00. • Distance: 3 mi. • Travel duration: 19 min; wait duration: N/A.

Source	Step	Key Action	Comments
Mobile device	10	Receives trip options information from the MMTP service.	N/A
Mobile device	11	Determines there is another route that the traveler can take to get to their destination faster.	The mobile device compares the alternate route to using the planned transfer point but waiting for the next bus along the connecting line.
Mobile device	12	Presents alternative trip information to the traveler. Prompts the traveler to select a new route or stay on the current route.	The mobile device compares the travel time, modes, and cost of the alternatives against the current itinerary. Note: It may be possible that the fastest travel time would be to wait for the next connecting bus at the same transfer point as the original itinerary. However, there may be an alternative route or modes for the traveler to take that they would not have considered or known about previously.
Traveler	13	Selects the new route.	N/A
Mobile device	14	Begins to provide navigation guidance along the newly selected route.	N/A
Mobile device	15	Continuously evaluates the traveler's progress along the newly selected itinerary.	Neither the original bus nor the connecting bus on the newly selected itinerary experience any further delays. Therefore, the mobile device does not need to utilize the MMTP service to evaluate alternative routes.
Traveler	16	Makes the planned connection and arrives at the destination.	N/A

To complete this scenario, six characteristics are included, along with a system diagram capturing the sources included in the scenario, as shown in figure 24.



Source: FHWA.

Figure 24. Diagram. Use Case 3—Scenario 2, sources.

The following characteristics complete Use Case 3—Scenario 2:

- **Postconditions—**The mobile device would provide the traveler with timely alternative route information that allows the traveler to arrive at the destination sooner than they would have while waiting for the next connecting bus on the originally planned route.

- **Messages—**The message types would include trip request messages, trip options messages.

- **Traceability—**The following user needs would apply to this scenario:

    - Transit UN1—Continuous Efficient Route Check.
    - Transit UN2—Trip Planning Service Access.

- **Mobile device inputs summary—**Inputs would include MMTP options (from travelers), select trip options (from travelers), and trip options messages (from the MMTP service).

- **Mobile device—**The mobile device would send trip request messages (to the MMTP service).

- **Outputs summary—**Outputs would include audio/visual notifications to the traveler about alternative trip information.

Use Case 3—Scenario 3

Use Case 3—Scenario 3 describes a traveler using public transit while using a connected mobile device. This scenario is identified and titled "UC3-S3: Transit Connection Protection" with the following characteristics:

- **Short description—**A traveler (transit user) would use a mobile device to confirm they are taking a transit trip. The transit agency servicing this trip would use the confirmation to provide connection protection after the first leg of a two-leg transit trip is delayed.

- **Scenario objective—**To demonstrate the ability of the mobile device to enable connection protection.

- **Operational Event(s)—**The operational events would take place in the following order:

    - The mobile device would send a confirmed route itinerary to the transit management system.
    - When the route servicing the traveler's first leg is delayed, the transit agency would enable connection protection for the connecting leg and update its real-time transit data to reflect this delay.
    - The mobile device would periodically assess progress along the planned route (using an MMTP service) to determine whether there is a more efficient route.
    - The mobile device would not modify the traveler's itinerary because of the connection protection implementation.

- **Preconditions—**A traveler (transit user) would use a mobile device to plan a trip from home to downtown. The trip would consist of two legs—both legs are different routes on the same transit system—but unforeseen congestion causes delay on the first leg. The trip would take place in a region where transit service is less frequent and connections between multiple routes are strategically planned to enable connectivity.

- **Traveler actor role**—The traveler would navigate the planned itinerary safely and successfully.

- **Mobile device actor role**—The mobile device would provide relevant wayfinding information to the traveler (based on the location of the mobile device in the transportation environment) and send and receive messages that enable the traveler's needs to be met.

- **Transit vehicle in-vehicle device actor role**—The in-vehicle device would release a transit vehicle approaching message and alert the transit vehicle operator when a stop must be serviced.

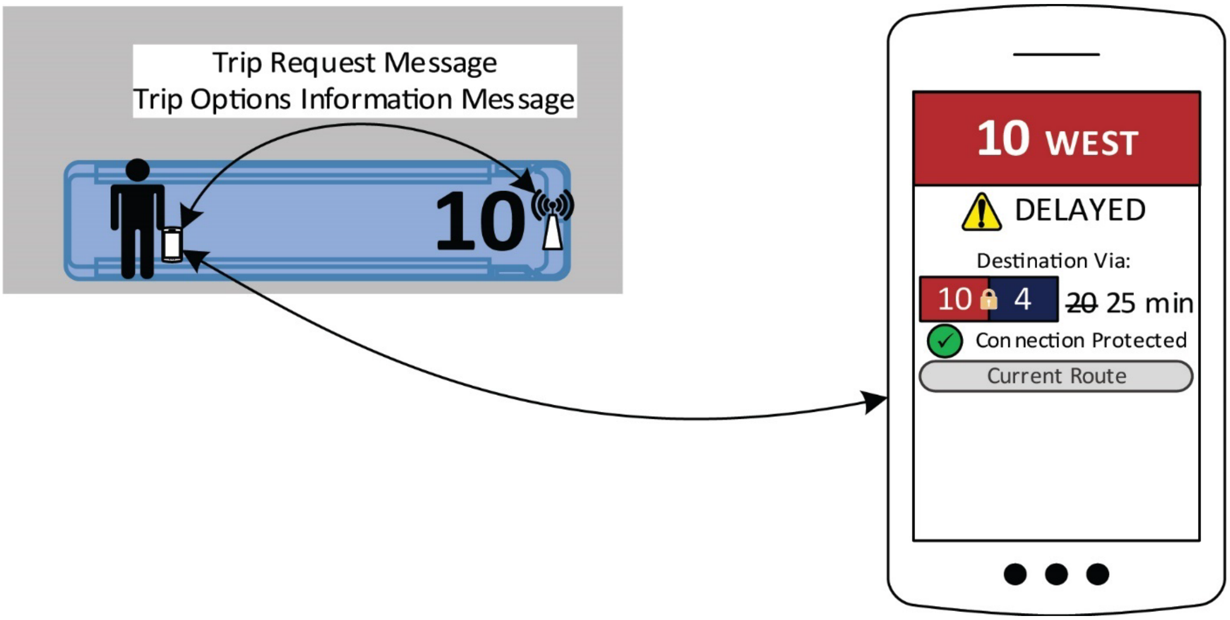
- **Transit vehicle operator actor role**—The transit vehicle operator would service transit vehicle stops and monitor their surroundings for safety.

- **Nearby vehicle in-vehicle device actor role**—The in-vehicle device would receive pedestrian location and heading and alert the driver as necessary.

- **Driver actor role**—The driver would operate the vehicle safely and react to alerts from the in-vehicle device.

- **Pedestrian signal actor role**—The pedestrian signal would control traffic and pedestrian movements at the intersection and exchange messages that allow a mobile device to request a pedestrian phase.

The scenario then describes key actions and the flow of events of eight sources: traveler, transit vehicle, mobile device, MMTP service, transit management center, transit management agency, transit vehicle 1, and transit vehicle 2. Table 21 describes steps 1 through 28 of this scenario, with greater detail shown in figure 25 of steps 15–20.



Source: FHWA.

Figure 25. Diagram. Use Case 3—Scenario 3, steps 15–20.

Table 21. Use Case 3—Scenario 3, steps 1–28.

Source	Step	Key Action	Comments
Traveler	1	Starts a transit trip.	The traveler uses a trip planner to find a suitable transit route from their current location to their destination.
Traveler	2	Opens the trip planning application on the mobile device and enters trip details.	The traveler provides trip details, including origin (automatically populated with current location), destination, preferred mode, and so forth.
Mobile device	3	Sends an MMTP trip request message to the MMTP service.	N/A
MMTP service	4	Receives trip request.	N/A
MMTP service	5	Evaluates potential options based on traveler preferences.	N/A
MMTP service	6	Sends trip options information back to the transit management center.	If a publicly available communications network will be used to facilitate the connection between the mobile device and the MMTP service, then the MMTP service can capture the trip options easily (in accordance terms of use established for utilizing the network). Otherwise, this step will require an established relationship between the MMTP service and the transit management center or driver incentivization through a reduction in fare or another incentive (such as connection protection).
MMTP service	7	Sends MMTP trip options information back to the mobile device.	N/A
Mobile device	8	Receives trip options information from the MMTP service.	N/A
Mobile device	9	Presents transit route information to the traveler. Prompts the traveler to select the route and begin navigation.	The mobile device shows the selected route, which includes a single transfer.
Traveler	10	Confirms route by using a mobile device.	N/A

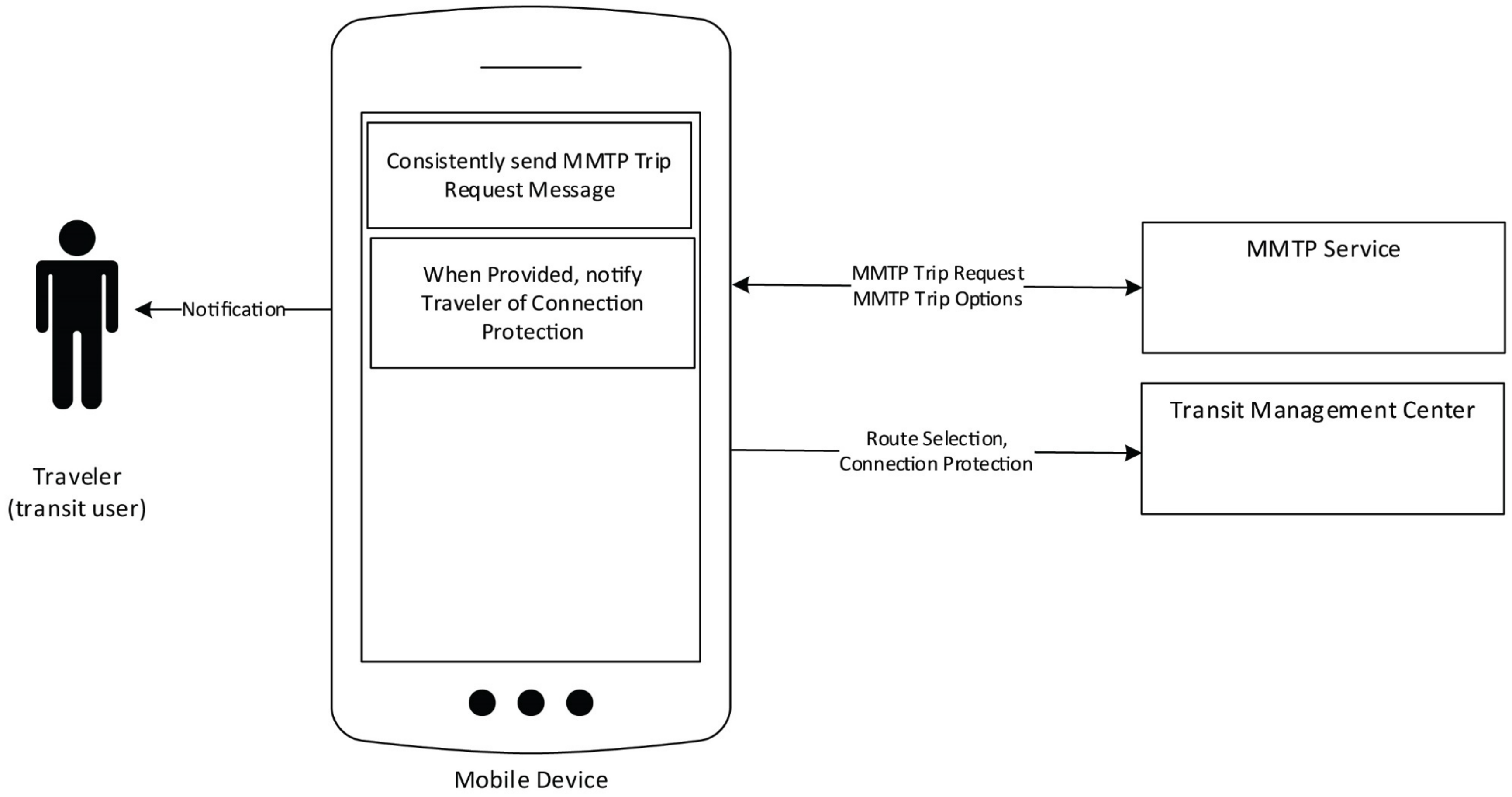
Source	Step	Key Action	Comments
Mobile device	11	Begins to provide navigation instructions to the traveler.	The mobile device is presumably in a location where it can be easily seen and heard by the traveler, such as in the traveler's hand, pocket, or backpack. The traveler may be using headphones to make it easier to hear audio outputs from the mobile device.
Mobile device	12	Sends confirmation of route choice to the transit management center.	N/A
Transit management center	13	Receives route choice data.	The transit management center uses route choice confirmation to enable connection protection for this trip. The transit management center may require a certain minimum number of requested connections before providing connection protection. Note: The transit management agency would take the itinerary information and uses it for management activities (e.g., dynamic transit operations, connection protection) that are available to the managing agency. The archived data could be used for long-term planning studies, O/D studies, and transit demand to influence route design and choice.
Traveler	14	Onboard transit vehicle 1.	The traveler uses the itinerary to make a connection to another bus line. The itinerary, which is based on real-time transit data, anticipates a 5-min window for the traveler to make the connection.
Transit vehicle	15	Encounters unexpected congestion along the route.	This congestion adds 10 min to the transit vehicle's typical travel time.
Transit management agency	16	Continuously evaluates the progress of the two buses.	As the bus (first leg) sits in traffic, the transit management agency compares its position against its anticipated position.
Transit management agency	17	Determines that the traveler will miss the connection as planned in the selected itinerary.	Once the bus falls 5 min behind schedule of the planned itinerary, the transit management agency determines that the connection cannot be reliably made.

Source	Step	Key Action	Comments
Transit management agency	18	Sends a notification to the transit vehicle (second leg) to wait until a specified time (after the bus servicing the first leg arrives).	The transit management agency intermittently evaluates the progress of the transit vehicle (first leg) and provides updates to the transit vehicle (second leg). The transit management agency may decide not to provide connection protection if the amount of time the transit vehicle (second leg) would have to wait exceeds a certain threshold. Note: The transit agency would update the "connection protection" status of the transit vehicle (second leg) in its real-time transit feed.
Mobile device	19	Continuously receives real-time transit data and evaluates the traveler's progress along the selected itinerary.	N/A
Mobile device	20	Updates the traveler regarding the trip status.	The mobile device indicates that connection protection would be provided for the next transfer and updates the anticipated arrival time to reflect the delay.
Transit vehicle 1	21	Continues along route.	N/A
Transit vehicle 2	22	Arrives at connection stop.	Transit vehicle 2 stops and waits for transit vehicle 1 to arrive to the connecting stop.
Transit vehicle 1	23	Arrives at connection stop.	No further delays are experienced.
Traveler	24	Alights transit vehicle 1, navigates to transit vehicle 2, and boards transit vehicle 2.	N/A
Transit vehicle 2	25	Leaves the connection stop after all passengers have made transfer.	The transit management agency may also provide the number of passengers making transfer to ensure that the transit vehicle operator knows that all transferring passengers are accounted for.

Source	Step	Key Action	Comments
Transit vehicle 2	26	Continues to service the trip of the traveler	N/A
Mobile device	27	Continuously evaluates the traveler’s progress along the newly selected itinerary.	Neither the bus nor the connecting bus on the newly selected itinerary experience any further delays.
Traveler	28	Arrives at destination.	N/A

O/D = origin-destination.

To complete this scenario, six characteristics are included, along with a system diagram capturing the sources included in the scenario, as shown in figure 26.



Source: FHWA.

Figure 26. Diagram. Use Case 3—Scenario 3, sources.

The following characteristics complete Case 3—Scenario 3:

- **Postconditions—**The traveler makes the planned connection and arrives at their destination slightly delayed. The transit management agency executes a connection protection holdover for Transit Vehicle 2 to allow the traveler to make the connection—effectively accounting for the late arrival of Transit Vehicle 1.

- **Messages—**The message types would include trip request messages and trip options information message.

- **Traceability—** The following user needs would apply to this scenario:

  - Transit UN1—Continuous Efficient Route Check.
  - Transit UN2—Trip Planning Service Access.
  - Transit UN5—Connection Protection.

- **Mobile device inputs summary—**Inputs would include MMTP options (from travelers) and trip options information messages (from the MMTP service).

- **Mobile device—**The mobile device would send trip request messages (to the MMTP service).

- **Outputs summary—**Outputs would include audio/visual notifications to the traveler about connection protection.

Use Case 3—Scenario 4

Use Case 3—Scenario 4 describes a traveler using public transit while using a connected mobile device. This scenario is identified and titled "UC3-S4: Transit En route Adjustment (Alternative Mode)" with the following characteristics:

- **Short description—**A traveler (transit user) would use a mobile device to find a better route to navigate to destination after the first leg of a transit trip is delayed.

- **Scenario objective—**To demonstrate the ability of the mobile device to provide an en route adjustment (alternative mode).

- **Operational event(s)—**The operational-related events would take place in the following order:

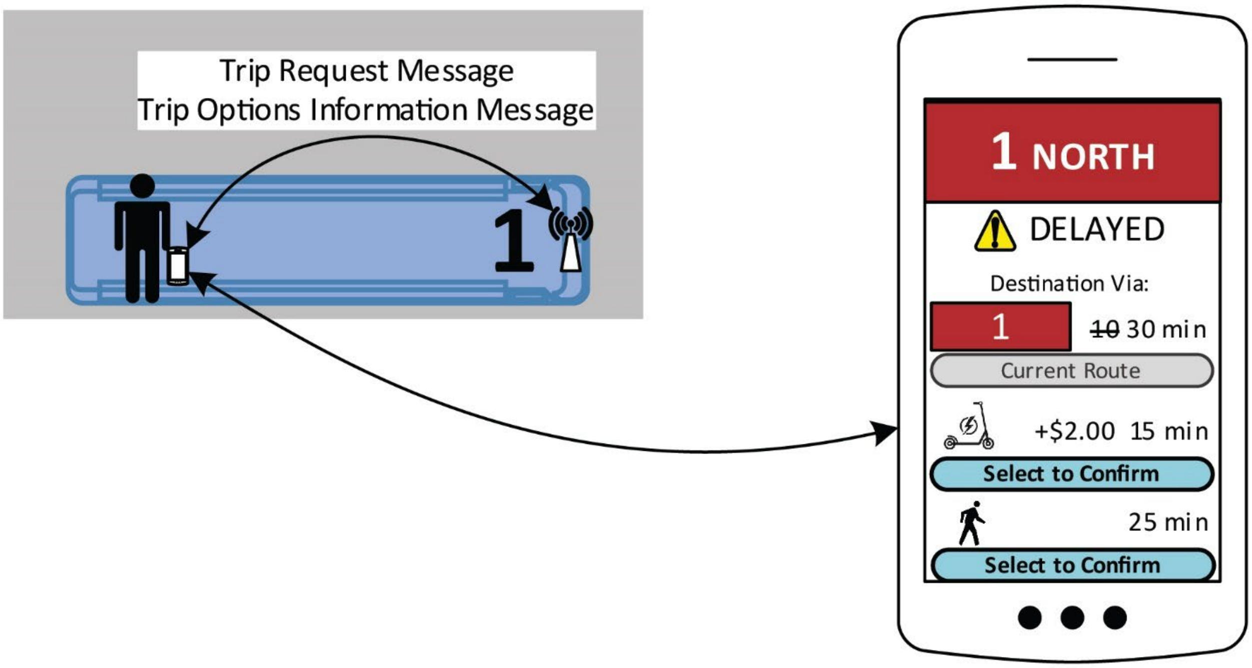
  - The mobile device would periodically assess progress along the planned route (using an MMTP service) to determine whether there would be a more efficient route.
  - The mobile device would send a notification to the traveler when a more efficient route becomes available.

- **Preconditions**—The traveler (transit user) would use a mobile device to plan a trip from home to downtown. The trip would consist of a single transit leg, but unforeseen congestion causes delay. The traveler would have indicated (provided input to the mobile device) that they would prefer to use transit, bikeshare, and shared electric scooters to complete their trip.

- **Traveler actor role**—The traveler would navigate the planned itinerary safely and successfully.

- **Mobile device actor role**—The mobile device would provide relevant wayfinding information to the traveler (based on the location of the mobile device in the transportation environment) and send and receive messages that enable the traveler's needs to be met.

The scenario then describes key actions and the flow of events of six sources: traveler, transit vehicle, mobile device, MMTP service, transit management center, and transit management agency. Table 22 describes steps 1 through 51 of this scenario with greater detail shown in figure 27 of steps 17–26.



Source: FHWA.

Figure 27. Diagram. Use Case 3—Scenario 4, steps 17–26.

Table 22. Use Case 3—Scenario 4, steps 1–51.

Source	Step	Key Action	Comments
Traveler	1	Starts a transit trip.	The traveler uses a trip planner to find a suitable transit route from their current location to their destination.
Traveler	2	Opens a trip planning application on a mobile device and enters the trip details.	The trip details include origin (automatically populated with current location), destination, preferred mode, and so forth.
Mobile device	3	Sends an MMTP trip request message to the MMTP service.	N/A
MMTP service	4	Receives trip request.	N/A
MMTP service	5	Evaluates potential options based on traveler preferences.	N/A
MMTP service	6	Sends trip options information back to the transit management center.	If a publicly available communications network will be used to facilitate the connection between the mobile device and the MMTP service, then the transit management center can easily capture the trip options (in accordance with terms of use established for utilizing the network). Otherwise, this step will require an established relationship between the MMTP service and the transit management center or driver incentivization through a reduction in fare or other incentives (such as connection protection).
MMTP service	7	Sends the MMTP rip options information back to mobile device.	N/A
Mobile device	8	Receives trip options information from MMTP service.	N/A
Mobile device	9	Presents transit route information to the traveler. Prompts the traveler to select the route and begin navigation.	The mobile device shows the selected route, which includes a single transfer.
Traveler	10	Confirms route by using mobile device.	N/A

Source	Step	Key Action	Comments
Mobile device	11	Begins to provide navigation instructions to the traveler.	The mobile device is presumably in a location where it can be easily seen and heard by the traveler, such as in the traveler's hand, pocket, or backpack. The traveler may be using headphones to make it easier to hear audio outputs from the mobile device.
Mobile device	12	Sends confirmation of route choice to the transit management center.	The route choice confirmation message contains the following content: • Trip ID. • Route ID.
Transit management center	13	Receives route choice data.	The transit management agency uses route choice confirmation to enable connection protection for this trip. Note: The transit management center could require a certain minimum number of requested connections before providing connection protection. The transit management agency would take the itinerary information and use it for management activities (dynamic transit operations, connection protection, etc.) that would be available to the managing agency. Archived data could be used for long-term planning studies, O/D studies, and transit demand-influencing route design and choice.
Traveler	14	Onboard transit vehicle 1.	The traveler follows the itinerary to make a connection to another bus line. The itinerary, which is based on real-time transit data, anticipates a 5-min window for the traveler to make the connection.
Transit vehicle	15	Encounters unexpected congestion along the route.	This congestion adds 10 min to the transit vehicle's typical travel time.
Transit management agency	16	Continuously evaluates the progress of the two buses.	As the bus (first leg) sits in traffic, the transit management agency compare its current position against its anticipated position.

Source	Step	Key Action	Comments
Mobile device	17	Determines that the traveler will experience extreme delay on the current route.	N/A
Mobile device	18	Begins to assess alternative routes to get to the selected destination.	The mobile device utilizes the MMTP service to compare alternative routes.
Mobile device	19	Sends an MMTP trip request to the MMTP service.	The MMTP trip request message contains the following content: • Trip ID: 2468. • Origin (lat/long or address). • In vehicle: yes: o Service provider ID: 12. o Vehicle ID: 1010. • Destination (lat/long or address). • Preferences: o Mode: transit, shared scooter. o Accommodations: N/A. o Departure/arrival time: N/A. o Cost: N/A.
MMTP service	20	Receives trip request.	N/A
MMTP service	21	Evaluates potential options based on traveler preferences.	The traveler’s preferences include mode, travel time, trip cost, and maximum walking distance.
MMTP service	22	Sends MMTP trip options information back to the mobile device.	N/A

Source	Step	Key Action	Comments
MMTP service	22	Sends MMTP trip options information back to the mobile device.	The MMTP trip options information message contains the following content: • Route ID: 1 (selected route). • Trip ID: 2468: o Polyline (of route). o Total duration: 35 min. o Total cost: $2.00. o Leg: 1: • Mode: Transit. • Start location: ▪ Lat/long: 39.9705, −83.0022. ▪ Descriptive name: N/A. ▪ Stop ID: N/A. • End location: ▪ Lat/long: 40.0003, −83.0080. ▪ Descriptive name: High St. at 15th Ave. ▪ Stop ID: 7890. • Service provider ID: 12. • Route ID: 1. • Vehicle ID: 1010. • Cost: $2.00. • Travel duration: 25 min. • Wait duration: N/A.

Source	Step	Key Action	Comments
MMTP service	22	Sends MMTP trip options information back to the mobile device.	• Route ID: 1 (selected route). ○ Leg: 2: • Mode: walk (transfer). • Start location: ▪ Lat/long: 40.0003, −83.0080. ▪ Descriptive name: Broad St. at Front St. ▪ Stop ID: N/A. • End location: ▪ Lat/long: 40.0003, −83.0189. ▪ Descriptive name: N/A. ▪ Stop ID: N/A. • Distance: 0.25 mi. • Travel duration: 5 min. • Wait duration: N/A.

Source	Step	Key Action	Comments
MMTP service	22	Sends MMTP trip options information back to the mobile device.	• Route ID: 2 (new route): o Polyline (of route). o Total duration: 30 min. o Total cost: $2.00. o Leg: 1: • Mode: transit. • Start location: ▪ Lat/long: 39.9705, −83.0022. ▪ Descriptive name: N/A. ▪ Stop ID: N/A. • End location: ▪ Lat/long: 39.9727, −83.0025. ▪ Descriptive name: High St. at Spruce St. ▪ Stop ID: 7892. • Service Provider ID:12. • Route ID: 1. • Vehicle ID: 1010. • Cost: $2.00. • Travel duration: 3 min. • Wait duration: N/A.

Source	Step	Key Action	Comments
MMTP service	22	Sends MMTP trip options information back to the mobile device.	• Route ID: 2 (new route). o Leg: 2: • Mode: walk (transfer). • Start location: ▪ Lat/long: 39.9624, −82.9975. ▪ Descriptive name: Broad St. at Third St. ▪ Stop ID: N/A. • End location: ▪ Lat/long: 39.9722, −83.0039. ▪ Descriptive name: N/A. ▪ Stop ID: N/A. • Distance: 0.1 mi. • Travel duration: 2 min. • Wait duration: N/A. o Leg: 3: • Mode: shared scooter. • Start location: ▪ Lat/long: 39.9722, −83.0039. ▪ Descriptive name: N/A. ▪ Stop ID: N/A. • End location: ▪ Lat/long: 40.0003, −83.0189. ▪ Descriptive name: N/A. ▪ Stop ID: N/A. • Service provider ID: 18. • Route ID: N/A. • Vehicle ID: 614. • Cost: $2.00. • Distance: 2 mi. • Travel duration: 10 min.

Source	Step	Key Action	Comments
Mobile device	23	Receives trip options information from the MMTP service.	N/A
Mobile device	24	Determines that there is another mode the traveler can take to get to their destination faster.	The mobile device compares alternate modes to staying on the existing route.
Mobile device	25	Presents alternative trip information to the traveler. Prompts the traveler to select a new itinerary or stay on current route.	The mobile device shows the travel time, modes, and cost of the alternative route and compares that route against the current itinerary. Note: It could be possible that the fastest travel time would be to wait for the next connecting bus at the same transfer point as the original itinerary. However, there could be an alternative route or modes for the traveler to take that they would not have considered or known about previously.
Traveler	26	Selects the new route.	The traveler selects a route that requires them to get off bus at next stop and use a shared electric scooter to complete their trip.

Source	Step	Key Action	Comments
Mobile device	27	Sends a shared-use device reservation request to the shared-use device operations system.	The mobile device sends a reservation request that includes the traveler's account information. This scenario assumes the traveler has an active account with the shared-use device operations center. If the traveler does not have an active account, they will need to create one by using the payment account registration message and receiving a payment account registration confirmation. The shared-use device reservation request message contains the following content: • Account ID: 12345ABCDE. • Service provider ID (Payee ID): 777888999 (corresponds to the shared-use device operations). • Vehicle ID: 614. • Requested period: 5 min.
Shared-use device operations system	28	Receives the shared-use device reservation request from the mobile device.	The shared-use device operations system agrees to allow a "reserve" to be placed on a shared electric scooter for a predetermined period. The MMTP ensures that the traveler can navigate to the shared electric scooter during this predetermined period. Note: In a scenario where the shared-use device operations system does not accommodate reservations, the mobile device would continue to evaluate route options and provide the traveler with an updated route option if the availability of shared-use devices changes.
Shared-use device operations system	29	Sends the reservation to the shared electric scooter.	N/A

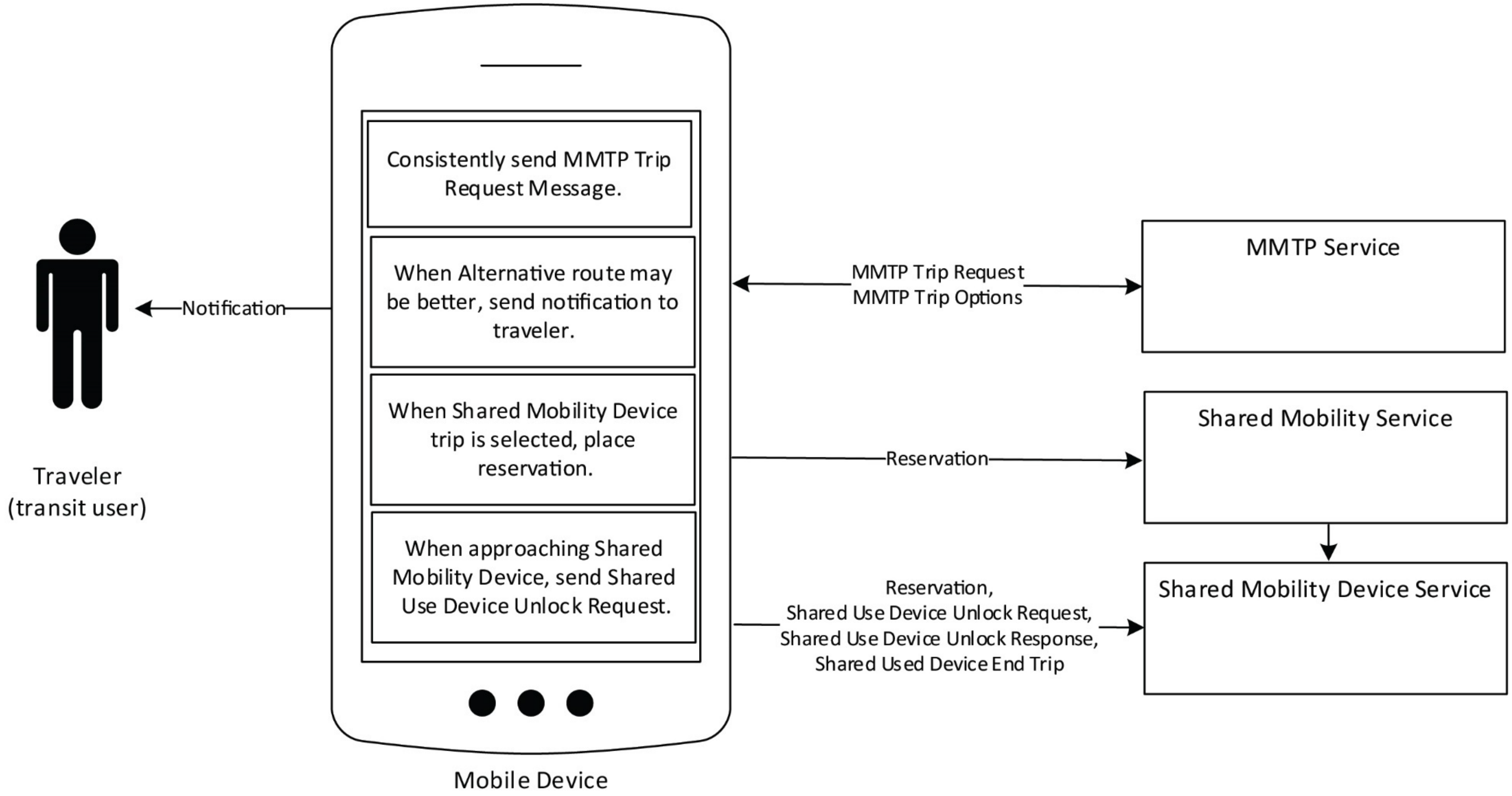
Source	Step	Key Action	Comments
Shared electric scooter	30	Receives the reservation.	N/A
Traveler 2	31	Locates the shared electric scooter 614 during the reserved period.	N/A
Traveler 2	32	Uses a mobile device to attempt to unlock the shared electric scooter.	In most cases, a traveler expects to use a mobile device to locate a shared electric scooter that has not been reserved and then reserve it for use. However, this scenario accounts for a case in which a traveler finds a shared electric scooter and decides to ride it before checking to see whether it is available.
Mobile device (traveler 2)	33	Sends a payment user ID message to the shared electric scooter.	The payment user ID contains the following content: • Payee ID: 777888999 (corresponds to toll payment system). • Account ID: ABCDE12345.
Shared electric scooter	34	Receives the payment user ID message from the mobile device.	The shared electric scooter determines that the account ID does not match the account ID of the reservation.
Shared electric scooter	35	Sends a payment user confirmation message back to traveler 2's mobile device to indicate that it is reserved.	The payment user confirmation message may include the amount of time left during the reservation period.

Source	Step	Key Action	Comments
Shared electric scooter	36	Sends a payment user confirmation message back to traveler 2's mobile device to indicate that it is reserved shared-use device unlock response message.	The payment user confirmation message may include the amount of time left during the reservation period. The shared-use device unlock response message contains the following content: • Payee ID: 777888999 (corresponds to shared-use device payment system). • Account ID: ABCDE12345. • User status: denied/reserved.
Mobile device (traveler 2)	37	Notifies traveler 2 that the shared electric scooter they are attempting to unlock has been reserved.	N/A
Traveler 2	38	Finds another scooter to reserve/use.	N/A
Mobile device	39	Continues to provide navigation instructions to the traveler. Notifies the traveler when they are approaching the stop.	N/A
Traveler	40	Alights the transit vehicle and navigates to the location of the shared electric scooter.	N/A
Mobile device	41	Determines that the traveler is near the shared electric scooter.	N/A
Mobile device	42	Prompts the traveler on whether they have identified the reserved shared electric scooter.	N/A
Traveler	43	Confirms that they have identified the shared electric scooter.	Traveler stands next to shared electric scooter.

Source	Step	Key Action	Comments
Mobile device	44	Sends a payment user ID message to the shared electric scooter.	The payment user ID message contains the following content: • Payee ID: 777888999 (corresponds to shared-use device payment system). • Account ID: 12345ABCDE.
Shared electric scooter	45	Receives the payment user ID message from the mobile device. Determines account ID matches the reservation and becomes unlocked.	N/A
Shared electric scooter	46	Sends a payment user confirmation message back to mobile device to indicate that it is unlocked.	The payment user confirmation message contains the following content: • Payee ID: 777888999 (corresponds to shared-use device payment system). • Account ID: 12345ABCDE. • User status: confirmed.
Mobile device	47	Receives an unlock indication.	N/A
Mobile device	48	Notifies the traveler that the shared electric scooter has been unlocked.	Notification: Unlocked—Ready for service. Ride safely.
Traveler	49	Receives notification and uses shared electric scooter to navigate to final destination.	N/A
Traveler	50	Arrives at final destination. Uses mobile device to indicate that they have completed the trip on the shared electric scooter.	N/A

Source	Step	Key Action	Comments
Mobile device	51	Sends shared-use device end trip message to the shared electric scooter.	The shared-use device end trip message contains the account ID: ABCDE12345. Alternatively, the traveler may use a physical button on the shared electric scooter to indicate the trip has ended.
Shared electric scooter	52	Receives an end trip message and sends this information to the shared-use device operations system.	N/A
Shared-use device operations system	53	Determines the total cost of the shared-mobility device trip.	The shared-use device operations system typically determines the cost of trip by using a fixed cost plus a per-minute usage rate. Note: The cost could include a discount if there is an agreement between the transit agency and scooter-share agency. For instance, if a cumulative usage is determined to be $2.00. The traveler's account would be charged.

To complete this scenario, six characteristics are included, along with a system diagram to capturing the sources included in the scenario, as shown in figure 28.



Source: FHWA.

Figure 28. Diagram. Use Case 3—Scenario 4, sources.

The following characteristics complete Use Case 3—Scenario 4:

- **Postconditions—**The traveler would use a mobile device to find a better route to navigate to the destination after the first leg of a transit trip is delayed.
- **Messages—**The message types would include trip request messages, trip options messages, route choice messages, shared-use device reservation request messages, and shared-use device end trip messages.
- **Traceability—**The following user needs would apply to this scenario:
    - Transit UN1—Continuous Efficient Route Check
    - Transit UN2—Trip Planning Service Access.
- **Mobile device inputs summary—**Inputs would include MMTP input (from travelers), trip options information messages (from the MMTP service), and shared-use device unlock response messaged (from a shared-use device).
- **Mobile device—**The mobile device would send trip request messages (to the MMTP service), route choice messages (to MMTP), shared-use device reservation request message (to the share-use device operations system), shared-use device unlock requests (to a shared-use device), and shared-use device end trip message (to a shared-use device).
- **Outputs summary—**Outputs would include audio/visual notifications to the traveler about alternative trip information.

CHAPTER 11. CONCEPT 4: TRAVELER RIDING IN A MOTOR VEHICLE USING A CONNECTED MOBILE DEVICE

CHAPTER OVERVIEW

This chapter is the final of four chapters that develop an example concept to showcase how mobile devices and electronic messages can be used to satisfy traveler needs. The concept in this chapter focuses on addressing an example set of needs for drivers using a mobile device. Through these example concepts, the reader can begin to understand the content included in a typical ConOps. A description specific to the concept is provided and walks through existing conditions, justification for changes, description of desired changes, operational policies and constraints, description of proposed operating environment, modes of operation, user classes, support environment, and operational scenarios. These example concepts begin to shape a system that enables the exchange of electronic messages with mobile devices to satisfy the needs of different types of travelers.

EXISTING CONDITIONS

Toll facilities require travelers to pay to use a roadway. Some toll facilities have physical toll booths that allow a driver to stop and pay with cash or credit. These types of facilities are slowly falling out of favor because of their high O&M costs. Other tolls facilities provide electronic toll collection, which requires the driver to have a transponder in their vehicle. The transponder has an identifying feature that can be linked to the traveler's personal information and payment information. Travelers use an online tool to maintain a balance on the account that is deducted as the traveler passes through toll facilities. Toll agencies are using toll-by-plate, an increasingly popular method by which toll agencies collect payment on facilities that do not have physical toll booths but that want to accommodate travelers who do not have electronic toll accounts (i.e., drivers who do not typically use the toll facility).

Toll amounts are typically provided to the traveler on physical signage along the roadway. Tolls for some facilities are static (i.e., they never change), some tolls vary by time of the day or day of the week, and other tolls vary based on mitigating demand to use the facility (i.e., high-occupancy toll (HOT) express lanes). Facilities with variable tolls should use physical signage to ensure that the proper cost to use the facility is displayed to the traveler. This signage is typically limited to displaying two or three toll amounts (to different exit points along the facility) to avoid overburdening the driver with information. In some instances, the travel times/speeds are displayed in advance of a toll facility to give the driver time to decide whether it is worth the cost of using the toll facility. Most toll agencies make tolling data publicly available via the toll agency's website, but these data may not be easily accessible during a trip.

Other types of signage are also located along a freeway to provide information about navigating the roadway network (primarily green/white signage), regulatory information (white/black/red signage), and warning information (yellow/black signage). A lot of thought and effort goes into the placement of this signage to account for the variable needs of many roadway users.

In complex segments of the roadway network, roadway engineers should avoid overloading the driver with too much information and locate signage far enough upstream of various decision points along the roadway to ensure that drivers who need that information have enough time to properly react to it, and this is true for toll information as well. If is common for signage along freeways to provide tolling information for express lanes. Because this signage can provide limited information (to reduce information overload to drivers), it may be difficult for the driver to ascertain the actual cost of the toll for their trip. Similarly challenging, existing route planning tools do not always have access to real-time toll information, leaving the traveler with unknowns.

Loop detector and video detection systems allow vehicle counts and speeds to be collected. Toll facilities that utilize toll transponders and overhead detection gantries can detect the movement of vehicles that have transponders as they pass through the toll facility. The more frequent the placements of the gantries, the more detailed information that can be discerned about movements that occur on the roadway.

JUSTIFICATION FOR CHANGES

Several aspects of the current conditions of the roadway environment could warrant the addition of technology to enable communication to and from mobile devices. These aspects are discussed in detail in the following subheaders.

Driving Wayfinding

The placement and use of static signage and dynamic signage along roadways is typically governed by the MUTCD.(10) Many States tailor the MUTCD to create a State-specific version, whereas some States use the Federal version. The concept of providing drivers with appropriate information about hazards and inefficiencies at strategic locations and times is known as positive guidance. The goal is to utilize knowledge rooted in human factors and traffic engineering to improve highway safety and operations.

One of the biggest drawbacks of the MUTCD (and the use of static signs and DMSs in general) is that they are unable to account for the speed at which a traveler is moving when they encounter a sign.(10) The placement of these signs depends on the amount of time it takes a driver to cover a given distance based on an expected speed and acceleration of the vehicle. However, if the vehicle is moving at a speed that is greater than the speed limit, then the driver will have less time than the engineers intended to react to that sign. Alternatively, at slower speeds, there may be too much time, resulting in expectancy issues. Ideally, signage information is displayed to the driver at a time and location that corresponds to their current speed. Another drawback of static signage and DMSs is that drivers may have to read and interpret information that may apply to them.

Provision of Toll Facility Information and Payment

Regulatory signs at managed lanes and toll facilities should address pricing, vehicle eligibility, hours of service, and possibly enforcement. However, the potential for information overload is greater with guidance signs, especially if a complex operational strategy is in place. The information shown on these signs must account for the various conditions under which a driver could arrive to the facility. Toll agencies maintain a matrix of tolling information for every allowable combination of entry and exit points along the facility to use for determining what information to display to drivers at different locations along the facility. For example, in an express lane facility with multiple access and egress locations, the tolling agency should determine which combinations of access and egress locations to provide tolling information. Due to this limitation, the driver may not receive the data needed for their specific trip (with a specific access/egress pair). Most tolling agencies provide the cost for the driver to use the next segment as it is approached by the driver. Some drivers need to add the cost of these segments up as they drive along the corridor to determine the specific cost of their trip.

Driving trip planners are unable to leverage toll information for the following reasons:

- Drivers have to slow down to make payments at physical toll booths, and physical toll booths are expensive for tolling agencies to operate and maintain.
- Some drivers do not have electronic toll accounts—especially drivers who do not typically use the toll facility or are driving in an unfamiliar area.

Data Collection for Traffic Management

Many current traffic detection technologies are location based. That is, these technologies can detect vehicles at a location, and they have several other attributes such as detecting speed. The collection of vehicle movement data along a broader stretch of roadway would allow for more complex analyses to be performed and greatly enhance the ability of traffic management agencies to manage traffic along the roadway using any number of strategies at hand.

Furthermore, the ability to use detection data to predict future conditions would be limited because of the real-time nature of the collection process. Although simulations (running in near realtime) that use these data could provide a certain degree of predictive capability, it would be difficult to make assumptions regarding increases and decreases in demand that would also affect future conditions. As drivers utilize trip planning services to determine the most efficient route to service their trip, it would be advantageous for management agencies to receive and utilize these planned trip data to predict future conditions more effectively to proactively manage the roadway network. The traveler may be hesitant to share planned trip information but may be more open to the idea if incentives are provided (in the form of a shorter trip time or as a discount for using toll facilities).

DESCRIPTION OF DESIRED CHANGES

Examples of driver user needs are provided in table 23, followed by mobile device-based applications that could address these needs.

Table 23. Driver user needs.

User Need ID	Title	Description
Driver UN1	Roadway Signage	A driver needs spatially and temporally relevant roadway signage information.
Driver UN2	Customized Travel Information	A driver needs traveler information customized to a predetermined route (i.e., does not need information that does not pertain to them).
Driver UN3	Toll Information	A driver needs tolling information for toll facilities that could be used to get to their destination when using a personal vehicle.
Driver UN4	Travel Time Comparison	A driver needs a method of knowing how much travel time will be saved by using a toll facility.
Driver UN5	Toll Facility Payment	A driver needs a method to pay for tolls.

Rolling Toll Account Registration and Toll Payment

As electronic toll collection increases in popularity (to reduce system inefficiencies caused by staffed toll plazas), there is an opportunity for mobile devices to facilitate payment on toll facilities. As a driver passes through a toll facility, they are either charged a one-time fee or they are detected when they enter and exit the facility and are charged based on the distance traveled upon exiting the facility. As the driver passes a payment location, electronic messages could be exchanged between the toll facility and the mobile device in the vehicle to provide the mobile device with the charge, and the mobile device could provide the toll facility with payment information so that the driver's account can be charged. This process would require the driver to enter payment information into a mobile device that has been authorized to be used to make mobile payments. One potential benefit of using a mobile device to facilitate toll facility payments would be that it could be standardized across toll systems that currently do not have compatible toll tag detection systems.

Tailored Roadway Signage

The mobile device would be able to tailor the location and time at which signage information is displayed to a driver based on the driver's speed and location. It would be further able to reduce confusion that could be experienced by drivers by only displaying signage information relevant to the driver based on their selected route, as determined by a trip planning service.

Provision of Toll Facility Information

This use case would allow a mobile device to present tailored information to the driver to ensure that only the travel time and tolling information relevant to a selected route (as determined by a trip planner) would be presented to the driver. Furthermore, a mobile device would allow all information to be arranged and displayed simultaneously to reduce the burden on the driver of remembering information placed periodically along the freeway.

Capturing Traveler Decisions for Use in Traffic Management Activities.

Using data from CVs for traffic management is a growing area of interest among traffic managers to supplement traffic conditions data collected from other existing ITS equipment. Probe data would become more available as the number of vehicles and handheld mobile devices that can communicate these probe data increases. This increase in data availability would result in an expansion of access to high-quality, real-time, multimodal transportation data captured from CVs, mobile devices, and infrastructure methods for capturing decisions made by travelers while in the process of traveling. Furthermore, various wireless communications technologies can provide multiple methods for a mobile device to access multimodal trip planning services, which would improve the ability for system managers to capture data contained in interactions between travelers and a trip planning service.

Data captured from the mobile devices of drivers could be input to a process that transforms disaggregate data collected from all drivers using the travel planning service (along with other real-time and historic data sources) into an advanced prediction of future conditions. These data could be used to proactively manage the system using any number of strategies available to the traffic management agency, which may include, but would not be limited to, adjusting express lane tolls, implementing lane control, adjusting ramp meter timing, and adjusting a variable speed limit.

Priorities Among Changes

This section prioritizes user proposed functionality presented in the previous subsection. This prioritization would be typically done by classifying each possible change as essential, desirable, or optional. The classification method used would be determined by each deploying agency. Functions related to safety or other high-priority needs would be considered as essential, whereas desirable functions would provide enhanced functionality but would not be necessary for the system to meet user needs. Optional needs would be generally limited to needs that would be discretionary in nature. Prioritizing user needs would be a subjective practice and would vary from agency to agency and from region to region.

Changes Considered But Not Included

This section identifies changes and new features considered but not included and the rationale for not including them. Not including certain features could be due to implementation difficulties, technology limitations, or other systems’ ability to adequately meet the needs of users. Consideration of changes that were considered but not included would vary from agency to agency and from region to region.

Assumptions and Constraints

This section lists assumptions and constraints that would (or could) limit how the system could be designed and implemented. The following examples describe common assumptions and constraints could affect the design of the proposed system:

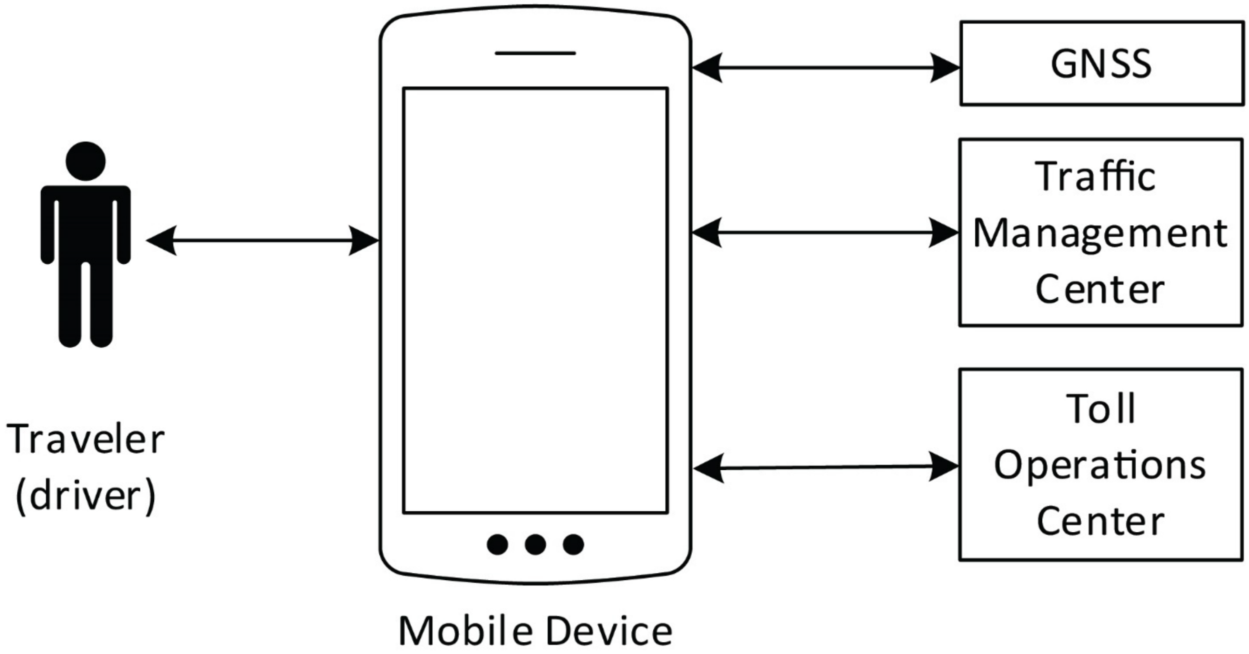
- Communications, technology, hardware, or software availability.
- Off-the-shelf technology procurement (as opposed to the development of a new device).

- Operational policies and constraints.
- Existing laws and regulations (e.g., governing the operations of motor vehicles, pedestrians, and bicyclers on the roadways).

PROPOSED OPERATING ENVIRONMENT

As discussed in previous chapters, sharing and using electronic messages with connected mobile devices can be described as systems that work together. For this concept, this environment includes a mobile device, a GNSS, a TMC, and a toll operations center.

Figure 29 illustrates a systems diagram for this concept. The interfaces, hardware, messages, and facilities and external systems that comprise this figure are discussed in detail in the proceeding subsections.



Source: FHWA.

Figure 29. Diagram. Mobile device driver system.

Interfaces

The TMC would provide roadway signage information and the toll operations center would provide the toll matrix message to the mobile device. The mobile device would receive both messages before the traveler reaches the location where the information would be needed. The mobile device and the toll payment system would exchange payment messages. Payment registration (with the toll payment system) would be completed before the traveler uses the tolled facility, whereas the payment user ID would be exchanged as the traveler enters and exits the facility and could be collected intermittently as the traveler uses the facility.

Hardware

The following hardware would need to be provided to enable this concept:

- **Mobile device—**The mobile device would be a self-contained apparatus that wirelessly sends and receives messages, receives data from its onboard sensors, has a processor to execute functions, and has an HMI that allows it to receive input from and provide output to the pedestrian (audio/visual/haptic). The mobile device would receive highway signage information and toll information messages, and the mobile device would position itself in the roadway environment to determine what signage would be around it or when it would be approaching a toll facility. If the traveler's route is known, the mobile device could tailor information (signage and toll information) displayed to the traveler according to the route. A mobile device that uses a toll facility would send a payment information message to RSE along the corridor so that the traveler can be charged for the trip taken along the toll facility.

- **RSE—**The RSE would be capable of wireless communications with a mobile device (method not specified), would contain a processor to execute functions, and would be backhaul connected to a TMC. The RSE located intermittently in advance of and along a toll facility would receive toll data from the tolling management center and would generate and broadcast the toll information message. Other RSE along the roadway network would receive signage data from the TMC, would generate highway signage information messages, and broadcast it. The RSE would receive payment information messages and would forward them to the toll payment facility.

Messages

The following messages would be needed to enable this concept:

- **Toll information message—**The toll information message would convey toll information for a single toll facility or multiple connected toll facilities. The toll information would consist of a matrix of tolls that would account for all possible travel options between entrance and exit points. Various toll amounts would be provided for different vehicle classes and special discounts would be available for toll tag-pass holders. The message would also contain the name, location, and direction of the toll facility access points, among other characteristics that would locate and identify the entrance and/or exit point. The message would also contain the period over which the posted toll would be active, which would enable a tolling management agency to update the toll amount on actively managed facilities.

- **Highway signage information message—**The highway signage information message would contain information about MUTCD-compliant signage that would be on overhead signs and on the roadside.(10) The message would not contain the geometry of the sign itself but would contain a code that represents each sign. These codes could correspond to the codes presented with each sign in the MUTCD.(10) Information in the message would contain specific information for each sign such as a highway number, a speed limit value, an exit number, or a distance. In a location where multiple signs would be shown, additional data would be needed to specify how signs are displayed with respect to one another. Such data could be appropriate to consider for inclusion in the SAE International J2354 standard, which describes standardized medium-independent messages needed by information service providers for advanced traveler information systems.(25)

- **Payment account registration message**—The payment account registration message would be sent from a mobile device to an agency's payment system for the purpose of registering payment information and associating that payment information with a traveler. This message would contain the traveler's payment account information (e.g., card/account number, name, billing address), agency payment identifier, and an account activation period. This message would be sent only when the mobile device would not have an active registration with the payment system for a given agency providing a service the traveler intends to use.

- **Payment account confirmation message**—The payment account confirmation message would be sent to the mobile device after an agency's payment system has determined whether a valid method of payment has been provided (the registration was successful or not). Information in this message would include the payment status, an account ID, and a date of expiration for the account activation period. This account ID would be used in all future transactions between the mobile device and the payment service with which the mobile device would be registered until the end of the activation period (at which time, the payment account must be reactivated).

- **Payment user ID message**—The payment user ID message would be sent from the mobile device to pay for services after a payment account has been registered. This message would contain the intended payment system ID along with the travelers account ID. No payment information would be exchanged.

- **Payment user confirmation message**—The payment user confirmation message would be sent in response to the payment user ID message, and it would contain the payment system ID, the account ID, and payment confirmation status.

Facilities and External Systems

The following external systems would be needed to enable this concept:

- **Toll management center**—The toll management center would be responsible for managing the toll facility and would set tolls, which could be static, vary by time of day/day of week, or vary in realtime based on demand. Toll data would be sent to RSE in the vicinity of the toll facility. Toll information would need to be updated on a continuous basis to reflect real-time conditions.

- **Toll payment facility**—The toll payment facility would receive payment information from RSE in the vicinity of toll facilities. This payment data would be used to charge the traveler for a trip taken on the toll facility.

- **TMC—**The TMC would receive signage inputs from traffic management staff and would forward this signage data to RSE near the actual location of the signage.

MODES OF OPERATION

Mobile devices are intended to complement existing methods of providing toll and signage information, and payment for utilizing a toll facility. Information and notifications provided to the traveler are expected to improve the ability to make informed decisions and mobility of mobile device users. Mobile devices are not intended to override existing methods of receiving information or payment. If the mobile device-based system experiences nonnormal modes of operations, the mobile device user would have to rely on existing methods of receiving signage or tolling information and for making a payment to use the toll facility. (This situation could preclude the traveler from using the facility.) Various issues that could result in nonnormal operations are provided in general context in chapter 8, Modes of Operation.

USER CLASSES AND INVOLVED PERSONNEL

The primary user class would be the traveler (driver). The traveler would carry a mobile device in their personal vehicle to provide mobility benefits. The traveler would be responsible for processing roadway signage information, determining what information displayed on the signage would be applicable to them, and responding to this information as necessary. When presented with the option to use a parallel toll facility, the traveler would need to know the requirements to use the facility, the cost to use the facility, and the benefit of using the facility. If the traveler uses the toll facility, the traveler would be the responsible for making a payment to use the facility. (This payment process could involve the traveler establishing an account before use.)

SUPPORT ENVIRONMENT

The toll agency would be responsible for the following actions:

- Determining and implementing tolls for a HOT facility or other tolled facility.
- Maintaining communications equipment that allows for electronic toll collection.
- Making real-time toll matrix data publicly available so that data can be used for trip planning purposes.
- Managing the collection of tolls.

The local transportation agency/TMC would be responsible for the following actions:

- Maintaining and operating ITS/communications hardware on the roadside:
    - Traffic signal controller.
    - Roadside communications.
- Managing intersection geometry data.
- Maintaining roadway signage inventory.

OPERATIONAL SCENARIOS

The operational scenarios in this section intentionally contain details that are typically beyond the scope of what would be necessary for ConOps, such as including the functions carried out by each component, detailing the sending and receiving of messages, and revealing the content of those messages. This level of detail would be typically found in subsequent SE documentation. However, in this concept, this additional detail is included to provide the reader with additional context about how such a system could work and how messages can be used to enable the use case to underscore the theme of sharing electronic messages with mobile devices to satisfy the needs of different types of travelers.

Use Case 4—Scenario 1

Use Case 4—Scenario 1 describes a traveler riding in a motor vehicle while using a connected mobile device. This scenario is identified and titled “UC4-S1: Roadway Signage and Toll Facility” with the following characteristics:

- **Short description—**A traveler (transit user) would use a mobile device to receive notifications regarding roadway signage that would be tailored to a planned route. The mobile device would also provide information about parallel managed-lane facilities and would facilitate payment on an ad-hoc basis (i.e., would not require the traveler to preregister) if the traveler decides to use the facility.

- **Scenario objective—**To Demonstrate the ability of the mobile device to provide the following options:

    - Receive tailored roadway signage information.
    - Pay for use of toll facility.
    - Capture traveler decisions for use in traffic management activities.

- **Operational event(s)—**The functioning-related events would take place in the following order:

    - The mobile device would receive roadway signage information as the vehicle moves along the roadway.
    - The mobile device would assess the traveler’s planned route to determine which roadway signage could be shown to the traveler.
    - The mobile device would provide information regarding parallel toll routes (e.g., toll amount, travel time, occupancy requirements) that would be specific to the traveler’s planned route.
    - The mobile device would provide payment information to the tolling payment system to ensure that the traveler could be billed for a trip taken to the toll facility.

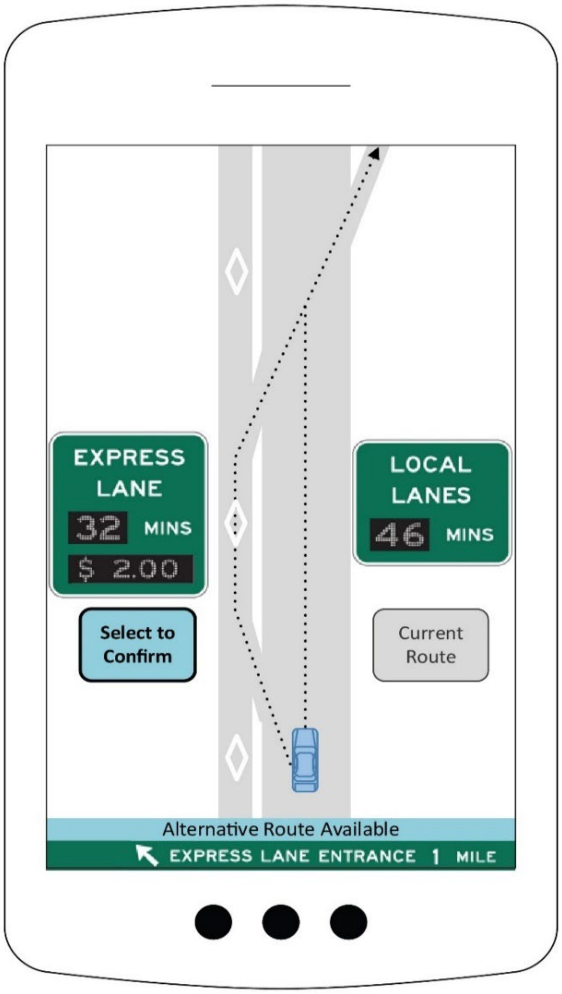
- **Preconditions—**A business traveler would return to an airport to catch a flight. They would a rental car and would return the car to a facility at the airport (i.e., the business traveler would not have the option of taking another mode). The traveler would have entered payment information when the mobile device was initialized.

- **Traveler actor role**—The traveler would efficiently navigate the roadway with knowledge of alternative options.

- **Mobile device actor role**—The mobile device would provide relevant signage information to the traveler (based on the location of the mobile device in the transportation environment) and would send and receive messages that would enable the traveler's needs to be met.

- **RSE role**—The RSE would facilitate the provision of information to/from the mobile device.

The scenario then describes key actions and the flow of events of six sources: traveler, mobile device, MMTP service, TMC, general, and RSE. Figure 30 and table 24 describe steps 1 through 26 of this scenario, table 25 further describes steps 27 through 37 as detailed in figure 31, and table 26 describes steps 38–41.



Source: FHWA.

Figure 30. Diagram. Use Case 4—Scenario 1, steps 23–26.

Table 24. Use Case 4—Scenario 1, steps 1–26.

Source	Step	Key Action	Comments
Traveler	1	Starts a driving trip from a meeting location to the airport.	The traveler uses a trip planner to find a suitable driving route from their current location to the airport.
Traveler	2	Opens trip planning application on mobile device and enters trip details.	The trip details include origin (automatically populated with current location), destination, preferred mode, and so forth.
Mobile device	3	Sends MMTP trip request message to MMTP service.	The MMTP trip request message contains the following content: • Trip ID: 1357. • Origin (lat/long or address). • In vehicle: no: • Destination (lat/long or address). • Preferences: o Mode: driving. o Accommodations: N/A. o Departure/arrival time: N/A. o Cost: N/A.
MMTP service	4	Receives trip request message.	N/A
MMTP service	5	Evaluates potential options based on inputs and traveler preferences.	N/A
MMTP service	6	Sends trip options information back to the TMC.	If a publicly available communications network is used to facilitate the connection between the mobile device and the MMTP service, then the MTTP service can capture this information easily (in accordance with terms of use established for utilizing the network). Otherwise, this process will require an established relationship between the MMTP service and the TMC, or a driver incentivization through a reduction in toll, or another incentive.

Source	Step	Key Action	Comments
MMTP service	7	Sends trip options information back to mobile device.	The MMTP trip options information message contains the following content: • Trip ID: 1357. • Route ID 1: o Start location (lat/long or address). o End location (lat/long or address). o Polyline (of route). o Leg 1. • Mode: driving. • Service provider ID: N/A. • Vehicle ID: N/A. • Cost: N/A. • Payee ID: N/A. • Distance: 15 mi. • Duration: 50 min.
Mobile device	8	Receives trip options information from the MMTP service.	N/A
Mobile device	9	Presents driving trip information to the traveler. Prompts the traveler to confirm the route and begin navigation.	N/A
Traveler	10	Confirms route by using mobile device.	N/A
Mobile device	11	Begins to provide navigation instructions to the traveler.	The mobile device is presumably in a location where it can be easily seen and heard by the traveler, such as on a dash mount or windshield-mount device. The driver does not hold the mobile device in-hand while driving.

Source	Step	Key Action	Comments
Mobile device	12	Sends route choice confirmation message to the TMC.	The route choice confirmation message contains the following content: • Trip ID: 1357. • Route ID: 1.
TMC	13	Receives route choice data.	The TMC uses route choice confirmation to predictively analyze future traffic conditions. The TMC can preemptively enable strategies at hand to proactively manage traffic along select corridors. Note: The tolling agency and the traffic management agency would take the express lanes itinerary information and use it for management activities (e.g., adjust variable speed limit adjustment, ramp meter adjustment, implement integrated corridor management strategy, adjust lane control) that would be available to the managing agency. Archived data could be used to conduct long-term planning studies, to perform O/D studies, and to understand how driver behavior affects freeway throughput.
Traveler	14	Travels along the selected driving route.	N/A

Source	Step	Key Action	Comments
Mobile device	15	Receives roadway signage information as the traveler moves along the route.	The roadway signage information contains the following content: • Sign. • Type. • MUTCD ID. • Prominence. • Applicable zone (polygon). • Advance notification zone (polygon). Note: To conserve bandwidth, the mobile device would receive information about signage only within a given radius of the vehicle or within a given radius of the expected forward path of travel.
Mobile device	16	Assesses the vehicle location and path of travel with respect to the applicable time and locations of each sign to determine what signage is applicable to the driver.	The mobile device determines the relevant signage by assessing the selected route polyline (MMTP responses) and the applicable zone for signage (roadway signage information). Note: The applicable time and location for each sign would depend on the speed of the vehicle and the time of day in which it would be driving. For instance, certain warning and guidance signage would be displayed to the driver at an earlier time and location for a driver moving at a higher rate of speed than for a driver moving at a lower rate of speed.
Mobile device	17	Displays relevant signage information to the driver.	The mobile device also displays signage that is not relevant to the driver, but that information is secondary in importance to the signage pertaining to the driver’s selected route.

Source	Step	Key Action	Comments
Mobile device	18	Queries local roadway conditions.	The mobile device intermittently checks conditions along the route to determine whether there is an alternative option.
General	19	Congestion starts to build along the route.	N/A
Traveler	20	Approaches initial ingress point to a parallel managed land facility.	The HOT lane requires payment for single-occupant vehicles. Tolls may vary based on traffic conditions in general-purpose lanes.
RSE	21	Sends data about managed-lane facility.	The RSE sends the managed-lane toll matrix message, which contains the following content: • Ingress location: o Lat/long: 38.641033, −77.287508. o Mile marker: 157. o Egress location: 1: • Lat/long: 38.652832, −77.281661. • Mile marker: 158. • Requirement: single occupant. • Cost: $1.00. • Express travel time: 20 min. • General purpose lanes (GP) travel time: 35 min. o Egress location: 5: • Lat/long: 38.732394, −77.196360. • Mile marker: 166. • Requirement: single occupant. • Cost: $2.00. • Express travel time: 32 min. • GP travel time: 46 min.

Source	**Step**	**Key Action**	**Comments**
RSE	21	Sends data about managed-lane facility.	○ Egress location: 10 (last exit): • Lat/long: 38.787950, −77.177165. • Mile marker: 170. • Requirement: single occupant. • Cost: $10.00. • Express travel time: 40 min. • GP travel time: 60 min. Note: Data would include toll and travel-time matrix (i.e., the toll and travel time for every ingress and egress combination.)
Mobile device	22	Receives information about a managed-lane facility.	N/A
Mobile device	23	Alerts the driver that an express lane option is available.	N/A
Mobile device	24	Provides a travel time estimate to get to the destination in the general-purpose lanes and in the express lanes.	N/A
Mobile device	25	Provides the amount of the toll to use the express lanes from the traveler’s current location to the airport.	N/A
Traveler	26	Decides to take the express lane.	The traveler decides that it would be worth the cost of the toll to save time and get to the airport. Note: This decision would be based on personal judgment.

Table 25. Use Case 4—Scenario 1, steps 27–37.

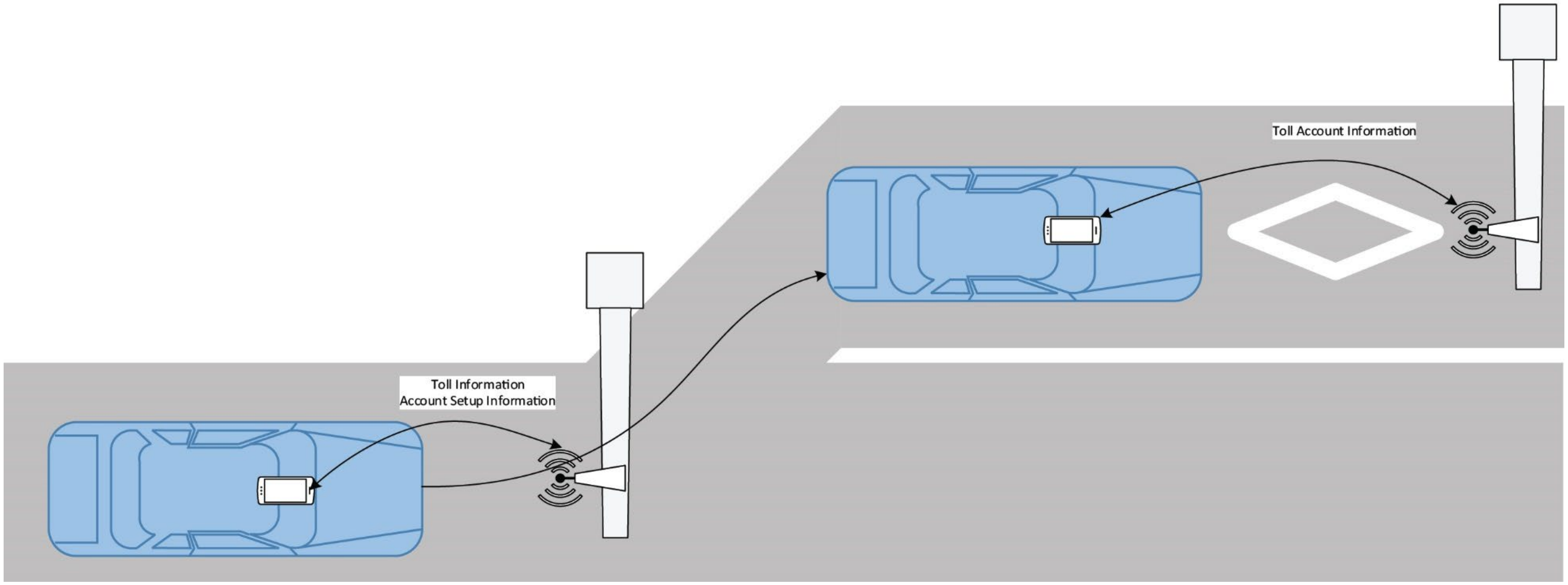
Source	Step	Key Action	Comments

Mobile device	27	Sends payment account registration message to toll operations center.	The payment account registration message contains the following content:
			- Payment account information:
			  - Account number: 1234567890123456.
			  - Name: John Doe.
			  - Payment billing address: 123 Main St.
			- Payee ID: 444555666 (corresponds to toll payment system).
			- Account activation period: 1 d.
			Note: The traveler would have previously entered payment information into the mobile device when it was initialized. If multiple payment options have been entered, the mobile device would prompt the traveler which payment method to use.

Toll operations center	28	Receives payment account registration message.	The toll operations center stores the payment account information until the end of the account activation period.
Toll operations center	29	Authorizes payment method.	The toll operations center authorizes the payment method.

Source	Step	Key Action	Comments
Toll operations center	30	Sends payment account registration confirmation to mobile device.	The payment account registration confirmation message contains the following content: • Payee ID: 444555666 (corresponds to toll payment system). • Payment status: authorized. • Account ID: 6F7G8H9I0J. • Account activation period: 1 d. Note: the payee ID and account ID would be used in the payment user ID messages for all trips taken using facilities managed by the toll agency during the account activation period (1 d). This process would limit the number of times account information would need to be exchanged.
Mobile device	31	Sends an itinerary of the driver's selection of the express lanes to the tolling agency and the traffic management agency.	N/A
Mobile device	32	Instructs the traveler to enter the express lanes at the next access location.	N/A
Traveler	33	Maneuvers to enter the express lanes.	N/A
Mobile device	34	Notifies the traveler that they are about to enter a tolled facility.	Note: This would provide a traveler who may not be familiar with the area one last opportunity to move back to the general-purpose lanes (or to exit) to avoid inadvertently using the facility.
RSE	35	Detects the presence of the mobile device as the vehicle travels in the express lane.	RSE would establish connectivity with the tolling agency.
Mobile device	36	Sends payment user ID message to toll operations center.	The payment account ID message contains the following content: • Payee ID: 444555666 (corresponds to toll payment system). • Account ID: 6F7G8H9I0J.

Source	Step	Key Action	Comments
Toll operations center	37	Sends payment user confirmation message to mobile device.	The payment user confirmation message contains the following content: • Payee ID: 444555666 (corresponds to toll payment system). • Account ID: 6F7G8H9I0J. • User status: confirmed.



Source: FHWA.

Figure 31. Diagram. Use Case 4—Scenario 1, steps 27–37.

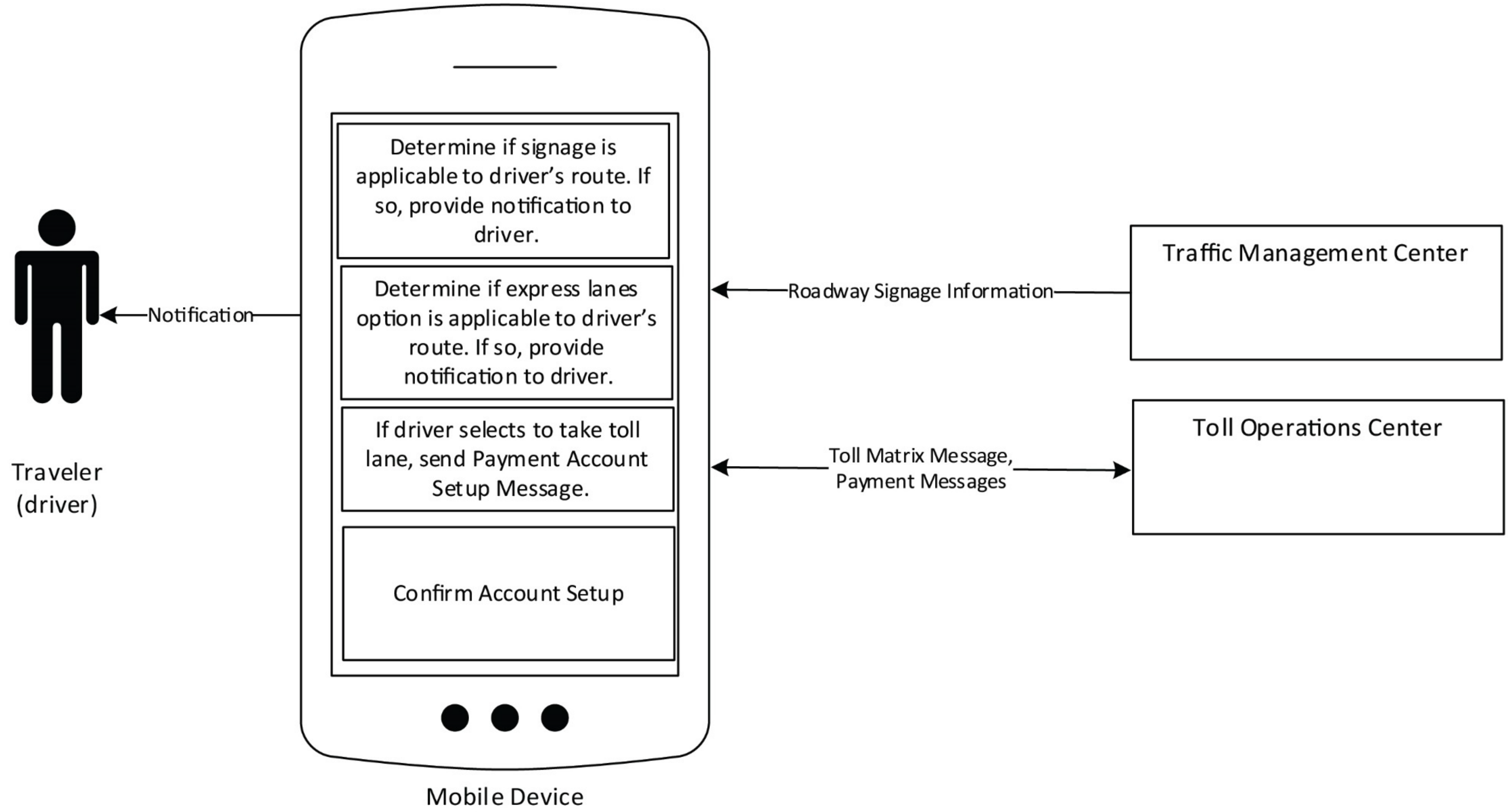
Table 26. Use Case 4—Scenario 1, steps 38–41.

Source	Step	Key Action	Comments
Mobile device	38	Instructs the driver when they approach the egress location for the express lane facility to continue to stay on the route for the airport.	N/A
Traveler	39	Maneuvers to exit the express lanes.	N/A
Toll operations center	40	No longer detects the presence of the mobile device and determines that the vehicle is no longer traveling in the express lane.	N/A
Toll operations center	41	Determines the total cost of the toll for the trip.	The toll operations center determines the cumulative toll to be $2.00. The traveler's account will be charged. Note: Entering and/or exiting the facility at nondesignated locations (as determined by the tolling agency) could result in additional fees being assessed for improper use of the facility.

To complete this scenario, four characteristics are included, along with a system diagram to capturing the sources included in the scenario, as shown in figure 32.

The following characteristics complete Use Case 4—Scenario 1:

- **Postconditions—**Traveler would receive toll facility information that would be customized for the trip they are taking:
    - Traveler would use toll facility and would pay (account would be generated on an ad-hoc basis, the traveler would not be required to have pre-established an account before using the toll facility).
    - Traveler would pay for use of parking facility.
    - TMC would receive information regarding the traveler's planned route. This information could be used to predict future traffic conditions and proactively apply traffic demand management strategies.
- **Messages—**The message types would include trip request messages, route options, selected route messages, toll lane detection messages, toll/travel time matrix messages, payment request messages, and payment information.
- **Traceability—**The following user needs would apply to this scenario:
    - Driver UN1—Roadway Signage.
    - Driver UN2—Customized Travel Information.
    - Driver UN3—Toll Information.
    - Driver UN4—Travel Time Comparison.
    - Driver UN5—Toll Facility Payment.
- **Mobile device inputs summary**—Inputs would include trip planner inputs (from the traveler), trip options information messages (from the MMTP), roadway signage information (from the TMC), and managed-lane toll matrix messages (from toll operations center).
- **Mobile device outputs summary**—Outputs would include trip request messages (to MMTP), route choice messages (to the TMC), roadway signage (to the driver), and toll information (to the driver).



Source: FHWA.

Figure 32. Diagram. Use Case 4 – Scenario 1, sources.

CHAPTER 12. CONCEPT IMPLEMENTATION

CHAPTER OVERVIEW

Implementing a mobile device information exchange capability involves more than technical knowledge and sound design to be successful. Leadership would be a critical aspect of the implementation and new technology applications (such as mobile device use) would benefit from the direction and support of a project champion and a technical working group. These positions would help organize and promote the system to build consensus among stakeholders. These positions would also provide the guidance to adjust the concepts and approaches that have been introduced and described throughout this document for local needs and conditions. SE, for instance, would be a framework process to guide stakeholders through a project and outreach and coordination to consider the local environment. Similarly, the use cases provided in this document are examples of what could be considered but may not be applicable to all locations. Supplementing this information with additional references could assist with planning, designing, or developing the ability to share electronic messages with mobile devices.

This chapter provides an overview of the following tactics that transportation agencies or service providers could implement to increase local application and improve project success:

- Identify local needs.
- Establish a working group.
- Identify a regional champion.
- Integrate the system with existing systems.

CONSIDERATIONS FOR LOCAL AGENCIES

Concepts developed in chapters 8, 9, 10, and 11 consider several traveler needs to demonstrate the ability of a mobile device to enable the communication of information that helps travelers make decisions before and during a trip. However, when developing concepts for a project or planning a study that supports sharing and using electronic messages with mobile device-carrying travelers, it would be important to consider the needs of local stakeholders, local transportation infrastructure, local transportation systems as well as the constraints and enablers that would need to be captured and reflected in SE documentation. Local agencies could use the concepts in chapters 8–11 as a starting point for developing SE documentation and could adapt the concepts, as necessary, to account for local needs and local conditions.

Identify Local Needs

Outreach would be a crucial component to capturing local facets that would play a role in developing SE documentation. Both stakeholder engagement and technical working group meetings are types of outreach that could be performed. Systems engineers, who are responsible for developing documentation, would be present during stakeholder engagement and technical working group meetings to ensure that all input would be adequately captured throughout the SE process.

To best capture the needs for the proposed, outreach would be conducted among potential users. This outreach could involve one or more groups that would focus on defining the needs of different user classes (e.g., pedestrian, bicyclist, transit user, driver). Ideally, the needs that would be elicited from the focus groups would represent the needs of the entire user class. Each stakeholder would bring a unique perspective—outreach would be performed to ensure that the needs elicited from all stakeholder feedback would be well-rounded.

Establish a Working Group

A working group would be established to work through technical aspects of the proposed system. Members of this group would ideally comprise stakeholders who would manage the system, network components, managers of external systems that the group may interface with, and technical staff developing SE documentation.

During the review of the any documentation, it would be important to establish one or more review cycles to allow for various stakeholders to provide input. Receiving feedback from stakeholders would allow systems engineers to refine content so that the intent of stakeholders would be adequately presented in the documentation.

A technical working group should be established that is knowledgeable about the needs of users, capabilities of existing systems, the ability of existing systems to be modified, and the scope of improvements that can be made to enable communications with mobile devices.

The technical working group would discuss detailed aspects of the system to meet specific needs of users by offering features that are applicable only to area users. Agencies that are considering the deployment of infrastructure to support mobile devices likely already have local transportation systems in place that are planned to be leveraged. It would be important to consider both the regional architecture and system architecture. Members of this group would be knowledgeable regarding the needs of users, the capabilities of existing systems, the abilities of existing systems to be modified, and the scope of improvements that could be made to enable communications with mobile devices.

Identify Regional Champion

More than one agency may be involved in deploying transportation technologies, especially in the regional context. Creating organization among these agencies would be an important factor in managing the project. Generally, there would be a lead agency organizing the efforts of the other involved agencies to achieve the common goal of developing a mobile device-based system. The lead agency would be generally accountable for the effectiveness of the deployed system. Once the lead agency has been established, it would be important to determine what other supporting agencies need to be involved. Supporting agencies would provide information that would support the design and deployment of the system and could be responsible for the following actions:

- Managing external systems that the deployed system would interface with TMC staff, transit management staff, toll management staff, and shared-use device management staff.

- Managing existing and/or deployed system components (e.g., technology organization that manages hardware, backhaul communication, and network configuration/settings).
- Representing users of the deployed system (i.e., advocacy organization, or focus group representative).
- Developing SE documentation.

> The efficiency with which a mobile device-based system can be successfully deployed may be aided by agency stakeholders being proponents of the proposed system and willing to cooperate.

The efficiency with which a mobile device-based system could be successfully deployed would be aided by other agency stakeholders being proponents of the proposed system and their willingness to cooperate. As supporting agencies are identified, the lead agency would need to develop a management approach that would establish a consensus regarding the structure of the group and the responsibilities and procedures of each member. In a case where there would be more than one lead agency (e.g., neighboring jurisdictions partnering on a project), it would be important to establish a management structure among the leading agencies to establish an internal management structure and a method for interacting with other supporting agencies.

Integrate with Existing Systems

Enabling communications with a mobile device or other wirelessly connected device, such as a CV, is still an emerging concept in the transportation industry. A limited number of agencies have experiences in deploying wireless communications networks that could be leveraged for (among other things) lessons learned and best practices.

Many nuances to the deployment of such a system cannot be effectively captured in high-level guidance. Agencies considering the deployment of a mobile device-based system could consider establishing a relationship with agencies that have previously successfully deployed similar infrastructure. This relationship would provide guidance and advice when the deploying agency experiences uncertainty about how to proceed with a design of the system or about how it would be implemented. Furthermore, coordinating with other agencies would encourage interoperability—whereby a mobile device (or other connected device) could use the same application in multiple environments (provided each environment has established connectivity with the same transportation services and external systems). SE documents developed by agencies with experience deploying similar systems could also be reviewed to provide additional guidance to inform the structure and concepts that would be included in a locally specific set of SE documents.

CHAPTER 13. SYSTEMS ISSUES TO CONSIDER

CHAPTER OVERVIEW

Implementing the capability for a TMS to share electronic messages with mobile devices should consider what may be needed to support developing, implementing, operating, and maintaining this capability or service. Agencies or service providers that operate the TMS would be encouraged to review and revise or develop operating policies, procedures, and management tools to ensure the information exchange would be not only functional but also secure. Managing information and user expectations are critical to maintaining public trust of the service and enabling technologies, which may involve raising the public's awareness to increase understanding among users.

Agencies should also consider the operating and staffing impacts the new technologies and services could have on the organization in terms of number and type of staff required to operate and maintain the equipment. This chapter provides an overview of operational, development, and deployment issues agencies may consider when considering TMSs sharing electronic messages with mobile devices.

OPERATIONS CONSIDERATIONS

To satisfy the data needs of travelers, the deployed system should consider interfacing with other external systems to enable data transmission between mobile devices and these external systems. Maintaining these interfaces would require coordination between the agency responsible for managing the deployed system and other external systems.

> For the deployed system to leverage the functionality external systems, it should be able to interface with the external system and process the data sent to and received from the external system.

As the services provided by external systems evolve, the inputs and outputs to these systems change to enable these evolving services. For the deployed system to take advantage of external system updates, it must be able to interface with the external system and process the data sent to and received from the external system. The agency responsible for managing the deployed system would be aware of changes to external interfaces to ensure that the system could be updated to support these interfaces (and the data that flow over them) as they update.

One of the primary aspects of a deployed system would be that it establishes a path of communication between a mobile device and an external system. An agency that would be responsible for a network over which data would be transmitted would also be responsible for determining what data can flow over the network and how those data would be handled. Some of the data described in the concept chapters of this report are considered personally identifiable information (PII). PII is considered to be any information that could be used to identify an individual. This information could include, but would not be limited to, origin information, destination information, vehicle ID information, payment account information, or locations (waypoints) along a traveler's route. Some of these data items are sensitive in nature, whereas other types of data must be corroborated with other information for a traveler's identity to be at risk.

As discussed in the concept chapters, the transmission of data between mobile devices and other systems over a publicly managed network could be leveraged for various types of advanced uses such as capturing traveler decisions for transit/traffic management purposes. Today these types of uses are commonly referred to "Smart City" uses. When these data are being captured for traffic or transit management activities, these transit and traffic agencies should carefully consider what data would be used and/or stored. These agencies would need to ensure that they adhere to internal policies and procedures regarding the use and storage of such data, including considering the following attributes:

- Usage policy:
    - What could data be used for?
    - Who would have access to what data?

- Storage:
    - Data could be filtered to obfuscate PII by being time- and or space-aggregated with other data.
    - How would information be encrypted? Stronger protections are necessary to transmit and store sensitive data.

- Data retention:
    - How long would each type of data be stored?
    - Data that have had PII removed could be stored for longer periods.
    - PII that is no longer needed could be deleted.

Although a single message may not be considered PII, it could be possible to reconstruct a trip from a group of messages that could lead to the identification of an individual and their whereabouts. Such circumstances exist when there are few vehicles on the roadway, or certain patterns exist in messages, allowing specialized pattern recognition software to distinguish between individuals in a group. The protection of PII would be crucial for maintaining the trust of a traveler who wishes to preserve their privacy.

Due the nature of data being transmitted to and from mobile devices over a publicly managed system, mobile device users should acknowledge the terms and conditions (or terms of use) to ensure they would understand how their data could be used before exchanging information.

ORGANIZATIONAL CONSIDERATIONS

The addition of the mobile device-based system would result in operations modifications for agencies that own and maintain equipment, manage the data gathered, and manage and maintain the enabling TMSs. This system could include fiber maintenance to support the additional responsibilities of the fiber backhaul network upon which the system relies (agencies could consider contracting fiber maintenance, if necessary).

CONSIDERATIONS DURING DEVELOPMENT

Considerations during development may include sustained stakeholder involvement and acquiring the proper permits for deploying communications technology. The lead agency would continually reach out to supporting stakeholder agencies to develop and maintain agreement on the features to include as part of the final system and to ensure a continued commitment by these agencies to provide support for external interfaces and internal system support.

Furthermore, public outreach would be necessary to enlist travelers who are willing to install equipment or software on their personal mobile devices and the deploying agency that would procure and distribute mobile devices to travelers or purchase a dedicated mobile device. The procurement of construction services would not be able to start until the system design is complete. This design could involve, but would be not limited to, the installation of fiber backhaul, roadside devices, and other equipment and network configuration.

> The network would need to utilize cyber-threat intelligence systems that identify, protect, detect, respond, and recover from potential threats to systems and devices connected to the network.

If the system includes the deployment of wireless communication technology, the deploying agency determines whether a Federal Communications Commission (FCC) license must be obtained. FCC applications are location-specific and specific to certain communications media and vary, depending on the types of messages that would be broadcast. The process of obtaining these licenses (if required) could be time-consuming (depending on the scale of deployment) and may affect the deployment schedule.

Finally, establishing communications security is important. Wireless access points (and to a lesser extent unsecured physical access points) are potential entrance points for hackers to access any number of other devices or systems on the network. Agencies may consider using cyber-threat intelligence capabilities that identify, protect, detect, respond, and recover from potential threats to systems and devices connected to the network. Before testing the system and initiating operations, the deploying agency may consider procuring these communications security services to protect systems and devices connected to the network and to ensure the legitimacy of information, so that all information originates from a trustworthy source.

CHAPTER 14. ANALYSIS OF MOBILE DEVICE-BASED SYSTEMS

CHAPTER OVERVIEW

Systems involving information exchange with mobile devices could provide new real-time information, capabilities, and functions to the travel environment with increased interaction with the system user. This chapter summarizes available improvements within the various categories of traveler safety, traveler mobility, payment processing, and interoperability. The listed improvements provide owner/operators with a sampling of possible concepts but are not be considered a comprehensive list.

As mobile device-based systems are designed and deployed, it would be important that owner/operators continually assess the system's role and performance. These systems would facilitate the exchange of electronic messages and therefore may require users to obtain and use equipment that may not be readily available. Evaluating the ability of users to interact with the system, the potential limitations, and any alternatives to improve the success rate would be key issues to consider during its development and after deployment. To help with this assessment, establishing key performance measures that provide quantitative measures could be used to track and assess performance over time.

This chapter provides an overview of the following topics:

- Summary of Improvements.
- Disadvantages and Limitations.
- Alternatives and Tradeoffs Considered.
- Performance Monitoring, Evaluation, and Reporting.

SUMMARY OF IMPROVEMENTS

This section describes the capabilities that would be afforded by the proposed system. This section addresses the benefits or advantages of sharing information with mobile devices over the previous way of performing the functionality. In addition to providing safety and mobility benefits, the concepts discussed herein provide increased accessibility in the form of payment and interoperability of mobile devices in different environments:

- Improved safety of mobile device-carrying travelers:
  - Bicyclist street safety.
  - Pedestrian phase extension.

- Improved mobility of mobile device-carrying travelers:
  - Enhanced crosswalk wayfinding.
  - Enhanced transit wayfinding.
  - Constant checks on progress on a multimodal trip to assess progress and provide alternatives.
  - Connection protection.

- Payment facilitation:
    - Rolling payment account registration.
    - Transit payment.
    - Toll payment.
    - Payment for other system.

- System-to-system and region to region interoperability:
    - Use a single device (mobile device) that allows the traveler to benefit.
    - Improve management capabilities.
    - Use a planned driving route and provide progress updates for use in traffic management activities.
    - Use a planned transit route and provide progress updates for use in transit management activities.

These types of improvements are only intended to provide examples of how mobile devices could help travelers (using various modes) make decisions and represent only a fraction of the applications that could assist mobile device-carrying travelers.

Another goal of the system could be to improve the accessibility of transportation services or information to mobile device users. This improvement would be done by establishing communications infrastructure that would provide connectivity between mobile devices and transportation services or systems that provide data.

Some services and systems are currently available through a wireless cellular service provider. However, accessibility would be improved if there were a communications infrastructure that could provide additional means of connectivity, whereby this infrastructure would not require the mobile device user to pay to connect, promoting equal access to these services and systems. Publicly managed networks established for the communication of transportation data could be used to provide free connectivity for transportation applications.

An agency could deploy equipment that would provide a single point of connectivity to one or more transportation services (e.g., TMC, transit management center, third-party services). Alternately, one or more wireless access points could be used along a physical communications backhaul to enhance mobile device connectivity. In areas where backhaul connectivity exists, agencies could use this existing backhaul connectivity to provide connectivity to mobile devices.

DISADVANTAGES AND LIMITATIONS

Regarding a mobile device-based system, the one limitation is that for a traveler to receive any benefit from the system, they would have to have a mobile device with the necessary communications capabilities (e.g., cellular). Prototypes and initial deployments could provide funding to procure mobile devices to distribute to travelers, but this process would not be a sustainable long-term approach. The availability of a device with the proper capabilities, and the public's ability to readily purchase such a device (i.e., would not be cost prohibitive) would provide fewer limitations to adoption and participation.

Precursor research (sharing data between mobile devices, CVs and infrastructure) has resulted in the generation of a prototype mobile device that requires the use of peripheral smartphone accessories that enable communications, specifically DSRC radios, that are not available on today's smartphones or other types of mobile devices. Given recent FCC rulemaking, it is clear that DSRC does not have a future. Furthermore, it is unknown whether smartphone manufacturers will consider C-V2X technology in future generation phones.

Ideally, the key to mobile device-based systems having a long-term goal of large-scale mobile device adoption may be to design a system that leverages off-the-shelf technology or uses technology that is already available or planned to be available. When an agency builds infrastructure and supporting software to enable functionality to support the needs of travelers, it would present a low barrier to entry to maximize adoption and likelihood of success. Thus, considering the current state of technologies and emerging trends in the smartphone and mobile device markets is important when assessing the feasibility or pursuing a mobile device-based system.

It is risky to design for the use of communications technologies that are not available or not planned to be available on off-the-shelf smartphones or mobile devices. A mobile device design that does not require the use of peripheral components (with a smartphone) would not be advisable, because this type of device would likely result in reluctance to adoption. Furthermore, convincing smartphone manufacturers to integrate or enable certain technologies into the next generation of devices (that they were not already planning to integrate) would also be difficult.

ALTERNATIVES AND TRADEOFFS CONSIDERED

> It is important to consider the ability to collect data (from the system or from external sources) to derive a given performance measure when considering which performance measures would be used to assess the mobile device-based system.

The use of mobile devices for vehicle-to-vehicle safety was not considered, because many vehicle-based safety and mobility applications are currently enabled through CV technology.

It would also not be the intent of a mobile device-based system to replace the means by which existing services are provided in the current system. However, it would be important to consider the current system to determine whether it would be potentially enough (or if it could be potentially modified) to implement a concept that has been developed.

PERFORMANCE MONITORING, EVALUATION, AND REPORTING

Assessing operations would play a critical role in understanding the operating characteristics of the mobile device-based system. To gauge whether a deployed mobile device-based system achieves the deploying agency's goals and objectives, performance measures would be developed. Deciding which type of performance measure to use would depend on a variety of factors, including data availability. Thus, it would be important to consider the ability to collect data (from the system or from external sources) to derive a given performance measure when considering which performance measures would be used to assess the mobile device-based system.

These measures could align to each deployed application to compare conditions before and after deployment (i.e., a before-after analysis). Other performance measures would compare areas where mobile device-based communications would be deployed compared to those that would not (i.e., a with-without analysis). The benefit of before-after comparisons would be that they could measure changes directly in the areas that would be improved from a baseline of current conditions. The benefit of with-without comparisons would be that they could be done at the same time, which would mitigate the impact of external variables. Other more complex analyses could be designed depending on the availability and complexity of the data that could be gathered.

It would also be important to address confounding factors that could affect performance measures. Controlling for confounding factors would improve the ability to isolate changes in the performance of the system that could be attributed to the integration of mobile device-based communications.

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