Transit Vehicle-to-Infrastructure (V2I) Applications: Near Term Research and Development

Transit Traveler Information Infrastructure Mobility Application: Operational Concept

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16. Abstract

This document serves as an Operational Concept for the Transit Traveler Information Infrastructure Mobility Application. The purpose of this document is to provide an operational description of "how" the Transit Traveler Information Infrastructure Mobility Application may operate.

The Transit Traveler Information Infrastructure Mobility Application connects transit vehicles and travelers to nearby infrastructure, such as a smart intersection, smart bus stop and smart parking. For example, transit vehicles would communicate with transit stops to provide travelers information on approaching vehicles, such as passenger loads, available disability seating, bicycle rack availability, fare information, etc. The application would support dynamic trip planning at transit stops. The Operational Concept discusses the following scenarios:

- Scenario 1: V2I (and I2V) traveler information and dynamic trip planning at bus stops for travelers without personal information devices.
- Scenario 2: V2I (and I2V) traveler information and dynamic trip planning at bus stops for travelers with personal information devices.

This document is intended to convey at a high-level how the application may work, so others may design and implement systems in the future. As such, the Transit V2I Operational Concept documents are "generalized" and not specific to a geographic area, an operating entity (e.g., transit agency), existing systems that may be in place for a region, agency operating procedures, nor political environment.

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1 Introduction

This document serves as an Operational Concept for the Transit Traveler Information Infrastructure application. The purpose of this document is to provide an operational description of "how" the Transit Traveler Information Infrastructure application may operate. Within this document, several potential scenarios that may be addressed by this application will be presented.

The Transit Traveler Information Infrastructure application connects transit vehicles and travelers to nearby infrastructure, such as a smart bus stop, smart intersection and smart parking. For example, connected transit vehicles would communicate wirelessly with transit stop infrastructure to provide travelers with information regarding available transportation services and approaching vehicles, such as passenger loads, availability of priority seating for persons with disabilities, bicycle rack availability, and fare information, among other data. Through connected infrastructure, this information would be transmitted to transit management centers and disseminated to travelers through the Transportation Information Center (TIC) applications. The TIC collects, consolidates, verifies, and refines transportation-related data. A key component of the application is the ability to support dynamic trip planning at transit stops. The Operational Concept discusses the following scenarios:

- **Scenario 1: V2I (and I2V) traveler information and dynamic trip planning at bus stops for travelers *without* personal information devices.** This scenario describes the provision of traveler information, including dynamic trip planning, at transit stops. The scenario assumes that the traveler does not have access to a personal information device (e.g., mobile device). An alternate scenario specific to the provision of connection protection information to travelers without personal information devices, en-route and on-board the transit vehicle, is also provided.
- **Scenario 2: V2I (and I2V) traveler information and dynamic trip planning at bus stops for travelers with personal information devices.** This scenario describes the provision of information to travelers with personal information devices. The device provides the capability for travelers to receive real-time information at the transit stop location and en-route through V2I communications. The device, through V2I communication through a roadside unit (RSU), may serve as a physical gateway for the traveler to access multi-modal travel planning applications hosted within the TIC. The device may also be used to communicate wirelessly with connected vehicle on-board equipment (OBE) (e.g., to request a transit stop or pay a fare). Some elements of this scenario may include limited V2P communications.

This Operational Concept describes how the application applies to transit buses and stops; however, it could be applied to all modes of transit, including light rail, heavy rail and commuter rail.

1.1 Goals

The Transit Traveler Information Infrastructure application is expected to meet the following goals:

- **Goal 1: Utilize and transmit transit vehicle data to improve service delivery and mobility through enhanced coordination and communication.** This application will focus on leveraging existing transit Intelligent Transportation Systems (ITS) and associated data to improve transit operations and the information made available to the public. Through connected infrastructure and personal information devices, the application provides a direct link for communication between the traveler and the transit service provider(s).

- **Goal 2: Leverage existing and emerging applications and tools in an integrated approach which benefits travelers and transit service providers.** This integrated application provides benefits greater than the sum of the leveraged applications when used independently. The application provides a cohesive method for the collection, processing, and dissemination of relevant mobility data through roadside and transit stop location infrastructure.
- **Goal 3: Research and develop innovative technologies.** This application is expected to research, develop, and integrate mobility-oriented technologies and applications enabled and/or supported by the connected vehicle environment. While the focus of this research is on V2I communications, additional V2P communications scenarios are presented in Appendix B for further consideration.

1.2 Connected Vehicle Research

Connected vehicle research is both a concept and a program of services that can transform travel as we know it. Connected vehicle research combines leading edge technologies – advanced wireless communications, on-board computer processing, advanced vehicle-sensors, Global Positioning System (GPS) navigation, smart infrastructure, and others – to provide the capability for vehicles to identify threats, hazards, and delays on the roadway and to communicate this information over wireless networks to provide drivers with alerts, warnings, and real time road network information. At its foundation is a communications network that supports vehicle-to-vehicle (V2V) two-way communications, V2I one- and two-way communications, and vehicle or infrastructure-to-device (X2D) one-and two-way communications to support cooperative system capability. In this context, the term “device” refers only to devices that are “carry-in” devices (i.e., devices that can be temporarily installed in vehicles and are not connected to in-vehicle information systems). These devices include ones (e.g., cell phones) that could also be carried by pedestrians or other users of the roadways (e.g., cyclists). Connected vehicles enable a surface transportation system in which vehicles are less likely to crash and roadway operators and travelers have the information they need about travel conditions to operate more effectively. Connected vehicle research will establish an information backbone for the surface transportation system that will support applications to enhance safety and mobility and, ultimately, enable an information-rich surface transportation system. Connected vehicle research also supports applications to enhance livable communities, environmental stewardship, and traveler convenience and choices.

The ability to identify, collect, process, exchange, and transmit real-time data provides drivers with an opportunity for greater situational awareness of the events, potential threats, and imminent hazards within the vehicle’s environment. When combined with technologies that intuitively and clearly present alerts, advice, and warnings, drivers can make better and safer decisions while driving. Additionally, when further combined with automated vehicle-safety applications, connected vehicle technology provides the vehicle with the ability to respond and react in a timely fashion when the driver either cannot or does not react quickly enough. Vehicle safety systems, because of the need for frequently broadcasted, real-time data, are expected to use dedicated short range communications (DSRC) technology for active safety applications. Many of the other envisioned applications could use other technologies, such as third generation (3G) or fourth generation (4G) cellular or other Wireless Fidelity (Wi-Fi) communications, as well as DSRC. The rapid pace of technological evolution provides tremendous opportunities for connected vehicles, and the program is positioned to capitalize upon these advances as they happen.

The U.S. Department of Transportation (USDOT) currently has a very active set of research programs that are focused on the development of crash avoidance systems based on both V2V and V2I (meaning both I2V and V2I) DSRC technology. In addition, the USDOT is actively researching ways to improve mobility and reduce environmental impacts of transportation, using wireless communications (not necessarily based on DSRC technology). The expectation is that, in the future, in-vehicle systems will run a combination of safety, mobility, and environmental applications that communicate using the most effective wireless technologies available.

1.3 The Transit V2I Research Program

The Intelligent Transportation Systems (ITS) Joint Program Office (JPO) is charged with planning and execution the ITS Program as authorized by Congress. The ITS JPO is part of the USDOT Office of the Assistant Secretary for Research and Technology (OST-R). This program encompasses a broad range of technologies applied to the surface transportation system. Under collaborative and transparent governance structure established for ITS JPO projects, the ITS JPO coordinates with and executes the program jointly in cooperation with all of the surface transportation modal administrations within the DOT to ensure full coordination of activities and leveraging of research efforts.

The USDOT is engaged in assessing applications that realize the full potential of connected vehicles, travelers, and infrastructure to enhance current operational practices and transform future surface transportation systems management. This effort is a collaborative initiative spanning the ITS JPO, Federal Highway Administration (FHWA), the Federal Transit Administration (FTA), the Federal Motor Carrier Safety Administration (FMCSA) and the National Highway Traffic Safety Administration (NHTSA).

One foundational element of the Connected Vehicle research efforts is the Transit V2I research area. The vision and objectives of the Transit V2I Program include:

Vision: Utilize Vehicle-to-Infrastructure communications to achieve safer, and more efficient, comfortable, reliable, and eco-friendly public transportation services that benefit all road users in general, and transit riders in particular.

Objectives: Use V2I technology:

- To prevent, reduce personal injury and loss of property resulting from transit vehicle collisions
- To optimize the effectiveness and efficiency of public transportation operations
- To improve traveler decision-making and access to transportation information
- To reduce transportation environmental impacts and maximize the benefits
- To quantify the transportation environmental impacts and benefits

A successful Transit V2I Program will lead to the more rapid and cost-effective deployment of interoperable technologies and applications that improve transit safety and enhance mobility for transit vehicles. The Transit V2I Program will act to promote the highest levels of collaboration and cooperation in the research and development of V2I applications for connected vehicles. The Transit V2I Program positions the federal government to take on an appropriate and influential role as a technology steward for a continually evolving integrated transportation system.

1.4 Document Overview

The purpose of this document is to communicate user needs and desired capabilities for and expectations of the Transit Traveler Information Infrastructure Mobility application. This document also serves to build consensus among transit user groups and stakeholders concerning these needs and expectations. It is expected that users will read this document to determine whether their needs and desires have been correctly captured. Potential system developers and integrators will use this document as a basis for understanding the purpose and scope of the application for future system development. Finally, the document should act as a guideline moving forward with research and development of any part of the Transit V2I Program.

As shown in the figure below, the Operational Concept provides a means for describing operational needs of a system without becoming overly detailed about technical issues that will be defined later in the process. Its purpose is to clearly convey a high-level view of the system to be developed that each stakeholder can understand. In doing so, the following questions are answered:

- **Who** – Who are the stakeholders/actors involved with the system?
- **What** – What are the elements and the high-level capabilities of the system?
- **Where** – What is the geographic and physical extent of the system?
- **When** – What is the sequence of activities that will be performed?
- **Why** – What is the problem or opportunity addressed by the system?

This document is intended to convey at a high-level how the application may work, so others may design and implement systems in the future. As such, this document and its complimentary Transit V2I Operational Concept documents are “generalized” and not specific to a geographic area, an operating entity (e.g., transit agency), existing systems that may be in place for a region, agency operating procedures, nor political environment.

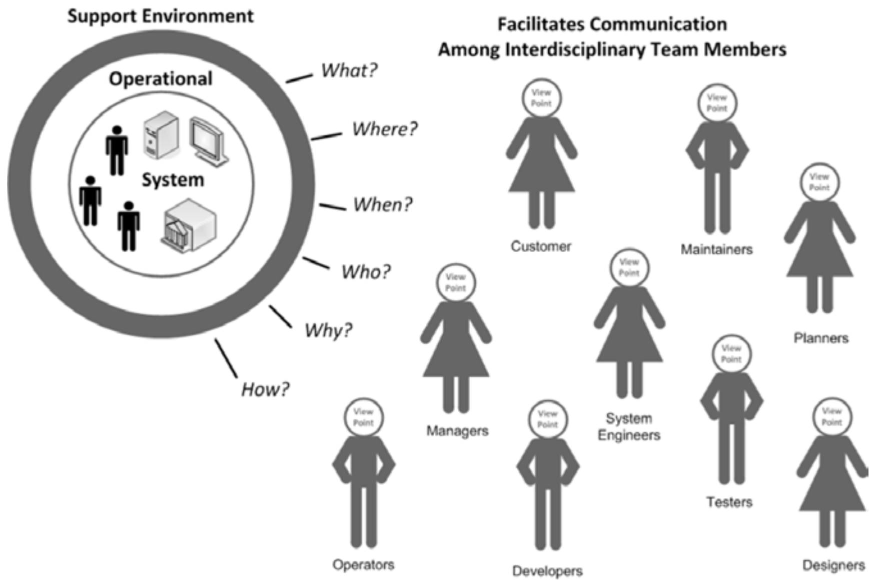

Figure 1-1: Conceptual Representation of the Operational Concept Document (*Source: USDOT, adapted from ANSI/AIAA's "Guide for the Preparation of Operational Concept Documents" ANSI/AIAA G-043-1992)*

This document is an interim document to a Concept of Operations that will be developed at a later date for specific prototypes and testing. Those Concept of Operations documents should use components of this document and present the materials in a format consistent with *IEEE Std. 1362-1998 IEEE Guide for Information Technology—System Definition—Concept of Operations (ConOps) Document*.

This document includes the following chapters:

- **Chapter 1** provides the scope, introduction to the Transit V2I Program, and an overview of the document.
- **Chapter 2** includes an overview of the Real-Time Data Capture and Management program and Dynamic Mobility Applications program, and the role of the Transit V2I Program to develop applications which leverage real-time data to improve mobility. This chapter also includes an overview of near term Transit V2I applications being investigated by the USDOT.
- **Chapter 3** provides a description of the current situation and is intended to help stakeholders better understand the reasons the application is desired. Included is a discussion of existing technologies that facilitate the communication and data exchange between transit vehicles and Transit Management Centers and between transit vehicles and wayside transit stop location infrastructure. In addition to V2I applications, a handful of I2P applications are included to provide greater context for the communication methods in use today by travelers to obtain information from transit management centers.
- **Chapter 4** describes the shortcomings of current systems, situations, or applications that motivate research and development of the prototype application. This chapter provides a transition from Chapter 3 of the Operational Concept, which describes the current situation, to Chapter 5, which describes the proposed prototype concept.

- **Chapter 5** describes the Transit Traveler Information Infrastructure Mobility application from a systems engineering perspective. This chapter begins with a description of the system and is followed by an architecture diagram of the application and user needs or desired capabilities of the system.
- **Chapter 6** provides scenarios which help the readers of the document understand how application may be implemented to provide mobility benefits to travelers. The scenarios are described in a manner that allows readers to walk through them and gain an understanding of how all the various parts of the application will function and interact.
- **Chapter 7** provides references used in the Operational Concept document.
- **Appendix A** provides a list of acronyms used in the report.
- **Appendix B** provides an alternate scenario with which to collect and disseminate Traveler-Sourced Data and Communication via Connected Infrastructure.

2 Overview of the Mobility Program and the Role of the Transit V2I Program

One of the main focuses of the USDOT's Connected Vehicle Research program is to use connected vehicle technology to improve mobility. Connected vehicle mobility applications provide a connected, data-rich environment. The network captures real-time data from equipment on-board vehicles (automobiles, trucks, and buses), within the infrastructure, and from travelers accessing trip planning and other mobility-oriented applications. The data are transmitted wirelessly and are used by transportation managers in a wide range of dynamic, multi-modal applications to manage the transportation system for optimum performance. With regards to mobility, there are two significant research programs oriented to the collection and development of applications which improve the safety and operational efficiency of transportation resources:

- Real-Time Data Capture and Management program; and
- Dynamic Mobility Applications program.

2.1 Real-Time Data Capture and Management

The objective of the Real-Time Data Capture and Management (DCM) research program is to enable the development of environments that support the collection, management, integration, and application of real-time transportation data or data sets.

Real-time data applications offer an ability to increase safety and operational efficiency nationwide. Not only will this data allow travelers to make better informed travel decisions, but public- and private-sector data on all modes and roads can be used to transform transportation management. Real-time data also have the potential to support a range of multi-modal mobility applications. Real-time information regarding transit schedule adherence, vehicle passenger capacity (for transit and ridesharing applications) and parking availability can enable more informed mode choice decisions and efficiencies for travelers. Updated freight movement data assists commercial freight operators with optimizing operations. Overall, the information developed from the DCM research program will reveal opportunities for achieving greater efficiencies within transportation systems.

Some types of data that can be captured and managed include: situational safety, environmental conditions, congestion data, and cost information derived from both traditional (e.g., traffic management centers, automated vehicle location systems) and non-traditional (e.g., personal information devices and connected vehicle equipment) sources. Data can also be collected from sources that generate data on elements of the transportation system such as transit stations and stops, toll facilities, and parking facilities.

The DCM Program plays a key role in supporting other initiatives identified in strategic plans, in the areas of safety, mobility, and environment. Many of these initiatives will require systematic capture and management of data over time to realize their objectives. The cross-cutting DCM Program is chartered to coordinate across these initiatives to identify comprehensive data needs.

The goals of the Real-Time DCM research program are to:

- Systematically capture real-time, multi-modal data from connected vehicles, devices, and infrastructure.
- Develop data environments that enable integration of high-quality data from multiple sources for transportation management and performance measures.

The Research Data Exchange (RDE) is a web-based data resource provided by the USDOT ITS JPO's DCM program. It collects, manages, and provides archived and real-time multi-source and multi-modal data to support the development and testing of ITS applications.

2.2 Dynamic Mobility Applications

The Dynamic Mobility Applications (DMA) program seeks to create applications that fully leverage frequently collected and rapidly disseminated multi-source data gathered from connected travelers, vehicles and infrastructure, and that increase efficiency and improve individual mobility while reducing negative environmental impacts and safety risks.

The USDOT has identified a portfolio of six high-priority mobility applications, including a common bundle collectively identified as Integrated Dynamic Transit Operations (IDTO), as part of the DMA program. The three applications under the IDTO bundle, Connection Protection, Dynamic Transit Operations and Dynamic Ridesharing, will ultimately enable transit systems to provide better information to travelers and increase the quality of service that they are able to provide. Being able to improve the transit experience will increase the use of public transit, allowing the program to meet its goals of improving the environment and increasing mobility.

In selecting these applications, the USDOT sought applications that had the potential to be transformative (i.e., they significantly alter existing transit services and result in substantial mobility improvements), are achievable in the near-term, and leverage the opportunities provided through connected entities. In the transit domain, this led to the selection of applications that already exist in some fashion today. These are applications that can evolve from their current state leveraging Connected Vehicle technology to offer significant transformative impacts while minimizing a number of the risks and delays inherent in developing entirely new concepts.

2.2.1 T-CONNECT

The goal of T-CONNECT is to improve rider satisfaction and reduce expected trip time for multimodal travelers by increasing the probability of automatic or intra-modal connections. T-CONNECT will protect transfers between both transit (e.g., bus, subway and commuter rail) and non-transit (e.g., shared ride modes) modes, and will facilitate coordination between multiple agencies to accomplish the tasks. In certain situations, integration with other IDTO bundle applications (T-DISP and D-RIDE) may be required to coordinate connections between transit and non-transit modes.

2.2.2 T-DISP

T-DISP seeks to expand transportation options by leveraging available services from multiple modes of transportation. Travelers would be able to request a trip via a handheld personal information device (or phone or personal computer) and have itineraries containing multiple transportation services (public transportation modes, private transportation services, shared-ride, walking and biking) sent to them via the same handheld device. T-DISP builds on existing technology systems such as computer-aided dispatch/automated vehicle location (CAD/AVL) systems and automated scheduling software. These systems will have to be expanded to incorporate business and organizational structures that aim to better coordinate transportation services in a region. A physical or virtual central system, such as a travel management coordination center (TMCC) would dynamically schedule and dispatch trips. T-DISP enhances communications with travelers to enable them to be presented with the broadest range of travel options when making a trip.

2.2.3 D-RIDE

The Dynamic Ridesharing (D-RIDE) application is an approach to carpooling in which drivers and riders arrange trips within a relatively short time in advance of departure. Through the D-RIDE application, a person could arrange daily transportation to reach a variety of destinations, including those that are not serviced by transit. D-RIDE serves as a complement subsystem within the IDTO bundle by providing an alternative to transit when it is not a feasible mode of transport or unavailable within a certain geographic area. The D-RIDE system would usually be used on a one-time, trip-by-trip basis, and would provide drivers and riders with the flexibility of making real-time transportation decisions. The two main goals for the D-RIDE application are to increase the use of non-transit ride-sharing options including carpooling and vanpooling, and to improve the accuracy of vehicle capacity detection for occupancy enforcement and revenue collection on managed lanes. By accomplishing these two goals, transit systems could also benefit from D-RIDE by reducing excess demand during peak periods, resulting in improved customer satisfaction and more appropriately and affordably scaled system designs.

2.3 Transit V2I Program Near-Term Applications

The Transit V2I Program identified twelve near term candidate applications that have the potential to maximize safety, mobility, and environmental benefits. The applications are depicted in Figure 2-1 and summarized below. Red icons indicate applications with the potential to impact safety, blue icons are related to mobility and the environment, and orange icons are crosscutting applications.

- **Red Light Violation Warning (Angle Crashes at Signalized Intersections).** The Red Light Violation Warning application includes a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes at intersections by warning the vehicle driver that a signal violation is predicted to occur. An equipped vehicle approaching an equipped intersection receives messages about the intersection geometry, signal phase and timing (SPaT) information, and if necessary, position correction information. The driver is issued an alert if the vehicle processing platform determines that, given current operating conditions, the driver is predicted to violate the signal such that the vehicle enters the intersection during the red phase.
- **Stop Sign Violation Warning (Angle Crashes at Non-Signalized Intersections).** The Stop Sign Violation Warning application includes a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes at intersections by alerting the vehicle driver that a stop sign violation is predicted to occur. An equipped vehicle approaching an equipped intersection receives messages about the intersection geometry and if necessary, position correction information. The driver is issued an alert if the vehicle processing platform determines that, given current operating conditions, the driver is predicted to violate the stop sign.

- **Left-Turn Assist (Left-turn Head-on Crashes at Intersections with Permissive Left-turn Phase.** The Left Turn Assist (LTA) application provides information to drivers performing unprotected left turns to judge the gaps in oncoming traffic and to warn them when it is unsafe to perform a left turn on a permissive green light. While this application may be supported using V2V communications where vehicles exchange information about their location, speed, trajectories, and other vehicles at the intersection, it may also leverage V2I communications such as SPaT, intersection map data, and infrastructure based vehicle and pedestrian detectors. The purpose of the application is to provide information to support the driver's decision making process regarding when it is unsafe to make a left turn at an intersection (i.e., gap rejection), but not make the decision for the driver. In other words, the LTA application does not tell the driver when it is safe to proceed, but assists with rejecting gaps that are unsafe.
- **Stop Sign Gap Assist.** The Stop Sign Gap Assist (SSGA) application provides the vehicle operator with timely, relevant information regarding unsafe conditions at a stop-controlled intersection. The SSGA safety application is intended to improve safety at two-way stop controlled intersections where only the minor road has posted stop signs. This application includes both onboard (for equipped vehicles) and roadside signage warning systems (for non-equipped vehicles). The purpose of the application is to provide information to support the driver's decision making process regarding when it is unsafe to proceed through the intersection (i.e., gap rejection), but not make the decision for the driver. In other words, the SSGA application does not tell the driver when it is safe to proceed, but assists with rejecting gaps that are unsafe.
- **Spot Weather Information Warning.** The Spot Weather Information Warning (SWIW) application is intended to improve safety in areas subject to repeated and localized adverse or inclement weather events, which may include relatively high-elevation or low-elevation areas that are more prone to reduced visibility, adverse surface conditions due to rain, snow, ice, and/or flooding, and high winds. This will be achieved through the integration of both vehicle-based and infrastructure-based technologies as well as backhaul networks to weather and TMCs, including onboard and roadside signage warning systems, to make drivers approaching an area with adverse weather conditions aware of the need to reduce speed or divert to safely navigate through or avoid the adverse weather impact area. This is not an application that is intended to provide the driver with weather information at every geographic location, but rather provide real time weather information at areas that are prone to adverse weather events, such as low-lying flood zones and bridges with high winds which may impose restrictions on high-profile vehicles. In this way, the SWIW application will help to increase driver awareness of the severity of hazardous weather conditions, reducing the risk potential for conflicts and crashes.
- **Transit Bus-Pedestrian/Cyclist Crossing Warning.** This application provides alerts to transit bus drivers of a pedestrian's or cyclist's presence while they are crossing the roadway at intersections and midblock crossings, using V2I wireless communications. When a pedestrian or cyclist is detected via the infrastructure, an RSU would send a message to nearby buses that a pedestrian or cyclist is in or may be entering the roadway. The application would provide alerts to bus drivers for all bus movements (left, right, and straight) at infrastructure-equipped signalized and non-signalized intersections and at midblock crossings when imminent conflicts with pedestrians and bicyclists are possible.

Figure 2-1: Transit V2I Applications (*Source: USDOT, 2014).*

- **3D Intersection Mapping for Collision Avoidance and Situational Awareness.** This 3D Mapping application enables RSU to rapidly recognize/update intersection configurations in 3D (latitude, longitude and elevation), including fixed objects such as signal cabinets and light poles. This 3D intersection configuration information embedded in the RSU will support V2I safety applications to mitigate single vehicle crashes.
- **Transit Bus Stop Pedestrian Safety.** The application, using V2I wireless communications, would provide alerts to pedestrians, via infrastructure (e.g., electronic signage with audible warnings), at major bus stops (e.g., those equipped with bus shelters serving multiple bus routes) indicating a transit bus' intention of pulling into or out of a bus stop. In certain situations and locations, the application may also alert pedestrians of motor vehicles in the vicinity of the bus stop, specifically alerting passengers alighting buses at the stop to address potential collisions of pedestrians with motor vehicles, whose sight are blocked by the bus.
- **Reduced Speed Zone Warning.** The Reduced Speed Zone Warning (RSZW) safety application features the concept of reduced speed zone where a reduction in transit approaching speed is required and/or advised, such as entrance to work zones, school zones, and roadway configuration alteration (e.g., lane closures, lane shifts). This will be achieved through the integration of both vehicle-based and infrastructure-based technologies, including onboard and roadside signage warning systems.

- **Transit Vehicle and Center Data Exchange.** Modern transit buses are equipped to collect/process data on transit vehicles (such as engine health monitoring) as well as the surrounding environment such as external facing digital cameras. This Transit Vehicle and Center Data Exchange application allows the authorized entities (such as traffic management centers, fire and emergency medical services [EMS], and Transit Management Centers) see what is happening at a location such as non-recurring congestion due to a crash or disabled vehicle by pinging an infrastructure point to request the next transit vehicle or vehicles passing the point to provide a snapshot of requested information, such as a short video. The bus could then capture a geo-referenced visual and upload at the next access point.
- **Transit Traveler Information Infrastructure.** The Transit Traveler Information Infrastructure application allows transit vehicles and travelers to be connected to nearby infrastructure, such as a smart intersection, smart bus stop, and smart parking. For example, transit vehicles would communicate with transit stops to provide travelers information on approaching vehicles, such as passenger loads, available disability seating, bicycle rack availability, fare information, etc. The application would support dynamic trip planning at transit stops.
- **Portable Infrastructure.** This transit V2I application features the concept of portable infrastructures such as portable RSUs and signage which may be used to handle special events (i.e., surging demand) at strategic locations, such as bus depots and light rail platforms to perform dynamic information collection/dissemination such as added buses or routes or assist transit vehicle maneuvers and detours.

Through a prioritization process that included both stakeholder input and USDOT strategic goals, two safety applications are being moved forward: Transit Bus-Pedestrian/Cyclist Crossing Safety Warning and Transit Bus Stop Pedestrian Safety. As the Crash Analysis showed, collisions with pedestrians and cyclists account for 14 percent of all motor bus collisions. The three costliest types of collisions (by average cost per collision) are all collisions with pedestrians, making it a high priority for USDOT and transit agencies alike.

Two potential mobility applications are also being investigated further: Transit Vehicle and Center Data Exchange; and Transit Traveler Information Infrastructure. These two applications show potential to leverage existing ITS technologies in a connected vehicle environment to improve mobility for all modes.

3 Description of the Current Situation

This chapter provides a description of the current situation and is intended to help stakeholders better understand the reasons the application is desired. Included are current projects, most of which are research projects or prototypes where the Transit Traveler Information Infrastructure Mobility Application may help improve traveler mobility. The end of this chapter briefly describes existing technologies and systems that have been implemented to improve mobility.

3.1 Introduction

While transit agencies across the country have been providing various levels of customer information via electronic means for the past several years, most of these systems have not utilized V2I technologies. For example, electronic signage that displays real-time arrival or departure information has been in existence for over 10 years, but is driven by communication between a transit control center and the signage, rather than between a vehicle and the signage. Further, the use of mobile devices to obtain traveler information typically uses cellular communication, which while included in V2I for mobility purposes, is not as prevalent as other types of wireless communication that are part of V2I. Wireless communication between travelers and transit stop infrastructure, parking infrastructure, and with transit vehicles themselves has also experienced limited implementation in operational environments.

However, there are several recent research projects and prototypes that are exploring or use V2I communications to provide traveler information. These projects are described in the following subsections.

3.2 Massachusetts Institute of Technology (MIT) EyeStops

The MIT SENSEable City Laboratory, in partnership with the City of Florence, Italy and ATAF Spa (the transit authority in Florence, Italy), is designing new bus shelters and related infrastructure to provide a variety of information to the traveler. The prototype designs incorporate digital technology and some V2I concepts. In these EyeStops, there are several services/applications available to travelers, including planning their trip on an interactive map, exchanging community information on a digital message board, accessing the Internet and using the media in the bus shelter as an interface to their personal information devices through wireless communication (e.g., Bluetooth).The design includes traveler information about "how far away their bus is and when it is expected to arrive using a lighting frame blinking with different intensity and modalities." [1]

Figure 3-1 and Figure 3-2 show the components of this type of bus shelter and bus stop sign, respectively. Rather than having to use cellular communication, travelers can use Bluetooth to request and obtain information on personal information devices. Transit vehicles can communicate with the infrastructure, providing location and real-time stop/station arrival estimates. Finally, "in addition to displaying information, the bus stop also acts as an active environmental sensing node, powering itself through sunlight and collecting real-time information about the surrounding environment." [2]

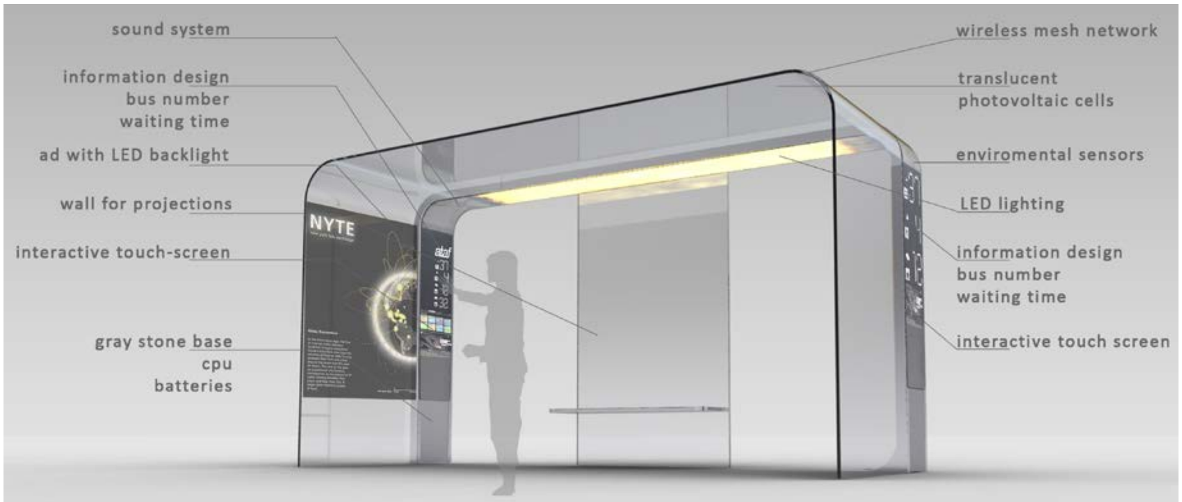

Figure 3-1: EyeStop Shelter *(Source: MIT SENSEable City Laboratory, 2009 [3])*

Figure 3-2: EyeStop Pole *(Source: MIT SENSEable City Laboratory, 2009 [4])*

3.3 Smart Bus Transport

In Auckland, New Zealand, Smart Bus Transport (SBT) was defined through a contest run by ChallengePost, a provider of hackathon and online technology challenge contests. SBT's design leverages an existing public application programming interface (API) and iBeacons (defined below) to assist public transport users. The key component of Smart Bus Transport, which is currently only a prototype, is a mobile application. SBT has the following major elements, including those that incorporate V2I, I2P, and V2P [5]:

- Journey planner. A mobile application leverages an existing journey planner coupled with the General Transit Feed Specification real-time (GTFS-RT) feed specification API to present enough data for a traveler to choose the best stop/route combination for the trip. The result groups various routes by stops and shows the walking distance to each stop and the bus' current distance to the stop.
- iBeacon bus stop verification. "iBeacon, Apple's implementation of Bluetooth low-energy (BLE) wireless technology, is used to provide location-based information and services to iPhones and other iOS devices. The same BLE technology is also compatible with Android 4.3. and above." [6] BLE, a wireless personal area network technology, enables hardware to send push notifications to devices in close proximity. BLE uses the same 2.4 GHz radio frequencies as Classic Bluetooth, which allows dual-mode devices to share a single radio antenna. In this I2P scenario when a traveler is within a certain range (e.g., 1 meter) of the correct bus stop's iBeacon, the mobile application would notify the traveler that they are standing at the correct stop location for the journey
- Bus arrival notification using iBeacon. In this V2I and I2P concept, buses will have iBeacon installed with which to wirelessly communicate with transit stops and passengers, respectively. For the V2P communication, when the mobile application detects that the correct bus' iBeacon is within a certain range, it notifies the traveler to board the bus. The mobile application, having previously received the iBeacon bus stop verification signal, simultaneously notifies the bus that a passenger is awaiting service at the stop location (V2I) and the traveler that the bus is approaching the stop location (I2P).
- Real-time bus position update with live map. This is a V2P element whereby a bus' real-time position will be displayed in the mobile application as text. A map can be provided to show a bus' current position.
- Driver dashboard to show passengers boarding status at each stop. When a traveler selects a specific trip, the application will update the boarding status of the current stop. The traveler's trip information is communicated from the mobile application to the wayside infrastructure in a P2I scenario. When the bus approaches the stop location, the wayside infrastructure communicates that a passenger is waiting to board. This is an I2V scenario.
- Stop arrival notification. The mobile application will notify the traveler when they arrive at the stop to alight the bus. This notification can be based on the distance between the traveler's current location and the destination bus stop. iBeacon can be used to increase the accuracy. The mobile application could communicate with the bus (P2V) to obtain the stop location data which is obtained through V2I communications.

Figure 3-3 shows the Smart Bus Transport system concept.

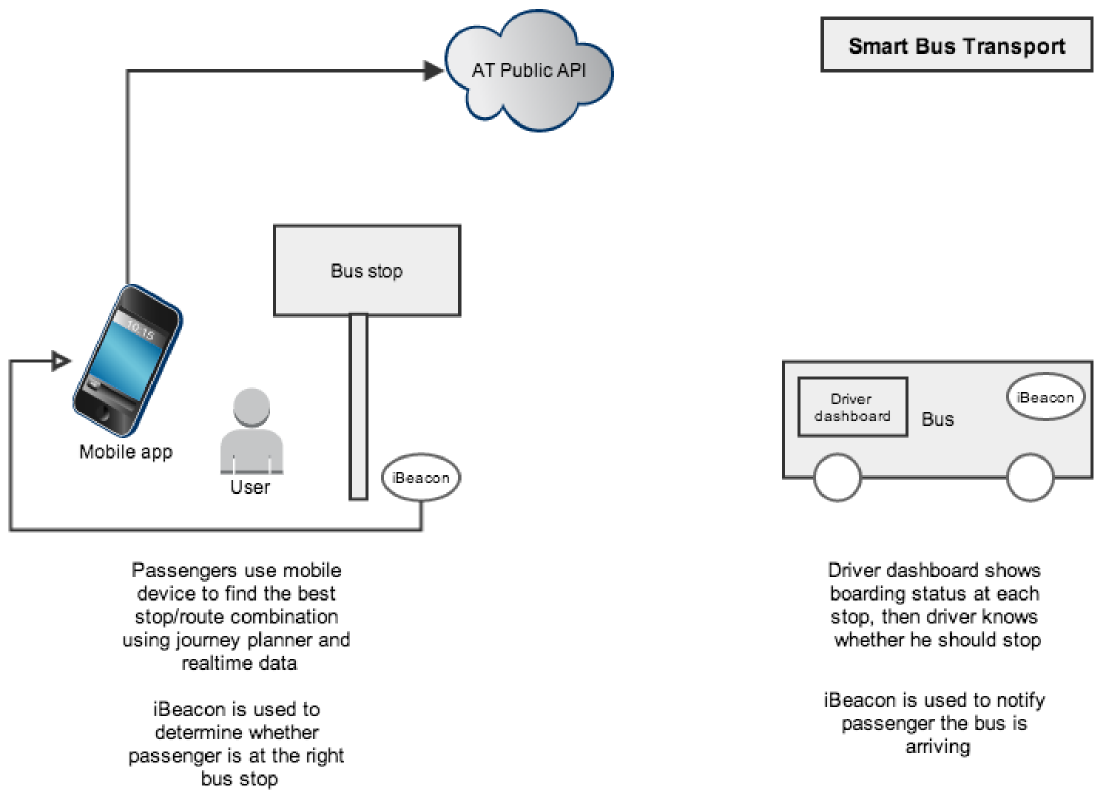

Figure 3-3: Smart Bus Transport *(Source: ChallengePost [7])*

3.4 Intelligence Bus System

In 2012, a Smart Bus System project initiated at the University of Victoria in Victoria, British Columbia resulted in the design of a system which applies available communication technologies (e.g., Bluetooth) to connect a transit authority and passengers. This system, which was never fully deployed, uses Bluetooth beacons installed in buses and bus stops to connect a bus and rider. The Bluetooth at the bus stop will detect the Bluetooth on buses that are approaching, and then inform the rider's Bluetooth-enabled cellphone of which buses are arriving. This system does not work well for persons with visual impairments since they would have to figure out which bus is the one they wish to board in the event there are multiple buses arriving at the same time. This situation led to a variation of this system in which a web service is used to connect buses, bus stops and riders' smartphones. Buses send GPS coordinates to the web service in real-time and the web service makes this information available at bus stops and on smartphones via a cellular data network. To request a pick-up, a rider standing at a bus stop sends a request to the web service; the web service determines which bus to forward the request to using the real-time database and forwards the request to this bus. Then the bus responds to the rider via the web service. When the bus arrives, the driver will stop the bus at the bus stop, and announce the bus number using a microphone or some other voice system so that the person who requested the ride knows if it is the correct bus to board. [8]

A bus stop will be equipped with both a radio frequency (RF) link as well as a Bluetooth beacon. The RF link will be used to receive real-time information from the transit center. This real-time arrival information will be displayed on electronic signs (e.g., liquid crystal display [LCD]). The Bluetooth beacon will enable communications with Bluetooth-enabled personal information devices at the stop. Real-time information will be available via a website and a personal information device app. This app will include real-time schedules, trip planner, bus stop locator and bus arriving alarm. The alarm will assist persons with disabilities by alerting their personal information device when the correct bus arrives. The bus stop will detect a Bluetooth-enabled personal information device within a specific distance and allow the app to transfer information displayed at the bus stop to the personal information device. When the bus arrives, the bus stop will alert the person(s) at the bus stop using voice or vibration function of the personal information device and at the same time sends a signal to let the bus know that a person with disabilities wishes to board.

3.5 The Smart Bus Stop

Yanko Design, a web magazine that reports on modern international design, described a V2I bus stop, primarily to assist travelers with visual and physical disabilities, as well as older people, “flag down” approaching buses by providing the driver with advance warning that a passenger is waiting at the stop. Figure 3-4 and Figure 3-5 show how the Smart Bus Stop works. It uses radio frequency identification (RFID) to identify which bus is approaching the stop, triggering an announcement to the waiting passenger.

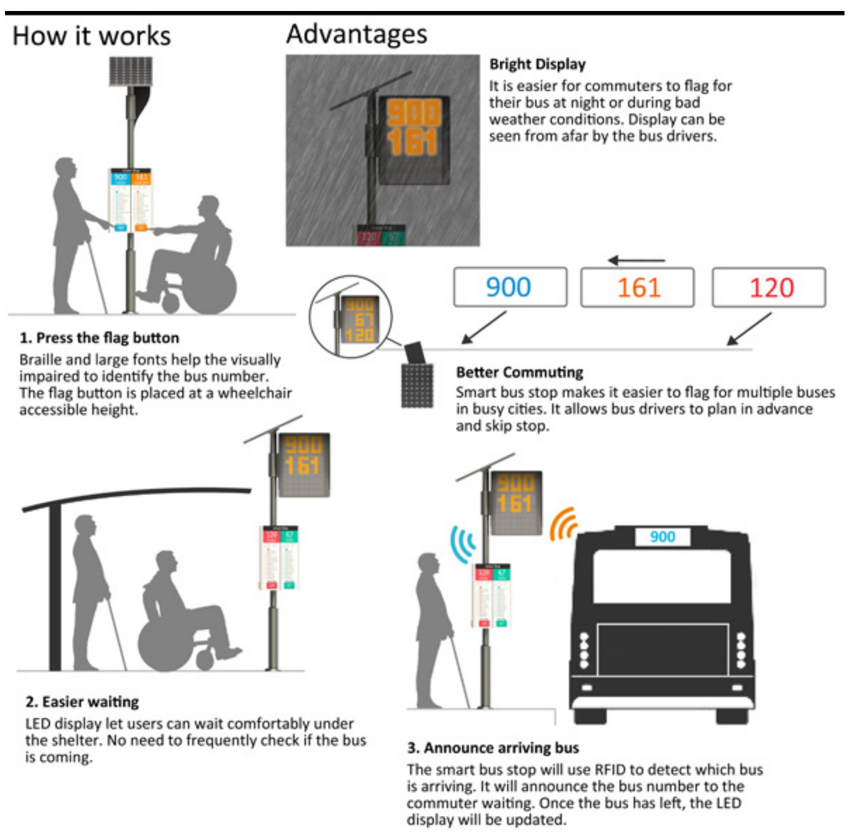

Figure 3-4: How the Smart Bus Stop Works *(Source: Yanko Design [10])*

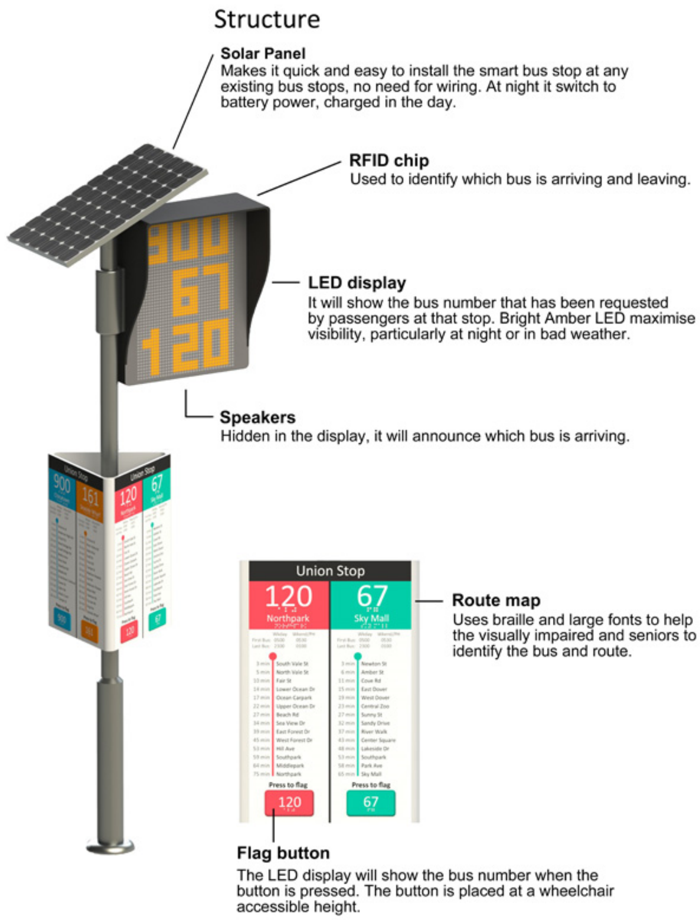

Figure 3-5: Bus Stop Sign *(Source: Yanko Design [11])*

3.6 Smart Cities Bluetooth Pilot

In Bremerhaven, Germany, in 2010 and 2011, there was a major test of Bluetooth technology as part of the European Bus System of the Future project to deliver community information to travelers in outdoor and indoor environments. People were able to obtain the information (text, audio, videos and pictures) using one of the info-terminals located around the city. These ten info-terminals, which were installed at selected locations along bus route 502, were equipped with Bluetooth technology so that users could receive information free of charge about the city direct to their personal information devices as they travel. During the project, the information was exclusively related to the city's tourist attractions, but it could be expanded in the future to include public transport announcements or even special offers from nearby retailers, for example. With the success of personal information devices, the results of the project recognized that there is an increasing demand for information exchange with these devices. The Bluetooth approach enabled customers to integrate the information available on the info-terminals with their personal information devices and take information with them for later use. [12]

Figure 3-6 shows the information terminals that were tested in Bremerhaven.

Figure 3-6: European Bus System of the Future (EBSF) Information Terminals *(Source: SmartCities Project [13])*

3.7 Next Vehicle Passenger Load/Vacancy Information System

Passenger load/vacancy information systems are designed to provide travelers waiting to board an approaching transit vehicle with the load information to solve the overcrowding issues that affect urban transit systems during the rush hour period. The information system is intended to allow for a more efficient distribution of travelers between cars. The concept was first described in *Subway passenger loading control system* (US Patent 5176082 A) [14]:

> "Displaying passenger vacancy information at each passenger entrance at the station prior to the arrival of the subway train is very important for more even loading of passengers in the subway cars. This is because passengers will seek and line up at the loading zone where vacancy on the subway train is indicated to be available. If no

vacancy is available in any loading zone then they will line up where the length of the queue minus the vacancy displayed is the smallest."

3.7.1 Check Room

"Check Room" is a concept presented at the 2014 Spark Design Awards. It aims at solving the overcrowding issue in the subways during rush hour by allowing a more efficient distribution of commuters between subway cars. Check Room calculates the aggregate weight of a subway car's passengers and compares it to the car's weight capacity. The ratio is displayed as a percentage on an LED screen outside the car door. The concept requires wireless V2I communication between the vehicle and dynamic message signs (DMS) located on the platform, so that commuters can identify in advance the least-crowded cars.

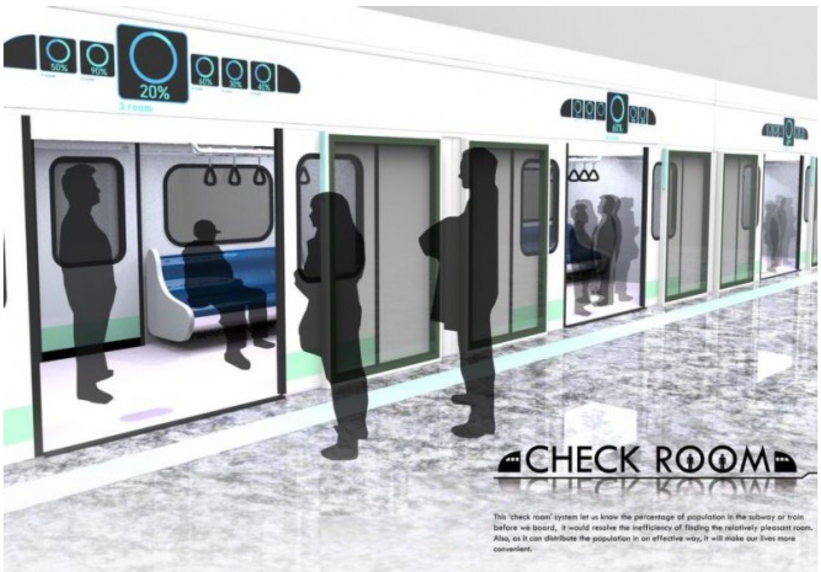

Figure 3-7-1: Check Room System Concept *(Source: PSFK [15])*

3.7.2 London Tube Concept

A digital platform display that indicates the passenger volumes of various cars has also been theorized as a potential solution for addressing crowding on the London Tub. This theoretical solution would obtain passenger load factors using body-heat camera sensors or carriage weight sensors. The information would be wirelessly communicated in real-time, from the vehicle to platform screens.

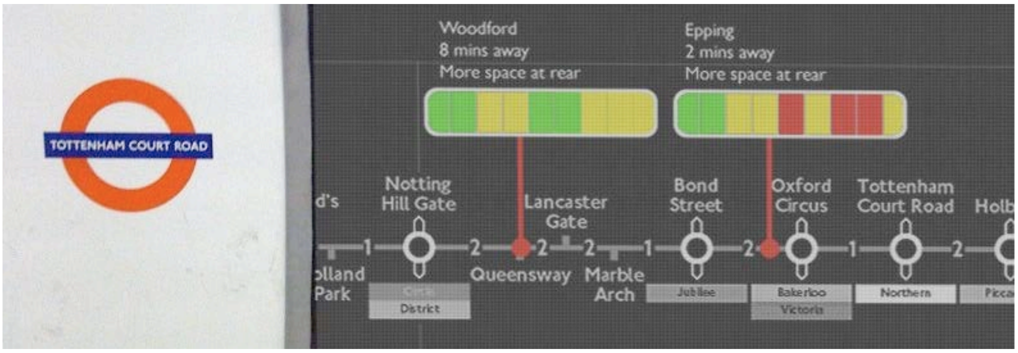

Figure 3-7-2: London Tube Operational Concept *(Source: Citylab [16])*

3.8 Other Examples

Before technological improvements provided easy access to the Internet, public transit authorities considered electronic signs (considered infrastructure in the V2I context) as the first step in providing both static and real-time information to passengers at stops and stations. According to *TCRP Synthesis 48: Real-time Bus Arrival Information (2003),* "the most prevalent medium used for the distribution of real-time bus arrival information is the electronic sign, also known as a dynamic message sign (DMS), located at a bus stop." [17] As of 2012, DMS deployment was growing rapidly throughout the United States and abroad as a result of positive customer reactions to real-time information and the prospect of increasing ridership because of sign implementation.

In recent years, agencies have been taking full advantage of almost universal access to the Internet and high mobile phone ownership rates to provide information through these media (using cellular communication) in addition to electronic signage. From *TCRP Synthesis 91: Use and Deployment of Mobile Device Technology for Real-Time Transit Information (2011)*, "The demographics of transit riders have changed significantly over the past five years with many more riders and non-riders using cell phones or even smartphones, which provide Internet access and other capabilities such as mobile e-mail and application programs. This has prompted transit agencies to look beyond providing information by means of traditional dissemination media such as dynamic message signs (DMS), which require more resources to implement (e.g., cost for installation, power, communication, and maintenance). At the same time, agencies' capabilities to provide real-time information have grown considerably with many agencies deploying technologies that allow them to provide customers with real-time information, such as when the next vehicles will arrive at a particular stop or station." [18] Further, current customer expectations for real-time information on mobile phones and smartphones have prompted many agencies to focus on meeting these high expectations through mobile device applications.

While cellular communication, which is typically used by most personal information devices, is part of V2I, other communication methods are more prevalent within V2I. For example, the use of Bluetooth to provide real-time arrival information is being used in several of the aforementioned projects within the V2I context. Further, transit agencies have recognized that not all of their customers carry mobile phones or smartphones, and these personal information devices can have limited use because of the availability of cellular communication networks. Therefore, information provided on these devices may need to be provided using other communication methods (e.g., Bluetooth) and on other media such as electronic signs (infrastructure). Thus, the mobility application described in this report should be considered for demonstration.

4 Limitations of Existing Systems and Justification for Change

Chapter 3 provided an overview of existing technologies and systems to enhance communication between a transit vehicle, Transit Management Centers, wayside infrastructure, and with travelers. While these systems have shown promise in improving safety and mobility, it is envisioned that connected vehicle technologies have the potential to provide additional benefits beyond current systems. This chapter discusses the limitations of existing systems and provides justification for connected vehicle applications.

This analysis was conducted based on very preliminary and incomplete definitions of the application. The findings will likely change to some extent as the concepts of operation and the requirements for the application are developed.

4.1 Limitations of Existing Systems

The connected vehicle environment will produce an enormous volume of data and a potential new interface to use to communicate with a traveler. Current practices will need to be modified to take advantage of these new capabilities. For example, connected vehicle systems will produce a large volume of raw traffic and transit data that will require real-time aggregation and processing. This may also require changes in the operating procedures for transit operators and managers. Similarly, if a different tool to deliver appropriate information to travelers becomes available, this will also change the procedures and the roles of operators and managers, resulting in a different form of service delivery.

4.2 Connected Vehicle Technologies

Connected vehicle technologies offer tremendous promise for safety and mobility improvements. Connected vehicle technologies function using a V2V and V2I data communications platform that, like the Internet, supports numerous applications, both public and private. This wireless communications platform provides the foundation to integrate data from the infrastructure (e.g., kiosks) with data from the vehicle (e.g., position, speed). For this particular transit mobility application, V2I communications protocols do not necessarily exist yet. However, data being generated by or sent to the infrastructure or vehicles can be used by mobility applications to provide travelers with information en-route or at the stop.

Connected vehicle V2I data communications will enable vehicles to communicate with infrastructure located on the roadway. V2I mobility applications can utilize DSRC and other low latency communications. Over the course of this mobility-oriented research, it became apparent that V2I mobility applications may require the creation of a standard protocol with which to communicate and transfer mobility-related information. It is conceivable that the Transit Communications Interface Protocols (TCIP) or other similar standard could be used to transmit the mobility data necessary to meet the intended functionality of the Transit Traveler Information

Infrastructure Mobility application. Further research is warranted regarding the transfer of mobility data in the connected vehicle environment.

Figure 4-1 illustrates the concept of data transmission to/from a transit vehicle in the connected vehicle environment. In context of the Transit Traveler Information Infrastructure mobility application, V2I communication would enable transit vehicles to communicate with infrastructure located at a transit stop or station. For example, transit vehicles may send messages to infrastructure about the vehicle's location and expected time of arrival at the stop or station. Likewise, data originating from the infrastructure at the stop/station (e.g., expected time of arrival for the next three transit vehicles arriving at/departing that stop/station) may be sent to transit vehicles approaching the stop/station. Travelers awaiting service at a stop/station may communicate with connected infrastructure to request transit services (e.g., I2V through a connected kiosk at the stop/station), indicate presence at the stop location to board oncoming transit services (e.g., I2V through a connected kiosk or in a P2I/P2V context), and to obtain relevant real-time information regarding services offered at the stop/station.

Figure 4-1. A Connected Transit Vehicle *(Source: USDOT, 2014)*

Connected vehicle technologies, as they relate to the Transit Traveler Information Infrastructure mobility application, are discussed in more detail in Sections 5 and 6.

4.3 Description of Desired Changes

In addition to safety, the objective of the Transit V2I Program is focused on how connected vehicles can provide mobility benefits for users of all modes. The focus of the changes to existing systems involves both the mechanism and nature of the information being provided to the motor bus from infrastructure (e.g., stop request from a traveler at a transit stop to a motor bus) and information being provided to infrastructure by the motor bus (e.g., vehicle passenger load). In short, the desire is to test the feasibility of using connected vehicle technologies to provide mobility enhancements. A key priority is to integrate the connected vehicle technologies onto an existing transit vehicle and at connected transit stop locations.

This Operational Concept presents an opportunity to enhance the level of detail provided to travelers while also facilitating a direct-line of communication between travelers and the transit agency. The increased level of detail includes the provision of additional information not currently provided to travelers through conventional ITS systems. This information includes: passenger loads aboard transit vehicles as they approach a transit stop, dynamic transit services including those identified as part of the IDTO bundle of applications, and other similar information communicated to travelers through the TIC to dynamic message signs, kiosks, personal information devices, and other associated physical infrastructure. The Operational Concept also satisfies a desired line of communication between the traveler and the agency that is not currently achievable through existing ITS technologies and associated applications. This direct communication enables the agency to collect valuable data at a granular level regarding personal travel patterns. It also facilitates the provision of specialized and/or dynamic transit services that better address actual travel patterns and needs.

From an operational perspective, significant impacts are expected after the application is implemented. Currently, many transit agencies operate independently and do not coordinate services with other agencies. While coordination results in a more efficient and effective mechanism to provide transit services, it does cause changes in the way agencies schedule and operate their services.

A fundamental limitation that must be considered in order to facilitate the transmission of mobility data is the standard message that will be used. As indicated in Section 4.2, BSM Part 1 and 2 does not account for the transmission of mobility data (e.g. passenger count aboard transit vehicles, transit vehicle-captured sensory data, etc.) As such, this operational concept suggests the formation of a new message or adaptation of an existing protocol that would serve as the standard communications protocol for transit mobility-oriented data.

5 Transit Traveler Information Infrastructure Mobility Application

5.1 Application Overview

The Transit Traveler Information Infrastructure application connects transit vehicles and travelers to nearby infrastructure, such as a smart bus stop, smart intersection and smart parking. Connected transit vehicles would communicate wirelessly with transit stop infrastructure, communicating key mobility information such as: schedule adherence, vehicle position/heading, travel speed, passenger loads, priority seating availability for persons with disabilities, bicycle rack availability, connection protection status, and fare information, among other data. Through connected infrastructure, this information would be transmitted to transit management centers and disseminated to travelers through the Transportation Information Center (TIC). A key component of the application is the ability to support dynamic trip planning at transit stops. The infrastructure will allow travelers to plan, schedule, and pay for transit and alternate transportation services including ridesharing services, bike/car share, parking, and other modes. The infrastructure will allow travelers to communicate stop requests to oncoming transit vehicles, indicating that travelers are awaiting service at the stop/station. The application will also enable travelers with personal information devices to communicate with the transit vehicle via the roadside infrastructure.

The Operational Concept discusses the following scenarios:

- **Scenario 1:** V2I (and I2V) traveler information and dynamic trip planning at bus stops for travelers without personal information devices. An alternate scenario specific to the provision of connection protection information to travelers without personal information devices, en-route and on-board the transit vehicle, is also provided.
- **Scenario 2:** V2I (and I2V) traveler information and dynamic trip planning at bus stops for travelers with personal information devices.

The system architecture for the Transit Traveler Information Infrastructure application includes the following nine actors:

- **Traffic Management Center (TMC).** The TMC monitors and controls traffic and the road network. It represents centers that manage a broad range of transportation facilities including freeway systems, rural and suburban highway systems, and urban and suburban traffic control systems. It communicates with ITS roadway equipment and Connected Vehicle RSU to monitor and manage traffic flow and monitor the condition of the roadway, surrounding environmental conditions, and field equipment status. It manages traffic and transportation resources to support allied agencies in responding to, and recovering from, incidents ranging from minor traffic incidents through major disasters.
- **Transit Management Center.** The Transit Management Center manages transit vehicle fleets and coordinates with other modes and transportation services. It provides operations, maintenance, customer information, planning, and management functions for the transit property. It spans distinct central dispatch and garage management systems and supports the spectrum of fixed route, flexible route, paratransit services, transit rail, and bus rapid transit

(BRT) service. With respect to the Transit Bus and Center Data Exchange application, the Transit Management Center is responsible for the delivery of transit services, the collection and dissemination of transit data (e.g. transit schedule, fares, and real-time departure information), and the maintenance of transit stop facilities and associated infrastructure (e.g. RSU, message signs, and kiosks). The Transit Management Center interfaces allow for communication between transit departments and with other operating entities such as emergency response services and traffic management systems, among others.

- **Transportation Information Center (TIC).** The TIC collects transportation-related data from other centers, performs data quality checks on the collected data and then consolidates, verifies, and refines the data and makes it available in a consistent format to applications. The TIC supports operational data sharing between centers and delivers traveler information to end-users. The TIC provides a bridge between the various transportation systems that produce the information and the other TICs and their subscribers that use the information. The TIC delivers traveler information to subscribers and the public at large. Information provided includes basic advisories, traffic and road conditions, transit schedule information, ridematching information, and parking information. The TIC is commonly implemented as a website or a web-based application service, but it represents any traveler information distribution service including systems that broadcast digital transportation data (e.g., satellite radio networks) and systems that support distribution through a connected vehicle network. The TIC can be accessed at transit stations through a dedicated kiosk, web-portal, or personal information device. The TIC is comparable to the Information Service Provider center subsystem in the National ITS Architecture.
- **Roadside Unit (RSU).** The RSU actor includes devices that are capable of both transmitting and receiving data using DSRC radios, using the 5.9 GHz band approved for DSRC use by the FCC. For this application, RSUs will be deployed at selected intersection and roadside locations and at designated transit stop locations. These RSUs will provide necessary infrastructure information (e.g., SPaT, Traveler Information Message [TIM], MAP, etc.) to the Transit Vehicle Actor for processing and triggering alerts to the Transit Vehicle Driver actor as appropriate. An RSU is a device that:
    - Contains multiple radio sets for localized communication over 5.9GHz, compliant with FCC regulations for DSRC
    - Contains an integrated GPS receiver for positioning and UTC time
    - Contains a PoE capable Ethernet interface that supports IPv4 and IPv6 connectivity, compliant with 802.3at, and is housed in a dedicated, NEMA 4X-rated enclosure
- **Public Information Device.** Provide access to traveler information at transit stations, transit stops, and other fixed sites along travel routes (e.g., parking facilities). Public information devices may be integrated with RSUs to provide advanced communication capabilities with transit vehicles and transit management centers, among other connected infrastructure. Public Information Devices support varied levels of interaction and information access and may include kiosks and informational displays. At transit stops, simple displays providing schedule information and imminent arrival signals can be provided. With respect to the Transit Traveler Information Infrastructure application scenarios, this information may be extended to include multi-modal information including traffic conditions and transit schedules. Personalized route planning and route guidance information is also provided based on criteria supplied by the traveler. It may also support the electronic payment of fares and the creation of user-accounts to facilitate trip planning, payment, and other individualized preferences.

- **Transit Vehicle.** This actor is a vehicle that provides the sensory, processing, storage, and communications functions necessary to support safe operations. DSRC radio communications allow the Transit Vehicle actor to disseminate information about its status (i.e., current speed, acceleration, braking, and average emissions) and receive information and/or commands from the TMC, Emergency Management Center (EMC), and transit dispatch center (e.g., engage on-board surveillance to monitor an incident) through the Roadside Unit actor or via existing cellular communications. The Transit Vehicle includes several subsystems, such as Driver-Vehicle Interface (DVI), GPS receiver and antenna, Automatic Passenger Counters (APCs), etc.
- **Traveler.** The Traveler represents any individual who uses transportation services. The interfaces to the traveler provide general pre-trip and en-route information supporting trip planning, personal guidance, and requests for assistance in an emergency that are relevant to all transportation system users. It also represents users of a public transportation system and refers to interfaces these users have within a Transit Vehicle or at transit facilities such as transit stops and centers.
- **Transit Vehicle Driver.** The Transit Vehicle Driver actor represents the human entity that operates a licensed transit vehicle on the roadway. For the purposes of this document, the driver operates a Transit Vehicle. This actor originates driver requests (e.g. emergency alarm) and receives driver information that reflects the interactions which might be useful to transit vehicle.
- **Personal Information Device.** The personal information device provides the capability for travelers to receive formatted traveler information regardless of their location. Capabilities include traveler information, trip planning, route guidance, and payment. It provides travelers with the capability to access route planning data from home, work, or en-route. The personal information device may be used to communicate wirelessly with infrastructure (I2P) or with transit vehicles (V2P). The Personal Trip Planning and Route Guidance application, located within the TMC and accessed via the personal information device, provides a personalized trip plan to the traveler. The trip plan is calculated based on preferences and constraints supplied by the traveler and provided to the traveler for confirmation. Coordination may continue during the trip so that the route plan can be modified to account for new information. Devices represented by this application object include desktop computers at home, work, or at major trip generation sites (e.g., kiosks), plus personal devices such as tablets and smart phones.

5.2 Assumptions

One significant assumption is that the use of Connected Vehicle technology for the Transit Traveler Information Infrastructure Mobility Application requires DSRC both in the transit vehicle and at infrastructure located near or at the transit stop locations. It is assumed that the Public Information Device infrastructure could include connected kiosks where travelers may access the TIC to trip plan and request dynamic services. It is also assumed that dynamic message signs (DMS) may serve as infrastructure at transit stop locations. Furthermore, the application is hinged on the development of the TIC whereby Travelers, through personal devices or kiosks, may access a slew of applications to obtain real-time departure information, request dynamic services, request connection protection, request transit stops, and provide travel plan details to the TMC, among other features.

During the design of the application careful consideration should be given to the type of communication required for this application. DSRC offer low latency communication whereas other forms of wireless communication may have higher latency that may not meet the requirements for the application. This Operational Concept document is technology agnostic, instead assuming that radio communication is available and being used by all vehicles and infrastructure and possibly travelers.

A second assumption is that there will be a standardized message for DSRC transmission of mobility data.

6 Scenarios

This chapter describes the scenarios for the Transit Traveler Information Infrastructure application. A scenario is a step-by-step description of how the proposed systems should operate, with actor interactions and external interfaces described under a given set of circumstances. Scenarios help the readers of the document understand how all the pieces interact to provide operational capabilities. Scenarios are described in a manner that allows the reader to walk through them and gain an understanding of how all the various parts of the Operational Concept will function and interact. Each scenario includes events, actions, stimuli, information, and interactions as appropriate to provide a comprehensive understanding of the operational aspects of the proposed systems. These scenarios provide readers with operational details for the proposed systems; this enables them to understand the actors' roles, how the systems should operate, and the various operation features to be provided.

The two scenarios described are:

- **Scenario 1: V2I (and I2V) traveler information and dynamic trip planning at bus stops for travelers *without* personal information devices.** This scenario describes the provision of traveler information, including dynamic trip planning, at transit stops. The scenario assumes that the traveler does not have access to a personal information device (e.g., mobile device). Connected transit vehicles communicate mobility data with RSU and connected transit stop/stations using DSRC. This data is provided to the Transit Management Center and processed by the TIC which disseminates information to travelers through mobility-specific planning applications and through Public Information Devices.
- **Scenario 2: V2I (and I2V) traveler information and dynamic trip planning at bus stops for travelers with personal information devices.** This scenario describes the provision of information to travelers with personal information devices. The device provides the capability for travelers to receive real-time information at the transit stop location (V2I) and en-route through V2I2P and P2I2V communications. V2I communication through an RSU, may serve as a physical gateway for the traveler to access multi-modal travel planning applications hosted within the TIC. The personal information device may also be used to communicate wirelessly with connected vehicle OBE (e.g., to request a transit stop or pay a fare).

All of the scenarios assume that the Transit Vehicle is equipped with the necessary on-board technology to collect and disseminate the required data.

6.1 Scenario #1: V2I (and I2V) traveler information and dynamic trip planning at bus stops for travelers *without* personal information devices

Description: This scenario describes the provision of traveler information and dynamic trip planning capabilities at transit stops/stations. The scenario assumes that the traveler does not have access to a personal information device. In this scenario, there are two primary Public Information Device infrastructure types used to provide information to the traveler at the transit stop: Dynamic Message

Signs (DMS) and Kiosks. It is assumed that both pieces of infrastructure will be integrated with RSU to communicate in a connected environment and possess the capabilities to collect, manage, and process data. The transit stop RSU will communicate wirelessly with transit connected vehicles using DSRC communications. The transit vehicles will provide mobility data including: location, heading, on-board passenger count, schedule adherence, availability of priority seating for persons with disabilities, service disruptions/delay or other traveler information-related concerns, and other relevant data. The transit stop location RSU will transmit, via backhaul communications, this information to the Transit Management Center, TMC, and TIC for processing and inclusion in trip planning and other mobility applications. This information will be made available to travelers at transit stop locations.

The first level of trip planning information is provided to Travelers as they approach the transit stop/station. The DMS displays the real-time departure information for the scheduled transit services at the stop location. This real-time information is communicated wirelessly from the transit vehicle to transit stop RSU. The estimated departure time is calculated by the Transit Management Center from the data obtained from the Connected Transit Vehicle's OBE. The TIC's Transit Center Information Services application collects the real-time information for the transit service and makes the data available to Travelers through the TIC for distribution. The Transit Stop Information Services application furnishes the DMS with the real-time travel-related information for the stop/station and the services available at the location. This real-time departure information allows the Traveler to decide if the scheduled transit services at the stop location satisfy the trip requirements. Two alternate sub scenarios are presented:

a) If the scheduled transit services *do* satisfy the trip requirements, the Traveler may indicate their presence at the stop/station and issue a stop request to the upcoming Transit Vehicle. A push button (or similar input) on the DMS or Kiosk enables the Traveler to issue stop request. The stop request is transmitted to the corresponding Transit Vehicle via DSRC communications. The Transit Vehicle DVI is updated, informing the Transit Vehicle Driver that a stop request has been made by a Traveler at the stop/station.

b) If the scheduled transit services *do not* satisfy the trip requirements (e.g., transit service does not travel to the destination of the traveler's trip), dynamic trip planning may be available to the traveler. At the transit stop, the connected kiosk allows the traveler to select from the dynamic services available. The kiosk serves as a physical infrastructure gateway for the traveler to access the applications of the TIC, including, but not limited to:

   - **Trip Planning.** This application provides pre-trip and en-route trip planning services for Travelers. It receives origin, destination, constraints, and preferences and returns trip plan(s) that meet the supplied criteria. Trip plans may be based on current traffic and road conditions, transit schedule information, and other real-time traveler information.
   - **On-Demand Service / Dynamic Ridesharing**. This application provides dynamic rideshare matches for Travelers, connecting travelers and drivers for specific trips based on preferences. This ridesharing/ridematching capability also arranges connections to transit or other multimodal services for portions of a multi-segment trip that includes ridesharing. Reservations and advanced payment are also supported so that each segment of the trip may be confirmed.
   - **Travel Services Information.** This application disseminates information about traveler services such as lodging, restaurants, and service stations. Tailored traveler service information is provided on request that meets the constraints and preferences specified by the Traveler.

The kiosk permits the Traveler to request dynamic services to the transit stop. A user profile is not required to request service; however Travelers are required to pay the fare for the service before the trip is scheduled. A Payment Device at the kiosk may facilitate the trip scheduling and payment, but is not required for the scenario. Once the trip is confirmed, the kiosk and/or DMS at the transit stop provide real-time departure information to the traveler once the transit vehicle (or rideshare vehicle) is assigned/dispatched and en-route. Rideshare vehicles would be required to be equipped with DSRC communications hardware with which to communicate location, availability (seats and rideshare), and other key data with the TMC and TIC.

Actors. Traveler; Public Information Devices (includes DMS and kiosks at the transit stop/station); RSU; TIC; Transit Management Center; and Transit Vehicle.

Constraints and Assumptions. The following constraints apply to this scenario:

- Transit Vehicles are equipped with communication radios capable of transmitting or receiving messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- The Transit Vehicle's OBE meets minimum performance requirements (e.g., SAE J2945) as needed.
- Positioning data is accurate to provide the predicted real-time departure time of the Transit Vehicle using global positioning (GPS) technology.
- The Transit Vehicle is equipped with a DVI to communicate transfer requests, schedule adherence, fare validation, and other service-oriented information to the vehicle operator.
- For dynamic ridesharing, connected vehicles are equipped with communication radios capable of transmitting or receiving messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- A Channel Plan is in place to allow the RSU to transmit and receive BSMs and other mobility messages.
- A Security Credential Management System is in place to allow RSUs to check BSMs and other messages.
- RSUs are equipped with communication radios to transmit messages or receive messages from infrastructure and vehicle. In this scenario, messages are transmitted and received using DSRC. The RSU may be integrated with Public Information Devices to allow travelers to communicate with the Transit Management Center or TIC from roadside infrastructure (e.g. kiosks).
- The Traveler Information Broadcast application within the TIC disseminates traveler information to the transit stop Public Information Devices via RSU.
- The TIC is equipped to handle trip planning, dynamic ridesharing, dynamic transit operations, and traveler information distribution, among other core connected vehicle functions. The TIC is equipped to communicate trip planning and trip requests to the Transit Management Center for overall demand responsive transit schedules and deployment.
- The Transit Vehicle is equipped with other OBE (not mentioned above) including but not limited to: an Automatic Passenger Count system, an Automatic Fare Collection System, Surveillance System, Interior/Exterior Dynamic Message Signs, Automatic Voice Announcement, and a Cellular Based Communications System.

- The Public Information Device displays the predicted departure information for the scheduled transit services on a display.
- The Payment Device is capable of wirelessly communicating with contactless fare media and/or with personal information devices.

Preconditions. The following preconditions apply to this scenario:

- A combination of or all of the following transit services are available at the transit stop and within the geographic area of the scenario: fixed-route transit, dynamic ridesharing, demand-response transportation, and dynamic transit services.
- The vehicles serving the stop location communicate transit schedule adherence and transit vehicle location information in real-time to the Transit Management Center. This is information is provided to the TIC, which is tasked with collecting, processing, storing, and disseminating transportation information to system operators and the traveling public.
- The scenario occurs within the regular operational hours of the transit services.

Flow of Events. The flow of events is included below:

A DMS is visible as the Traveler approaches the transit stop/station. The DMS displays the route name/number, destination and predicted real-time departure time for all transit services at the stop location.

1) The Traveler determines that the current scheduled services meet the trip requirements.

1a. The Traveler issues a stop request by selecting the route from the kiosk or by pushing a button attached to the DMS. The RSU emits a stop request message.

1b. The Transit Vehicle receives the message via DSRC. The vehicle DVI is updated and informs the Driver that a Traveler is requesting service from the stop/station location.

2) The traveler determines that the current scheduled services do not meet the trip requirements.

2a. The traveler approaches the dynamic trip planning kiosk. There are two-sub events within the scenario:

i. The traveler uses a contactless media card to wirelessly engage the Payment Device at the kiosk. The kiosk retrieves the traveler's profile from the TIC Interactive Traveler Information application. The provided information includes personal identification, traveler preferences (e.g., maximum transfer wait time, maximum walking distance, mode preferences, and special needs), device information, and information to support payment.

ii. The traveler does not have a Payment Device. The traveler elects to begin the TIC Trip Planning application on the kiosk.

2b. The application determines the trip origin (based on the transit stop location) or prompts traveler to input an origin. The application prompts the traveler to select the desired destination.

i. For travelers with user profiles, the traveler is provided with a list of common destinations specific to their prior travel requests. The traveler may also provide a destination for the trip request or select from a pre-populated list of destinations.

   ii. For travelers without user profiles, the traveler is required to provide a destination for the trip request or select from a pre-populated list of destinations.

2c. The application prompts the user to submit other trip constraints, including, but not limited to: the desired departure or arrival time, desired fare, mobility accommodations, and maximum number of transfers.

2d. Based on the criteria input into the TIC Trip Planning application, the TIC, through aggregated and processed real-time multi-modal data, determines location of existing vehicles, evaluates scheduling manifest of existing connected vehicles (for dynamic ridesharing) and selects the "best fit" vehicle to serve request.

2e. The traveler is presented with a prioritized list of travel options based on the input criteria. The application prompts the traveler to accept or decline the trip.

   i. For travelers with user profiles, when the trip is accepted, the payment may be automatically deducted from the user profile (in accordance with the user profile preferences).

   ii. For travelers without user profiles, when the trip is accepted, the application prompts the user to select a payment method and submit payment to the Payment Device at the kiosk.

2f. Once the payment is verified, the TIC communicates with the Transit Management Center to confirm the trip. The Traveler is provided with a unique confirmation code which validates the trip. The dynamic trip planning and scheduling process at the transit stop is complete.

6.1.1 Alternate Scenario: Connection Protection Information to Travelers without Personal Information Devices, En-Route and On-Board the Transit Vehicle

Description: This alternate scenario describes the provision of information to an en-route traveler *without* access to a personal information device aboard a transit vehicle. **<u>This alternate scenario is written specifically for travelers without personal information devices making at least one connection to another mode of transit.</u>** The alternate scenario offers a solution to provide these "unconnected" travelers with real-time information en-route by utilizing the vehicle OBE and connected infrastructure.

At the origin transit stop, prior to boarding, a kiosk permits the Traveler to trip plan, select dynamic services, and pay fares. The kiosk serves as a physical gateway for the traveler to access the applications hosted in the TIC. Travelers who utilize the kiosk for trip planning, select a connecting service originating from the transit stop, and pay the fare at the Payment Device kiosk prior to boarding, will be issued a unique identifier that pertains specifically to their trip. The unique identifier, printed on the fare media, contactless media, or boarding pass, will enable the TIC to provide updates to the Traveler en-route through existing on-board DMS and other displays. Either right before or when the traveler boards the vehicle, the Payment Device validates the fare. The Vehicle OBE communicates the validated fare to the TIC via DSRC communications to the Transit Management Center. The Transit Vehicle On-board Fare Management application records the validated fare.

The validated fare confirms the traveler boarded the vehicle and prompts the TIC to actively monitor the trip. Should delays occur en-route, the TIC may request connection protection from the Transit

Management Center on behalf of the Traveler. The Transit Management Center would communicate the connection protection or alternate service to the traveler using the Transit Vehicle OBE (via DSRC). The message would be communicated to the passenger using the trip's unique identified code via the on-board DMS, audio announcement system, and/or entertainment systems.

Actors: Traveler; Public Information Devices (includes DMS and kiosks at the transit stop/station); Transit Vehicle; Transit Management Center; TIC; and RSU.

Constraints and Assumptions. The following constraints apply to this scenario:

- Transit Vehicles are equipped with communication radios capable of transmitting or receiving messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- The Transit Vehicle's OBE meets minimum performance requirements (e.g., SAE J2945) as needed.
- Positioning data is accurate to provide the predicted real-time departure time of the Transit Vehicle using global positioning (GPS) technology.
- The Transit Vehicle is equipped with a DVI to communicate transfer requests, schedule adherence, and other service-oriented information to the bus driver.
- The Transit Vehicle is equipped with OBE including but not limited to: an Automatic Passenger Count system, an Automatic Fare Collection System, Interior/Exterior dynamic message signs, Automatic Voice Announcement, and a cellular based communications system.
- RSUs are equipped with communication radios to transmit messages or receive messages from infrastructure and vehicle. In this scenario, messages are transmitted and received using DSRC. The RSU may be integrated with Public Information Devices to allow travelers to communicate with the Transit Management Center or TIC from roadside infrastructure (e.g. kiosks).
- The Traveler Information Broadcast application within the TIC disseminates traveler information to the transit stop Public Information Devices via RSU.
- The TIC is equipped to handle trip planning, dynamic ridesharing, dynamic transit operations, and traveler information distribution, among other core connected vehicle functions.
- The TIC is equipped to communicate trip planning and trip requests to the Transit Management Center for overall demand responsive transit schedules and deployment.
- The transit stop is equipped with a kiosk which enables travelers to communicate with the TIC to trip plan and schedule dynamic ridesharing, dynamic transit services, and obtain other traveler information.

Preconditions. The following preconditions apply to this scenario:

- Fixed-route, ridesharing, demand-response, and dynamic transit services are available at the transit stop and within the geographic area of the scenario.
- The vehicles servicing the stop location, communicate dynamic transit schedule adherence and transit vehicle location information to the TMC. This is information is provided to the TIC, which is tasked with collecting, processing, storing, and disseminating transportation information to system operators and the traveling public.

- All parts of the trip occur on transit or dynamic services monitored by the TMC. The TIC collects, processes, stores, and disseminates the transportation information pertinent to these services to system operators and the traveling public.

Flow of Events. The flow of events is included below:

1) A Traveler accesses the Dynamic Trip Planning application from the transit stop/station kiosk to plan a trip and to purchase a fare for a service that includes a connection or transfer. The Traveler will pay for the service at the kiosk Payment Device. The kiosk will issue the traveler a fare media, receipt, or boarding pass coded with a unique identifier.

2) The Traveler boards the next available Transit Vehicle which corresponds with the first leg of the planned journey. The Payment Device validates the fare as the Traveler boards the Transit Vehicle.

   a. The Vehicle OBE communicates the validated fare to the TIC via DSRC communications to the Transit Management Center.

   b. The Transit Vehicle fare payment system records the validated fare.

3) The validated fare confirms the traveler boarded the Transit Vehicle and prompts the TIC to actively monitor the trip.

4) En-route, the Transit Vehicle is delayed. As the time available for the Traveler to make the connection decreases due to the delay, the TIC issues a request to the Transit Management Center to protect the connection for the Traveler.

5) The Transit Management Center confirms the connection protection. Notice is issued to the TIC through the Transit Center Connection Protection application. The absence of a user profile (or user preferences enabling personal information device alerts) warrants the Transit Management Center to communicate the connection protection status to the Traveler using the Transit Vehicle OBE including DMS, audio announcement system, and entertainment systems.

6) Aboard the transit vehicle, a distinct audio tone is made prior to the audio/visual announcement. The announcement identifies the trip (using the unique identifier) and states that the original connection has been preserved for an additional time-value threshold.

6.2 Scenario #2: V2I (and I2V) traveler information and dynamic trip planning at bus stops for travelers *with* personal information devices

Description: This scenario describes the provision of information to a Traveler pre-trip and en-route via a personal information device. The device provides the capability for Travelers to receive formatted traveler information (e.g., data specific to the Traveler's geographic location). The device also serves as a physical gateway for the Traveler to access TIC mobility applications. The personal information device may be used for Travelers to communicate wirelessly with connected infrastructure at transit stop/station locations. I2P (and P2I) communication may be used to indicate that traveler is awaiting service from the transit stop/station. Further, personal information devices may be used to communicate wirelessly with connected vehicle OBE (e.g., to request a transit stop or pay fares), a V2I2P and P2I2V communications scenario.

At a minimum, the following functions and applications may be accessed by the Traveler through the device:

- **Trip Planning.** The device facilitates pre-trip and en-route trip planning services for travelers. It receives origin, destination, constraints, and preferences and returns trip plan(s) that meet the supplied criteria. Trip plans may be based on current traffic and road conditions, transit schedule information, and other real-time traveler information.
- **Traveler Information.** The device enables the request and receipt of personalized traveler information. Specifically, the personal information device facilitates access to the TIC Personal Traveler Information Reception application. The traveler receives formatted transit, traffic, broadcast alerts and other general traveler information broadcasts and presents the information to the traveler. The traveler information broadcasts are received by devices including personal computers and personal portable devices such as smart phones.
- **Dynamic Trip Planning.** The device allows the traveler to plan and request dynamic services en-route. The device enables travelers to access TIC applications which facilitate trip planning, dynamic ridesharing, and provide travel services, among other functions. A user profile is required to request service as travelers are required to pay the fare for the service before the trip is scheduled. The Payment Device and personal information device may be integrated to facilitate the trip scheduling and payment. When booking dynamic transit services using the personal information device, the device may provide the traveler with real-time departure information, upon request.
- **Transit Stop Request.** The Transit Stop Request application allows a waiting Traveler to send a stop request to an approaching transit vehicle. This application allows a transit vehicle to know that a Traveler has requested a transit stop from an infrastructure device.
- **Transit Connection Protection.** The Transit Center Connection Protection application allows Travelers to initiate a request for connection protection anytime during the trip using a personal information device and to receive a confirmation indicating whether the request is accepted.
- **On-Demand Service / Dynamic Ridesharing**. The Dynamic Ridesharing application provides dynamic rideshare matches for eligible travelers, connecting riders and drivers for specific trips based on preferences. This ridesharing/ride matching capability also arranges connections to transit or other multimodal services for portions of a multi-segment trip that includes ridesharing. Reservations and advanced payment are also supported so that each segment of the trip may be confirmed.

Actors. Traveler; Transit Vehicle; RSU; TIC; Transit Management Center; and Personal Information Device.

Constraints and Assumptions. The following constraints apply to this scenario:

- Transit Vehicles are equipped with communication radios capable of transmitting or receiving messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- The Transit Vehicle's OBE meets minimum performance requirements (e.g., SAE J2945) as needed.
- Positioning data is accurate to provide the predicted real-time departure time of the Transit Vehicle using global positioning (GPS) technology.
- The Transit Vehicle is equipped with a DVI to communicate transfer requests, schedule adherence, fare validation, and other service-oriented information to the vehicle operator.

- The Transit Vehicle is equipped with OBE including but not limited to: an Automatic Passenger Count system, an Automatic Fare Collection System, Surveillance System, Interior/Exterior dynamic message signs, Automatic Voice Announcement, and a cellular based communications system.
- The TIC is equipped to handle trip planning, dynamic ridesharing, dynamic transit operations, and traveler information distribution, among other core connected vehicle functions. The TIC is equipped to communicate trip planning and trip requests to the Transit Management Center for overall demand responsive transit schedules and deployment.
- The Traveler Information Broadcast application within the TIC disseminates traveler information to personal information devices via wireless communication.
- The personal information device is able to communicate wirelessly with the Transit Vehicle OBE, RSU, and the applications hosted within the TIC.

Preconditions. The following preconditions apply to this scenario:

- Fixed-route, ridesharing, demand-response, and dynamic transit services are available at the transit stop and within the geographic area of the scenario.
- The vehicles servicing the stop location, communicate dynamic transit schedule adherence and transit vehicle location information to the Transit Management Center. This is information is provided to the TIC, which is tasked with collecting, processing, storing, and disseminating transportation information to system operators and the traveling public.
- The Personal Traveler Information Reception application is integrated with the user profile and payment device. The Traveler has authorized the application to access the GPS on the personal information device to determine the location of the traveler.

Flow of Events. The flow of events is included below:

Traveler Information – Stop Request

1) A Traveler is at a transit stop/station waiting for a scheduled Transit Vehicle to arrive. The Traveler is carrying a personal information device.

2) The Traveler accesses the Transit Stop Request application (via wireless communication to the TIC) to submit a request indicating the intent to board the transit vehicle.

3) The application receives the Traveler's location, within close proximity of the stop/station RSU, and grants the request to issue the stop request.

4) The TIC transmits the stop request to the stop/station RSU. The stop request is transmitted via DSRC to the Transit Vehicle.

5) The Transit Vehicle receives the message via DSRC. The vehicle DVI is updated and informs the Driver that a Traveler is requesting service from the stop/station location.

6.2.1 Alternate P2V Scenario: Connection Protection Information to Travelers with Personal Information Devices, En-Route and On-Board the Transit Vehicle

Flow of Events. The flow of events is included below:

1) A Traveler is aboard a scheduled transit service vehicle en-route to a transit stop where a connection will be made to another scheduled, fixed-route service. The Traveler is carrying a personal information device. The Traveler has used the device to plan a trip with the TIC. The TIC has retained a record of the trip plan and has linked it to the traveler's user profile.

2) En-route, the Personal Traveler Information Reception application calculates that estimated arrival time of the vehicle exceeds that of the departure time of the original connection. The application prompts the personal information device to alert (e.g., audio tone, haptic, etc.) the Traveler of the missed connection.

3) The Traveler receives the alert informing the missed connection. The traveler accesses the Personal Traveler Information Reception application to obtain the new estimated arrival time at the destination and a list of alternative dynamic services (e.g., rideshare) available at the transfer station.

4) The traveler elects to submit a connection protection request. The request is communicated from the Personal Information Device to the Transit Management Center via the Transit Center Connection Protection application. The application reports the Traveler's location and pairs the Traveler with the Transit Vehicle to obtain the vehicle's real-time arrival status. In the event that a requested transfer is not feasible, alternatives including other transit, rideshare and taxi modes are provided.

5) The transfer status is received and granted by the Transit Management Center. The traveler will continue to receive real-time updates regarding the transfer status if the transfer status changes up to and a reminder just prior to the transfer.

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APPENDIX A. List of Acronyms

Acronym	Meaning
AASHTO	American Association of State Highway and Transportation Officials
ABS	Antilock Braking System
API	Application Programming Interface
ATAF	Florence Public Transportation
AVL	Automated Vehicle Location
BLE	Bluetooth Low-Energy
BMM	Basic Mobility Message
BRT	Bus Rapid Transit
BSM	Basic Safety Message
CAD	Computer-Aided Dispatch
CAN	Controller Area Network
CWS	Collision Warning System
DCM	Data Capture Management
DMA	Dynamic Mobility Applications
DMS	Dynamic Message Sign
DOT	Department of Transportation
D-RIDE	Dynamic Ridesharing
DSRC	Dedicated Short Range Communications
DVI	Driver-Vehicle Interface
EBSF	European Bus System of the Future
EMS	Emergency Medical Services
FCC	Federal Communications Commission
FCW	Forward Collision Warning

Acronym	Meaning
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FOD	Forward Object Detection
FTA	Federal Transit Administration
GPS	Global Positioning System
GTFS-RT	General Transit Feed Specification Real Time
I2P	Infrastructure-to-Pedestrian
I2V	Infrastructure-to-Vehicle
IDTO	Integrated Dynamic Transit Operators
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
LCD	Liquid Crystal Display
LDW	Lane Departure Warning
LED	Light-Emitting Diode
LTA	Left Turn Assist
MIT	Massachusetts Institute of Technology
NEMA	National Electrical Manufacturers Association
NHTSA	National Highway Traffic Safety Administration
NTD	National Transit Database
OBE	On-Board Equipment
ODS	Object Detection System
OST-R	Office of the Assistant Secretary for Research and Technology
P2I	Pedestrian-to-Infrastructure

Acronym	Meaning
P2I2V	Pedestrian-to-Infrastructure-to-Vehicle
P2V	Pedestrian-to-Vehicle
PDS	Pedestrian Detection System
RCW	Rear Collision Warning
RDE	Research Data Exchange
RFID	Radio Frequency Identification
RITA	Research and Innovative Technology Administration
ROD	Rear Object Detection
RSE	Roadside Equipment
RSU	Roadside Unit
RSZW	Reduced Speed Zone Warning
SAE	Society of Automotive Engineers
SBT	Smart Bus Transport
SOD	Side Object Detection
SSGA	Stop Sign Gap Assist
SWIW	Spot Weather Information Warning
TCIP	Transit Communications Interface Profiles
T-CONNECT	Connection Protection
TCRP	Transit Cooperative Research Program
T-DISP	Dynamic Transit Operations
TIC	Transportation Information Center
TIM	Traveler Information Message
TMC	Transportation Management Center
TMCC	Travel Management Coordination Center

Acronym	Meaning
TRP	Transit Safety Retrofit Package
USDOT	U.S. Department of Transportation
V2I	Vehicle-to-Infrastructure
V2I2P	Vehicle-to-Infrastructure-to-Pedestrian
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
WMATA	Washington Metropolitan Area Transit Authority
X2D	Vehicle or Infrastructure-to-Device

APPENDIX B. Alternate Scenario

B1. Alternate Scenario: Traveler-Sourced Data and Communication via Connected Infrastructure

Description: This scenario illustrates how Traveler data may be aggregated in a connected vehicle environment by allowing Travelers to communicate with and provide feedback to the connected transit infrastructure. In this scenario Travelers will carry a personal information device in order to communicate information including seat availability, service issues and other traveler information-related data. The traveler-sourced data provides an additional layer of granularity to overall data aggregated by the TIC. Also, travelers may use personal information devices to communicate with transit infrastructure, including: RSUs, Transit Stop Infrastructure, and the Transit Vehicle itself.

This scenario illustrates how traveler data may be aggregated in a connected vehicle environment by allowing travelers to communicate with and provide feedback to the transit infrastructure.

Actors. Travelers; Personal Information Devices; Transit Vehicles; TIC; and RSU.

Constraints and Assumptions. The following constraints apply to this scenario:

- Transit Vehicles are equipped with communication radios to transmit messages or receive messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- The Transit Vehicle's onboard system meets minimum performance requirements (e.g., SAE J2945) as needed.
- Positioning data is accurate to provide the predicted real-time departure time of the Transit Vehicle using global positioning (GPS) technology.
- The Transit Vehicle is equipped with a DVI to communicate transfer requests, schedule adherence, and other service-oriented information to the bus driver.
- The Transit Vehicle is equipped with OBE including but not limited to: an Automatic Passenger Count system, an Automatic Fare Collection System, Interior/Exterior dynamic message signs, Automatic Voice Announcement, and a cellular based communications system.
- The TIC is equipped to handle trip planning, dynamic ridesharing, dynamic transit operations, and traveler information distribution, among other core connected vehicle functions.
- The TIC is equipped to communicate trip planning and trip requests to the TMC for overall demand responsive transit schedules and deployment.
- The transit stop is equipped with a kiosk which enables travelers to communicate with the TIC to trip plan and schedule dynamic ridesharing, dynamic transit services, and obtain other traveler information.
- The personal information device is able to communicate wirelessly with the Transit Vehicle OBE, TMC, and the applications hosted within the TIC.

Preconditions. The following preconditions apply to this scenario:

- Fixed-route, ridesharing, demand-response and dynamic transit services are available at the transit stop and within the geographic area of the scenario.
- The vehicles servicing the stop location, communicate dynamic transit schedule adherence and transit vehicle location information to the TMC. This is information is provided to the TIC, which is tasked with collecting, processing, storing, and disseminating transportation information to system operators and the traveling public.
- The Personal Traveler Information Reception application is integrated with the user profile and Payment Device. The Traveler has authorized the application to access the GPS on the personal information device to determine the location of the traveler.

Flow of Events. The flow of events is included below:

1) A Traveler carrying a personal information device is waiting for transit service at a connected transit stop. The Traveler has permitted a function on the device that enables automatic wireless communication between the Personal Traveler Information Reception application and the transit stop RSU and/or Transit Vehicle. The traveler is using the device and application to report information such as availability of priority seating for persons with disabilities, service disruptions/delay or other traveler information-related concerns.

2) The Traveler's proximity to the RSU is collected as a Traveler waiting for service at the stop location or en-route on a vehicle. If available, the RSU collects and transmits the Traveler's user profile to the TIC.

3) The TIC aggregates data obtained from passengers waiting for and using transit service and provides the Transit Management Center with this *crowdsourced* information. The Transit Management Center is prompted to take action depending on the reported conditions. For example, the Transit Management Center may decide to dynamically add service to the stop location based on the predicted wait time of customers at transit stop locations or the lack of seat availability reported by customers or via Transit Vehicle OBE. The Transit Management Center staff may choose to activate a vehicle on standby, adding additional, unscheduled service to the traveler's route thereby reducing the wait time due to the anticipated load along the route.

4) The TIC recalculates the traveler's trip time due to the service changes made by the Transit Management Center. The Personal Traveler Information Reception application alerts the traveler via the personal information device of the reduced wait time. Public Information Devices including DMS at the transit stop location are updated via DSRC communications from the RSU.

5) The transit vehicle arrives at the predicted time and the traveler boards the vehicle. The traveler can use the personal information device to validate the fare, and to report items such as availability of priority seating for persons with disabilities, vehicle issues, service issues, etc. The Transit Vehicle OBE recognizes the traveler as a valid passenger, enabling the device to access on-board features, including but not limited to device-based next stop announcements and request stops via the device application.

6) As the Transit Vehicle approaches the Traveler's destination, the Traveler requests the stop using the personal information device.

7) As the Traveler disembarks from the Transit Vehicle, the device comes within proximity to the destination Transit Stop Location RSU. The RSU collects the device's status, the TIC calculates the actual travel time between stop locations on an individual Traveler basis (including wait time at the origin stop location). The data is used to improve future estimates and to provide benchmarks for the transit agency to improve future service delivery based on historic Traveler trip patterns.

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