Transit Bus Stop Pedestrian Warning Application

Concept of Operations Document

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16. Abstract

This document describes the Concept of Operations (ConOps) for the Transit Bus Stop Pedestrian Warning (TSPW) application. The ConOps describes the current state of operations with respect to the integration of connected vehicle technology in transit vehicles and at transit stops, establishes the reasons for change, and describes the TSPW application in terms of its features and operations.

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Executive Summary

This document describes the Concept of Operations (ConOps) for the Transit Bus Stop Pedestrian Warning (TSPW) application. The ConOps describes the current state of operations with respect to the integration of connected vehicle technology in transit vehicles and at transit stops, establishes the reasons for change, and describes the TSPW application in terms of its features and operations.

The TSPW application will be developed as an application to be combined with and leveraging the components and technologies developed under the Enhanced Transit Safety Retrofit Package system. It will include additional capabilities to enhance and improve transit vehicle and pedestrian safety in an operational context. The combined E-TRP System + TSPW application will consist of two physically separate systems; an on-board, transit vehicle-based system and an infrastructure-based system at each of the selected transit bus stops. Both systems will share some common hardware and software subsystems, as well as having unique subsystem to themselves.

The objective of this project is to design, prototype develop, and test (in a real-world operational environment) a new transit vehicle-to-infrastructure safety application: Transit Bus Stop Pedestrian Warning. This application will:

- Alert pedestrians at a major bus stop of approaching transit buses
- Alert pedestrians at a major bus stop of departing transit buses
- Alert transit vehicle operators of a pedestrian potentially in harm's way at a major bus stop via a Driver-Vehicle Interface
- Alert on-coming connected vehicles of pedestrians potentially in harm's way at a major bus stop.
- Provide alerts to pedestrians via infrastructure components (e.g., Dedicated Short Range Communications actuated signage) and pedestrian carried mobile devices
- Alert pedestrians in the roadway in front of a stopped transit vehicle that there is an approaching DSRC –enabled vehicle that is obstructed by the transit vehicle.

The proposed system will include a number of hardware and software components. Conceptually, there are four main system components for the proposed system that include:

1. Hardware/Software Mounted Within Transit Vehicle – This hardware and software is contained within various hardware components mounted within the transit vehicle and controls the information presented to the transit vehicle operator regarding the status of pedestrians at transit stops. Additionally, this equipment provides external warnings to pedestrians of approaching vehicles. Finally, this equipment has the responsibility of receiving/broadcasting information to intersection components regarding the status of the transit vehicle. The primary sub-system components within the equipment mounted in the transit vehicle is a computational platform (referred to as the "Common Computational Platform" in the following) and the Data Acquisition System.

2. Infrastructure-Based Pedestrian Detection Equipment – This hardware and software will be pole mounted at a transit stop and will be responsible for identifying pedestrians at the transit stops and providing notification to the central processing and communications unit (i.e., the infrastructure version of the Common Computational Platform) for further processing.
3. Infrastructure-Based Pedestrian Warning Device(s) – This hardware is responsible for providing alerts and warnings to pedestrians waiting at transit stops.

Scenarios describe how the system will operate, with the primary focus centered on the transit vehicle operator as well as persons at the transit stop either waiting for a transit vehicle or as pedestrians. The TSPW application will generate alerts during dangerous and potentially dangerous situations.

- An "inform alert" refers to an indication that a potentially dangerous situation could occur.
- A "warning alert" refers to an indication that a dangerous situation is likely to occur.

Within the scenarios, graphics are provided indicating the type of feedback, and who the information will be presented to, as the scenario unfolds. The graphics used are for illustrative purposes only as the actual human interface designs will be developed during the system design phase. For the purposes of illustration, color coding is used to indicate that an alert is presented to a specific user group and the nature of the alert. The following color coding schema is used throughout the scenarios:

1. An enable alert to the transit vehicle operator that the transit stop is a TSPW equipped transit stop in the absence of any waiting passengers or pedestrians is indicated in Green.
2. Visual enable alerts will be presented to pedestrians and/or waiting riders via the Infrastructure Based, Pedestrian Warning Device when they are in the Safe Waiting Zone to provide the pedestrians and/or waiting riders with information on the status of the transit vehicle (arriving, at-stop). For the purposes of illustration, these enable alerts are indicated in Green.
3. Inform alerts to pedestrians and/or waiting riders will be issued when they are in the Danger Waiting Zone and are potentially at risk of being struck by a transit vehicle. These inform alerts will consist of audible, visual, and tactile notifications on their individual mobile devices and a visual display on the Infrastructure Based, Pedestrian Warning Device. For the purposes of illustration, these inform alerts are indicated in Yellow.
4. Warning alerts to pedestrians and/or waiting riders will be issued when they are in one of the four Roadway Zones and are at risk of being struck by a moving transit vehicle. These warning alerts will consist of activation of the Infrastructure Based, Pedestrian Warning Device; visual, audible, and tactile warnings on their mobile devices; and in cases where the pedestrian is crossing in front of the transit vehicle with an on-coming DSRC-equipped connected vehicle that is passing the transit vehicle, a visual and audible warning from the transit vehicle. The visual, audible, and tacticle warnings on mobile devices may be removed for scenarios when the pedestrian is in the street, based on stakeholder feedback. For the purposes of illustration, these warning alerts are indicated in Red.
5. Inform alerts, indicated in Yellow, will be presented to operators of on-coming DSRC-equipped connected vehicles to indicate that there is a pedestrian present and that this pedestrian may be moving to a position where they could be struck by the on-coming vehicle. A warning alert, indicated in Red will be presented if there is a pedestrian that is in one of the four roadway zones and is at risk of being struck by the on-coming vehicle.

It is expected that the TSPW application will need to assess and determine the conditions and resulting notifications based upon a number of factors. These factors could include aspects such as the:

- Telematics information from the transit vehicle and/or on-coming DSRC-equipped connected vehicle indicating current path of the vehicle as it approaches an intersection.
- Predicated path of the vehicle
- Pedestrian detection status and presence of a person in one of the six zones.

Revision History

Revision	Date	Change Description	Affected Sections/Pages
A	11/24/2015	Initial Release	
B	2/4/2016	Revised in its entirety based on U.S. DOT comments	All
C	3/1/2016	Incorporated U.S. DOT's comments and converted for 508 compliance.	All

Source: Battelle

Chapter 1 Scope

This document describes the Concept of Operations (ConOps) for the Transit Bus Stop Pedestrian Warning (TSPW) application. The ConOps describes the current state of operations with respect to the integration of connected vehicle technology in transit vehicles and at transit stops, establishes the reasons for change, and describes the TSPW application in terms of its features and operations.

The U.S. Department of Transportation (U.S. DOT) Connected Vehicle Research Program[1] was initiated to tackle some of the biggest challenges in surface transportation. The program is a multimodal initiative that aims to enable safe, interoperable wireless communications among vehicles, infrastructure, and personal communications devices.

The concept of connected vehicles was developed from previous intelligent highway vehicle programs; including the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, the Transportation Equity Act for the 21st Century (TEA-21) of 1997, and finally the Intelligent Vehicle Initiative (IVI) that was created through TEA-21. Connected vehicle technologies and applications seek to improve traffic safety and mobility while enhancing commerce in the areas where they will be implemented. In broad terms, the Connected Vehicle program envisions a communications infrastructure that includes elements of vehicle-based communication units or on-board equipment (OBE), static roadside sensors and communications or Roadside Unit (RSU), and the centralized network that manages the exchange of data. The various OBEs will be able to communicate from vehicle to vehicle and to the RSU using various wireless communications, including Dedicated Short-Range Communications (DSRC).

As a part of the Connected Vehicle Research program and The Safety Pilot Model Deployment[2], a suite of transit-focused applications were developed, called the Transit Safety Retrofit Package (TRP). The TRP application suite allows transit vehicles to communicate using Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) technologies, with the ultimate goal of enhancing both transit vehicle and pedestrian safety. In 2013, a demonstration of the TRP technology was deployed on three University of Michigan buses, and the benefits of the application in conjunction with 5.9GHz DSRC wireless technology were tested and evaluated.[3] Following this initial research, the Federal Transit Administration and Battelle, under a Cooperative Agreement,[4] are expanding the TRP concepts and developing an Enhanced Transit Retrofit Package (E-TRP) that will include:

- Improved pedestrian detection system
- Improved locational accuracy of the transit vehicle
- Interface for the transit vehicle driver (visual and/or audible)

[1] http://www.its.dot.gov/connected_vehicle/connected_vehicle_research.htm

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

[3] Valentine, D.; Zimmer, R.; Mortensen, S.; Sheehan, R., "Transit Safety Retrofit Package (TRP): Leveraging DSRC for Transit Safety – Fielding Results and Lessons Learned," Prepared by Battelle under Contract to FHWA: DTFH61-12-R-00001, November 2014.

[4] E-TRP Cooperative Agreement Project, No. OH-26-7252-00

- Newer DSRC radios
- On-board storage capabilities
- Design for remote system management.

As part of the E-TRP cooperative agreement, Battelle will be designing, developing, and deploying the E-TRP in transit vehicles and intersections in Cleveland, Ohio. The TSPW project will leverage this development and deployment in Cleveland by using some of the same transit vehicles, hardware, and infrastructure components.

Identification

This document represents the first in a series of System Engineering documents being prepared for the TSPW. This ConOps document describes the concept of operations for the TSPW application and components. Specifically, it focuses on describing the current state of practice as well as introducing proposed concepts for the TSPW application. This ConOps is restricted to describing the expected enhanced functionality and operation of the TSPW application and its components.

Document Overview

The purpose of this document is to provide a summary of the system and scenarios that will be created, tested, and demonstrated during this project. This document will serve as a platform for U.S. DOT and other stakeholders to confirm the concept is aligned to the objectives of this project. Ultimately, the concept and scenarios will serve as a basis for determining system requirements and demonstration test plans.

The primary audience for this document is threefold:

1. U.S. DOT staff and stakeholders who are leading and interested in improving transit vehicle and pedestrian safety.
2. Greater Cleveland Regional Transit Authority (GCRTA) who has partnered to be the operations deployment site.
3. Battelle staff responsible for the design, development, and implementation of the system components.

Additional audiences may include the system developers, engineers, other transit agencies, and transit vehicle manufacturers.

This ConOps document is intended to:

- Communicate the need for and expected benefits of the TSPW application.
- Communicate an understanding of how the TSPW application will be designed, installed, operated, and tested.
- Serve as a basis for system development activities.

The remainder of this document consists of the following sections and content:

- **Section 2 (Referenced Documents)** describes the external documentation referenced within this document.
- **Section 3 (Current System)** describes the current situation among transit fleets with respect to communicating pedestrian warnings to transit vehicle operators and communicating warnings to waiting riders and pedestrians in the vicinity of a transit stop.
- **Section 4 (Justification for and Nature of Changes)** describes the justification for and nature of the proposed changes. This section identifies deficiencies of the existing situation and the benefits of change.
- **Section 5 (Concepts for the Proposed System)** describes the proposed system that will result from the desired changes. This is a high-level description, indicating the operational features of the demonstration system when deployed.
- **Section 6 (Operational Scenarios)** contains operational scenarios for the demonstration. A scenario is a step-by-step description of how the proposed system might operate and interact with its users and its external interfaces under a given set of circumstances. The scenarios tie together all parts of the proposed system, the users, and other entities by describing how they interact.
- **Section 7 (Summary of Impacts)** describes the operational impacts of the proposed system on the users, the developers, the maintenance organizations, and the support organizations.
- **Section 8 (Analysis of the Proposed System)** describes the benefits, limitations, advantages, disadvantages, and trade-offs considered for the demonstration system.
- **Section 9 (Notes)** provides definitions for the terms, acronyms and abbreviations used throughout the document.

System Overview

The TSPW application will be developed as an application to be combined with and leveraging the components and technologies developed under E-TRP system. It will include additional capabilities to enhance and improve transit vehicle and pedestrian safety in an operational context. The combined E-TRP System + TSPW application will consist of two physically separate systems; an on-board, transit vehicle-based system and an infrastructure-based system at each of the selected street intersections. Both systems will share some common hardware and software subsystems, as well as having unique subsystem to themselves.

The hardware systems used for the TSPW application will utilize many of the same hardware systems as the E-TRP applications, but a number of additional components will be added to provide additional functionality. The following E-TRP subsystems and components will be used as part of the TSPW application:

- Common Computing Platform (CCP) – The heart of the E-TRP system and the TSPW application is the CCP, which will be utilized in both the on-board and the infrastructure systems. The CCP is the central processor providing the interface to the other subsystems and hosting the software applications.

- Dedicated Short-Range Communications (DSRC) Radios – DSRC radios will also be utilized in both the on-board and infrastructure-based systems, and serve as the low-latency wireless communications method between the two systems.
- Cellular Communications – Each CCP will be outfitted with a cellular modem to allow for wireless connectivity to the Cloud-based Management System (CMS).
- Cloud-based Management System (CMS) – The CMS will serve as the remote portal for the on-board and infrastructure-based systems collected data storage and retention, as well as monitoring of the deployed fleet system health status (near real-time operational state dashboard).
- Pedestrian Detection System (PDS) – Transit stop based sensors to detect the presence of pedestrians and waiting riders inside a specified detection zone. The PDS will contain its own processing and software capability, which would then communicate to the infrastructure-based CCP whether a pedestrian or waiting rider is detected, and the zone in which they were detected.
- Global Positioning System (GPS) – A GPS module will be utilized in the on-board system to provide real-time lane-level positioning data to the CCP.
- Human Interface System (HIS) for Transit Vehicle Operator – the TSPW interface to the transit vehicle driver will be developed to provide the transit vehicle driver information and status alerts for waiting riders and pedestrians at transit stops. A robust assessment of the user experience will ultimately determine the final design of the HIS.

The following new hardware systems are unique to the TSPW application and are needed to provide additional functionality in providing warnings to waiting riders and pedestrians:

- Data Acquisition System (DAS) – Information captured and processed by the CCP as well as system logs and video will be captured to support evaluation of the TSPW application using an on-board and infrastructure-based DAS.
- Mobile Devices – Waiting riders and pedestrians in the vicinity of an equipped transit stop will be able to receive alerts on their personal mobile devices regarding approaching, at-stop, and departing transit vehicles.
- On-Board Transit Vehicle Pedestrian Warning Device – This hardware component is expected to reside on the transit vehicle and, in certain situations, provide a visual and audible warning to a pedestrian in the roadway that they are in danger from the transit vehicle or an approaching vehicle that is passing the stopped transit vehicle.
- Infrastructure Based Pedestrian Warning Device – This hardware is expected to be mounted off to the side of the transit stop so that it can be seen by waiting riders as they look for approaching transit vehicles. This system will consist of a digital message board capable of displaying text messages, flashing, and emitting an audible tone.

There are several software components that will collectively comprise the TSPW application. In particular, software components on the transit vehicle will be used to manage alerts to the transit vehicle operator and to activate the On-Board Transit Vehicle Pedestrian Warning Device. Software components embedded within the transit stop infrastructure will be used to detect and alert waiting riders and pedestrians and communicate this information to transit vehicles and other connected vehicles. A software component residing upon the waiting rider's or pedestrian's mobile device will provide individualized alerts to each waiting rider or pedestrian.

Chapter 2 Referenced Documents

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

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- Transit Vehicle-to-Infrastructure (V2I) Applications Near-Term Research and Development: Transit Bus Stop Pedestrian Safety Application Operational Concept (report number FHWA-JPO-14-174). http://ntl.bts.gov/lib/54000/54400/54483/FHWA-JPO-14-174_v1.pdf
- J.D. Schneeberger, Gwo-Wei Torng, Dawn Hardesty, and Amy Jacobi,"Transit Vehicle Collision Characteristics for Connected Vehicle Applications Research Analysis of Collisions Involving Transit Vehicles and Applicability of Connected Vehicle Solutions." FHWA Report Number: FHWA-JPO-13-116, 2013.
- Kelley Pecheux , Jason Kennedy; Applied Engineering Management Corporation, with James Strathman; Portland State University, "Evaluation of Transit Bus Turn Warning Systems for Pedestrians and Cyclists: Draft Final Report." FTA Report No. 0084, May 2015.

Institute of Electrical and Electronics Engineers (IEEE)

IEEE 1609.2	Wireless Access in Vehicular Environments (WAVE) – Security Services for Applications and Management Messages
IEEE 802.11p	IEEE Standard for Information technology – Local and metropolitan area networks – Specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments

Society of Automotive Engineers (SAE)

SAE J1939	Serial Control and Communications Heavy Duty Vehicle Network, SAE International
SAE J2735	Dedicated Short-Range Communications (DSRC) Message Set Dictionary, SAE International

Battelle Drawings/Documents

CV Infrastructure Urban Bus Ops Safety Platform SOW 7_10_2015 – Final

Chapter 3 Current System or Situation

Background

Pedestrian safety is a significant concern in the U.S. In 2013, pedestrian travel accounted for 10.5 percent of all trips in the U.S., and annually pedestrians represent 13 percent of all motor vehicle traffic-related deaths.[5] While public transportation is an overall safe mode of travel, accidents involving transit vehicles and pedestrians do occur. According to the National Transit Database, the nation's primary source for information and statistics on the transit systems, in 2013 there were 428 injuries and 29 fatalities involving a transit vehicle and pedestrians.[6]

The use of technologies and applications to improve transit and pedestrian safety has been an active research topic for years. The U.S. DOT has sponsored a number of projects in the past several years to develop and test new technologies with the goal to further reduce transit collisions. These studies and demonstrations examine the potential costs, benefits, and provide an overall business case for integrating safety systems, both hardware and software, into transit vehicles. In particular, the U.S. DOT investigated several transit vehicle and pedestrian safety related issues as part of the Integrated Vehicle Based Safety Systems Initiative[7] (IVBSS). The objective of this initiative was to evaluate the business case related to the development and implementation of various transit-based versions of collision avoidance systems in transit vehicles.

Analysis of the National Transit Database (NTD) by Noblis in 2014, revealed that 20.4 percent of all transit incidents involving a pedestrian occurred at a transit stop.[8] Of this percentage, the majority occurred when the transit vehicle was in motion either departing the transit stop (13.9 percent of the total) or approaching the transit stop (6.5 percent of the total). Furthermore, these incidents are typically serious with "on average 82.6 percent of all reported motor bus 'making a stop' or 'leaving a stop' collisions resulted in at least one injury and 6.0 percent resulted in a fatality." These statistics speak toward a need for improvements in safety of waiting riders and pedestrians at transit stops when transit vehicles are present. These safety improvements are the primary focus of the TSWP application.

This section of the ConOps describes the current state of safety applications in transit vehicles, based on recently published reports and existing literature.

[5] U.S. Department of Health and Human Services, CDC; 2013. Available at http://www.cdc.gov/injury/wisqars/index.html.

[6] National Transit Database, Safety and Security Time Series Data, available at: http://www.ntdprogram.gov/ntdprogram/data.htm

[7] http://www.nhtsa.gov/Research/Crash+Avoidance/Integrated+Vehicle-Based+Safety+Systems+%28IVBSS%29

[8] Noblis, "Motor Bus Collisions with Pedestrians," Presentation provided to Battelle by the Federal Transit Administration, November 2015.

Description of Current Systems

Originally, and continuing to this day, pedestrian detection technologies are primarily used as a mechanism to supplement or replace pedestrian calls to the traffic signal controller as initiated via a push button located near the intersection.[9] These pedestrian detection systems use infrared, microwave or video detection systems, as well as pressure-sensitive mats, to activate a call.[10] The need for these additional technologies emerged as approaches to better accommodate pedestrians with mobility needs were identified. These same technologies also help improve the intersection safety for pedestrians who choose not to use the existing call buttons.

There have been many studies and evaluations of new technologies for vehicle-based platforms for pedestrian detection but few of the current on-board sensor technologies are being used for pedestrian detection at transit stops. The current thrust in the industry has been to explore the use of pedestrian detectors mounted on infrastructure components that then interface with the traffic signal controller (i.e., do not communicate directly to the transit vehicle). Pedestrian detection is currently being deployed, in limited scale, as either vehicle-only or infrastructure-only solutions. Both of these are discussed in greater detail below.

Vehicle Based

From an on-board vehicle standpoint, many approaches to object detection/collision warning systems, have been evaluated and demonstrated the capability to detect the presence of objects within the field of view of the sensors mounted on the vehicle. These technologies in use include video, radar, lidar, and ultra-sonic technologies, each with strengths and limitations. According to the 2007 U.S. DOT study, "Assessing the Business Case for Integrated Collision Avoidance Systems on Transit vehicles,"[11] which presents an analysis of IVBSS for transit vehicles, only video systems truly exhibit the ability to distinguish a pedestrian from other obstacle types, and as such, are presently the only approach that has a reliable detection capability. But in less-than-ideal lighting conditions, the effectiveness of video systems diminishes, leaving its true usefulness in question. Use of visible and infrared video systems helps extend the environment under which it can be used, but it is still limited.

Presently, some of the high-end passenger vehicles and commercial truck manufactures offer systems based on single or a combination of these technologies. However, similar to the infrastructure-based systems, none of these technologies have truly realized widespread adoptions, particularly in the transit community. Of the systems evaluated in the 2007 U.S. DOT report mentioned previously, only two were deemed suitable for transit applications such as pedestrian detection. However, research studies by others, such as Redmill, et. al.[12] were successful in prototyping a Lidar-based system to detect pedestrians at transit stops from the roof of a mobile

[9] Hughes, Ronald; Huang, Herman, Zegeer, Charles; Cynecki, Michael, "Evaluation of Automated Pedestrian Detection at Signalized Intersections," Federal Highway Administration, Report No. FHWA-RD-00-097, August 2001.

[10] Fanping Bu, Ching-Yao Chan, "Pedestrian Detection in Transit Bus Application:

Sensing Technologies and Safety Solutions," 0-7803-896 1-1 /05 WOO5 IEEE

[11] Dunn, Travis; Laver, Richard; Skorupski, Douglas; Zyrowski, Deborah, "Assessing the Business Case for Integrated Collision Avoidance Systems on Transit vehicles," Federal Transit Administration, 2007.

[12] Redmill, K.A., Coifman, B., McCord, M.R., Mishalani, R.G., 2011. "Using Transit or Municipal Vehicles as Moving Observer Platforms for Large Scale Collection of Traffic and Transportation System Information." Proceedings of the 14th International IEEE Annual Conference on Intelligent Transportation Systems, Washington, D.C.

vehicle. In more recent history, organizations such as Mobileye[13], have developed vision-based systems for pedestrian detection that have and are being installed in transit vehicles as windshield mounted equipment. According to Mobileye, "Mobileye's pedestrian detection technology runs on EyeQ2 based systems and is currently the only mono-camera automotive pedestrian detection system in production globally." Pedestrian detection was added to Mobileye's product line in 2009.

Others have followed suit with additional systems for alerting transit vehicle operators of pedestrians. For example, a "system being developed by researchers at the Polytechnic University of Valencia (UPV) in conjunction with Spanish company Cognitive Robots, combines video image capturing technology and software that analyzes the images and issues warnings to the driver."[14] At the same time, still others have developed systems to warn waiting riders and pedestrians of transit vehicle operations employing transit mounted audible systems, variable message boards, and other technologies (see Table 3-1 for examples[15]).

Table 3-1. Examples of transit mounted pedestrian warning systems

Transit Agency	Type of Vehicle-Warning System
GCRTA	Audible Speaker on Bus – "Caution, look both ways. Pedestrians, bus is approaching; bus is approaching."
GRTC	Audible Speaker on Bus – "Caution, bus moving left/right. Pedestrians look both ways."
NJ Transit	Audible Speaker on Bus – "Caution, bus turning."
WMATA	"Caution, pedestrians, bus is approaching." "Pedestrians, bus is turning." Clicking noise
Metro	Beeping noise
TriMet	Directional LED and Stobe lights

Source: Battelle – Extracted from Pecheux et. al.

Infrastructure-Based

In the present Intelligent Transportation System (ITS) community, most of the research and fielded deployments for infrastructure-based pedestrian detection systems focus on either generating the pedestrian call to the signal controller (in lieu of or in addition to a call button press), or to extend an existing pedestrian phase when it is determined that a pedestrian will remain in the intersection beyond termination of the current pedestrian phase. Among the approaches used for this method of detection, microwave and infrared sensors have emerged as two more common technologies.

A Federal Highway Administration (FHWA) Report, entitled *Evaluation of Automated Pedestrian Detection at Signalized Intersections*[16], includes site profiles for a few deployment locations that use

[13] http://www.mobileye.com/technology/applications/pedestrian-detection/

[14] http://www.gizmag.com/bus-stop-safety/32654/

[15] Information extracted from: Kelley Pecheux , Jason Kennedy; Applied Engineering Management Corporation, with James Strathman; Portland State University, "Evaluation of Transit Bus Turn Warning Systems for Pedestrians and Cyclists: Draft Final Report." FTA Report No. 0084, May 2015.

[16] Hughes, Ronald; Huang, Herman, Zegeer, Charles; Cynecki, Michael, "Evaluation of Automated Pedestrian Detection at Signalized Intersections," Federal Highway Administration, Report No. FHWA-RD-00-097, August 2001.

either microwave or infrared technologies as the sensor. These detectors are interconnected with the local traffic signal controller, and are typically wired in parallel with the call button, when used as an alternative to the button, or activated in conjunction with the pedestrian phase of the signal when used to extend the signal. Infrastructure based pedestrian detectors at transit stops are not widely utilized.

Vehicle and infrastructure based pedestrian detection technologies have proven to be useful; however, no specific technology has found widespread adoption. Current statistics on the number of intersections equipped in this fashion are not available, but given the limited amount of published studies or articles available on this subject, it seems reasonably safe to assume that there is a fairly low concentration either of these technologies at this time.

Operational Policies and Constraints

There are four primary constraints to the current adoption of pedestrian technologies. These constraints include:

- Limitations of the technology due to environmental conditions
- The ability of the sensors and corresponding algorithms to operate with 100 percent accuracy in the detection of pedestrian, while minimizing 'false' detections.
- The limited field of view for each sensor often requires multiple sensors to be deployed, greatly increasing the costs of installation and operation.
- Any technology deployment involving providing information to transit vehicle operators while they are operating the transit vehicle must minimize the impact to the cogitative work load on operators.

The technologies presently used for most pedestrian detection applications involve electromagnetic waves of various frequencies, either emitted or reflected by the pedestrian, and detection by a sensor (i.e., 'camera'). As with any waveform, environmental conditions may affect the transmission and reception of these waveforms. For instance, video detection systems dependent of the visible light spectrum are subject to variations in accuracy based on the lighting conditions. Similarly, the algorithms necessary to detect and classify objects in the field of view of the various sensor systems continue to be refined, but have not yet reached a point where the accuracy rate is sufficient enough without the inclusion of false 'positives,' which can have negative effects on operations. This level of acceptance has yet to be determined by agencies, but will need to be a consideration for adoption and enhancement of these technologies in the future.

Modes of Operation

Vehicle-Based

Pedestrian detection systems implemented using vehicle-based video capture capabilities operate by capturing video of the environment surrounding the vehicle, and subsequently processing the captured video using sophisticated image detection algorithms. This capture and detection process all occurs in hundredths of seconds. The outcome of the analysis algorithm may then be used to raise a warning to a driver in some form of a visible or audible alert.

Infrastructure-Based

Pedestrian detection systems implemented using infrastructure-based solutions typically operate in conjunction with a traffic signal controller or other infrastructure-based equipment. For example, when the controller commences a pedestrian phase, a pedestrian detector system is activated and upon completion of the phase, the detector remains active for a period of time to determine if the pedestrian phase should be extended. For transit stop applications, pedestrian detection systems, such as an optical camera, Lidar, RADAR, etc., are tied back to a computational platform through a wired or wireless bridge.

User Cases and Other Involved Personnel

One of the issues to be addressed in this ConOps is determining and defining the system's key stakeholders. By establishing key stakeholders, the system's primary and secondary goals and objectives can be better understood. Additionally, ongoing input can be solicited from these stakeholders to narrow the focus and refine the system's design, resulting in a system that will provide maximum benefit to the U.S. DOT and the stakeholders who may adopt the technologies developed and enhanced under this project. Currently, transit safety and connected vehicle systems support and are used by several user classes. These user classes are illustrated in Table 3-2 and described in the section below.

Table 3-2. Summary of user classes for existing system(s)

User Group	System Operator	Data Consumer	Maintainer	Beneficiary
Transit Agency	X	X	X	X
Maintenance Staff			X	
Transit Vehicle Driver		X		X
Transit Passengers				X
Waiting Transit Riders and Pedestrians				X
Other Drivers				X

Source: Battelle

Transit Agency

The Transit Agency is currently responsible for the selection, deployment, and operation of vehicle-based detection and alert systems. It is a tremendous benefit, both in terms of public perception and costs to the agency, to improve safety by reducing or eliminating any incidents involving transit vehicles through the use of detection systems. And as a consumer of the data generated by the systems, the agency can further evaluate the effectiveness of these systems and the path forward for future adoption of these systems. Additionally, transit agencies can act as the maintainer of transit stop facilities along some routes.

Maintenance Staff

Maintenance staff are responsible for the repair and maintenance of all installed detection equipment, whether infrastructure or vehicle based. These staff reside with the respective agency and would have the necessary tools and equipment to support the deployed technologies.

Transit Vehicle Driver

The transit vehicle driver is one of the primary beneficiaries of the current vehicle-based detection systems. By providing situational awareness and appropriate indicators and warnings to the driver, the driver will be better prepared to react to or avoid incidents.

Transit Passengers

Transit passengers are secondary beneficiaries of the system. As these detection systems work to reduce the number of incidents involving transit vehicles, passengers are not only beneficiaries of the safer operations of the vehicle, but also benefit from not having service disruptions that are prevented as a result of the deployment of these detection systems.

Waiting Transit Riders and Pedestrians

Waiting transit riders and pedestrians are primary beneficiaries of these systems. The reduction or elimination of any incident involving a transit vehicle and a rider waiting at the transit stop or a pedestrian in the roadway near a transit stop is a significant positive benefit.

Other Drivers

Drivers of other vehicles operating near a transit vehicle benefit from the TSPW application in that their travel will be less congested with less delays due to a transit/pedestrian incident. Additionally, if these drivers are operating a connected vehicle, they will benefit from the TSPW application by receiving alerts regarding pedestrians in the roadway near an equipped transit stop enabling them to avoid an accident.

Support Environment

Vehicle Based

Vehicle-based pedestrian detection is dependent typically on the operating agency, and potentially, depending on the size and needs of the agency, support contracts with the vendor of the detection system. The policy of the agency and any support contracts with vendors would determine the necessary level of spare units to have in inventory.

Maintenance primarily consists of keeping the lenses clear of dirt and debris, and potentially updates to device firmware in order to support updated detection algorithms. Again, the latter is dependent on the support contracts the agency has in place. Most of these systems do not have repairable components, so remove and replace is the expected approach for repair, using tools that would typically be available in a transit maintenance facility.

Infrastructure Based

Infrastructure-based pedestrian detection is typically dependent on the agency or organization responsible for maintaining intersection traffic signal controllers and related devices. Depending on the size and needs of the agency, support contracts with the vendor of the detection system, or with a maintenance company, may be in order. The necessary level of spare units to have on hand also depends on the policy of the agency and any support contracts with vendors. Maintenance primarily consists of keeping the lenses clear of dirt and debris, and potentially updating the device firmware in order to support updated detection algorithms. Again, the latter is dependent on the support contracts the agency has in place. Most of these systems do not have repairable components, so "remove and replace" is the expected approach for repair, using tools that would typically be available for work performed at a signalized intersection or electronically equipped transit stop.

Chapter 4 Justification for and Nature of Changes

The safety of pedestrians and passengers on transit vehicles has been of critical concern to U.S. DOT for several decades, recently summarized in the report *Transit Vehicle Collision Characteristics for Connected Vehicle Applications Research: Analysis of Collisions Involving Transit Vehicles and Applicability of Connected Vehicle Solutions* (FHWA-JPO-13-116). For example, in 2008, FHWA issued a "Pedestrian Safety Guide for Transit Agencies," whose purpose was to help transit agencies improve the safety of pedestrians.[17] Recent incidents such as those reported by the Star-Ledger on January 7, 2012, citing pedestrian injuries from transit vehicles continue to highlight this issue. In this case, a woman badly injured by a New Jersey Transit vehicle that struck her in the crosswalk was awarded $7.85M in a lawsuit settlement.[18] In another case, a San Francisco Municipal Railway bus driver fatally struck a pedestrian in the crosswalk in the city's Castro District in August 2011.[19] In a more recent incident, two pedestrians were struck by a transit vehicle departing the transit stop after first being struck by an oncoming vehicle as they crossed in front of the transit vehicle.[20] While the operator was acquitted of vehicular manslaughter, over $2.8M in damages were awarded to the pedestrian's family. The frequency and severity of such incidents suggest that further research is needed and changes to the current operations of transit vehicles need to be researched, considered, and implemented.

In response to concerns over pedestrian and vehicle safety, the U.S. DOT has initiated a multimodal research program that aims to enable safe, interoperable networked wireless communications among vehicles, the infrastructure, and passengers' personal communications devices. This research leverages the potentially transformative capabilities of wireless technology to make surface transportation safer, smarter, and greener. The Program includes research on technical issues, policy and non-technical issues, and safety (V2V and V2I), mobility, and environmental application areas. This research also will assess technologies and applications to determine their potential benefits and costs. Public transit has had and will continue to play an integral role in all aspects of this program.

The V2V Safety Application Research Plan as part of the multimodal research program is focused on conducting research, testing, and providing the information needed to understand the safety benefits that could be realized by the deployment of V2V wireless communications technology and the associated applications that are enabled by such technology. The initial research, development, and proof-of-concept testing of crash warning systems is based on wireless 5.9 GHz. DSRC has been focused on light vehicles. The U.S. DOT has been working for several years with light vehicle original equipment manufacturer (OEM) to conduct this foundational research—including participation on standards committees that are tasked with the development and refinement of wireless

[17] Nabors, Dan; Schneider, Robert; Leven, Dalia; Lieberman, Kimberly; Mitchell, Colleen, "Pedestrian Safety Guide for Transit Agencies," FHWA-SA-07-017, February 2008.

[18] http://www.nj.com/news/index.ssf/2012/01/woman_badly_hurt_by_nj_transit.html

[19] http://www.mercurynews.com/ci_27633907/san-francisco-jury-acquits-former-muni-bus-driver.

[20] http://www.post-gazette.com/local/city/2015/10/26/Port-Authority-bus-involved-in-accident-in-Hill-District/stories/201510260168

communications standards (IEEE P1609 WAVE standards set), as well as an efficient messaging protocol (ref. SAE J2735 standard) tailored for use with the DSRC communications medium. The U.S. DOT would like to expand DSRC-based safety application research, and apply these improved and enhanced technologies and systems to transit vehicles.

Justification for Changes

While transit vehicle accidents are not as common as passenger vehicle accidents, reports of transit vehicles striking pedestrians in crosswalks are common in agency incident/accident reports. For example, 30 pedestrians were killed in Chicago as a result of transit vehicle strikes in 2010 with 80 percent of all pedestrian-to-vehicle incidents occurring in crosswalks while the walk signal is active. The 2014 analysis performed by Noblis[21] clearly identifies several trends regarding transit vehicles striking pedestrians and waiting riders under different conditions. As observed from analysis of the National Transit Database, Noblis concluded that 20.4 percent of all transit-to-pedestrian incidents occurred when the transit vehicle was "making a stop" or "leaving a stop." Further analysis of the data indicates that among these types of incidents, "… the top three [types of incidents] were the "pedestrian rushing to catch the motor bus," "other pedestrian strike," and "pedestrian making contact with the side of the bus." At the same time, most incidents involving a transit vehicle and a pedestrian result in serious injury and/or fatality.

In 2013, Noblis conducted a research study on "Transit Vehicle Collision Characteristics for Connected Vehicle Applications Research Analysis of Collisions Involving Transit Vehicles and Applicability of Connected Vehicle Solutions[22]" using data from 2005-2010 contained in the National Transit Database. In this study, Noblis found that while the total number of collisions reported between 2005-2007 was significantly higher than the corresponding number reported between 2008-2010, motor buses have by far the most reported collisions than any other transit mode. Although incidents involving pedestrians only accounted for a relatively small percentage of the overall incidents, transit vehicles striking pedestrians at transit stops accounted for approximately 22 percent of all incidents involving pedestrians. Further research sponsored by the FTA in 2015 regarding technologies for providing warnings to pedestrians and cyclists regarding bus movements found that "The results showed that the baseline scenario yielded net present value benefits approaching $3 million overall for the 45 warning systems in the demonstration test, or about $65,300 per bus/warning system. The associated internal rate of return on the warning systems investment for this scenario exceeded 34 percent, which translates into a payback period of about three years.[23]" These two studies clearly identify both the need and the potential benefits for technology solutions for pedestrian warning systems.

Sensor and detection technologies available today have vastly improved performance and reliability over those previously tested and deployed. A solution that uses newly-emerging technologies is needed. With multiple important applications that have significant commercialization opportunities, advances in pedestrian detection sensors are continual and accelerating. As technology has

[21] Noblis, "Motor Bus Collisions with Pedestrians," Presentation provided to Battelle by the Federal Transit Administration, November 2015.

[22] J.D. Schneeberger, Gwo-Wei Torng, Dawn Hardesty, and Amy Jacobi,"Transit Vehicle Collision Characteristics for Connected Vehicle Applications Research Analysis of Collisions Involving Transit Vehicles and Applicability of Connected Vehicle Solutions." FHWA Report Number: FHWA-JPO-13-116, 2013.

[23] Kelley Pecheux , Jason Kennedy; Applied Engineering Management Corporation, with James Strathman; Portland State University, "Evaluation of Transit Bus Turn Warning Systems for Pedestrians and Cyclists: Draft Final Report." FTA Report No. 0084, May 2015.

advanced, it has become increasingly practical to deploy an imaging system capable of effectively operating across a broad range of environmental conditions. Further, developments in GPS accuracy technologies, DSRC reliability, as well as the emergence of low-cost embedded computers and cloud-based computing contribute to the justification of this project.

Description of Desired Changes

The objective of this project is to design, prototype develop, and test (in a real-world operational environment) a new transit V2I safety application: Transit Bus Stop Pedestrian Warning. This application will:

- Alert pedestrians at a major bus stop of approaching transit buses
- Alert pedestrians at a major bus stop of departing transit buses
- Alert transit vehicle operators of a pedestrian potentially in harm's way at a major bus stop via a Driver-Vehicle Interface
- Alert on-coming connected vehicles of pedestrians potentially in harm's way at a major bus stop.
- Provide alerts to pedestrians via infrastructure components (e.g., DSRC actuated signage) and pedestrian carried mobile devices
- Alert pedestrians in the roadway in front of a stopped transit vehicle that there is an approaching vehicle that is obscured by the transit vehicle.

To achieve the project objectives, a design and development will be conducted over a one-year period followed by a fielding of the equipment over a several month period. This Field Test (FT) will capture data and identify operational constraints, issues, and other considerations required to enhance the transit safety applications for widespread use in an urban operational setting.

Priorities Among Changes

A key priority will be design, develop, and deploy those components that provide alerts to transit vehicle operators, waiting riders, and pedestrians to enhance existing transit safety methods. A second priority will be to extend the alerts to encompass alerts to pedestrians in the roadway of an approaching vehicle that is obscured by a stopped transit vehicle. Finally, evaluating the developed and deployed systems under a variety of different operational and environmental conditions is desired.

Considered But Not included

There are a number of different safety applications and technologies that could be explored and researched related to improving transit safety; however, safety of the pedestrian is a high priority of FTA and FHWA. In particular, reliance upon a completely vehicle-mounted system (or conversely an infrastructure-only based system) would not support one of the project charters to enhance connected vehicle research.

Assumptions and Constraints

One significant constraint applicable to the TSPW application related to alerting pedestrians in the roadway with an obscured view of an approaching vehicle is that the use of connected vehicle technology requires DSRC communications both in the transit vehicle as well as the other vehicle overtaking the transit vehicle. This ConOps assumes that such radio communications are available and being used by vehicles during that portion of the deployment even though that will not be the case in the immediate future. It is the intent of the developers that by integrating and testing the DSRC-enabled TSPW application now, GCRTA will be ready to enable V2V applications once connected vehicles become common-place on the roadway. It is also assumed that the GCRTA transit vehicles will support the conceptualized system. For example, communications between the CCP and the vehicle systems communications bus of the transit vehicle is assumed.

An independent evaluator will identify the evaluation approach, evaluation goals or hypotheses, performance measures, data elements, data sources/instruments, data quantities, collection timeframes, analysis methods, and a schedule. The independent evaluator will also develop instruments for gathering subjective data, such as questionnaires, interview questions, and focus group scripts.

Chapter 5 Concepts for the Proposed System

Background, Objectives, and Scope

The objective of this project is to design, prototype develop, and test (in a real-world operational environment) a new transit V2I safety application: Transit Bus Stop Pedestrian Warning. This application will:

- Alert pedestrians at a major bus stop of approaching transit buses
- Alert pedestrians at a major bus stop of departing transit buses
- Alert transit vehicle operators of a pedestrian potentially in harm's way at a major bus stop via a Driver-Vehicle Interface
- Alert on-coming connected vehicles of pedestrians potentially in harm's way at a major bus stop
- Provide alerts to pedestrians via infrastructure components (e.g., DSRC actuated signage) and pedestrian carried mobile devices
- Alert pedestrians in the roadway in front of a stopped transit vehicle that there is an approaching vehicle that is obscured by the transit vehicle.

This project is designed to enhance other transit safety and mobility applications previously developed and currently under development for the Federal Highway Administration and the Federal Transit Administration. In particular, this project extends the applications being developed as part of the E-TRP. The E-TRP project includes developing, testing, installing, and maintaining E-TRP systems on 80-100 transit vehicles and approximately five intersections and one mid-block crossing; enhancing transit safety applications developed for TRP; and collecting and providing data from the equipped transit vehicles for independent evaluation.

Operational Policies and Constraints

There are a number of operational policies and constraints that are imposed upon the development and operation of the TSPW Application:

- The TSPW needs to be compatible with the E-TRP system currently under development. The TSPW application will be installed on the same vehicles and near many of the same locations as the E-TRP system, and the two systems need to be interoperable and co-exist in the same hardware platform without interference or creating confusion to the transit vehicle operator, passengers, and pedestrians. However, it should be noted that this constraint is unique for this demonstration project and that future deployments would not require the presence or compatibility with the E-TRP system.

- The TSPW application will be installed in vehicles and at transit stops as a retrofit kit. As such, it needs to have the ability to be interoperable with existing transit systems, processes, and policies.
- The final number of transit vehicles and equipped locations is ultimately dependent on the cost of the transit vehicle retrofit kit as well as the roadside equipment (RSE) kit.

Description of Proposed System

The proposed system will include a number of hardware and software components.

Conceptually, there are three main system components for the proposed system that include:

1. Hardware/Software Mounted Within Transit Vehicle – This hardware and software is contained within various hardware components mounted within the transit vehicle and controls the information presented to the transit vehicle operator regarding the status of pedestrians at transit stops. Additionally, this equipment provides external warnings to pedestrians of approaching vehicles. Finally, this equipment has the responsibility of receiving/broadcasting information to intersection components regarding the status of the transit vehicle. The primary sub-system components within the equipment mounted in the transit vehicle is a computational platform (referred to as the "Common Computational Platform" in the following) and the Data Acquisition System.
2. Infrastructure-Based Pedestrian Detection Equipment – This hardware and software will be pole mounted at a transit stop and will be responsible for identifying pedestrians at the transit stops and providing notification to the central processing and communications unit (i.e., the infrastructure version of the Common Computational Platform) for further processing.
3. Infrastructure-Based Pedestrian Warning Device(s) – This hardware is responsible for providing alerts and warnings to pedestrians waiting at transit stops.

The following provides an overview of each subsystem component that will be deployed as part of the project.

Hardware Components

There are several hardware components that will comprise the joint E-TRP and TSPW system. These include both hardware on the transit vehicle (DSRC radio, CCP, and the human interface system, etc.), as well as the hardware components associated with roadside infrastructure (DSRC radio, CCP, etc.).

Common Computing Platform

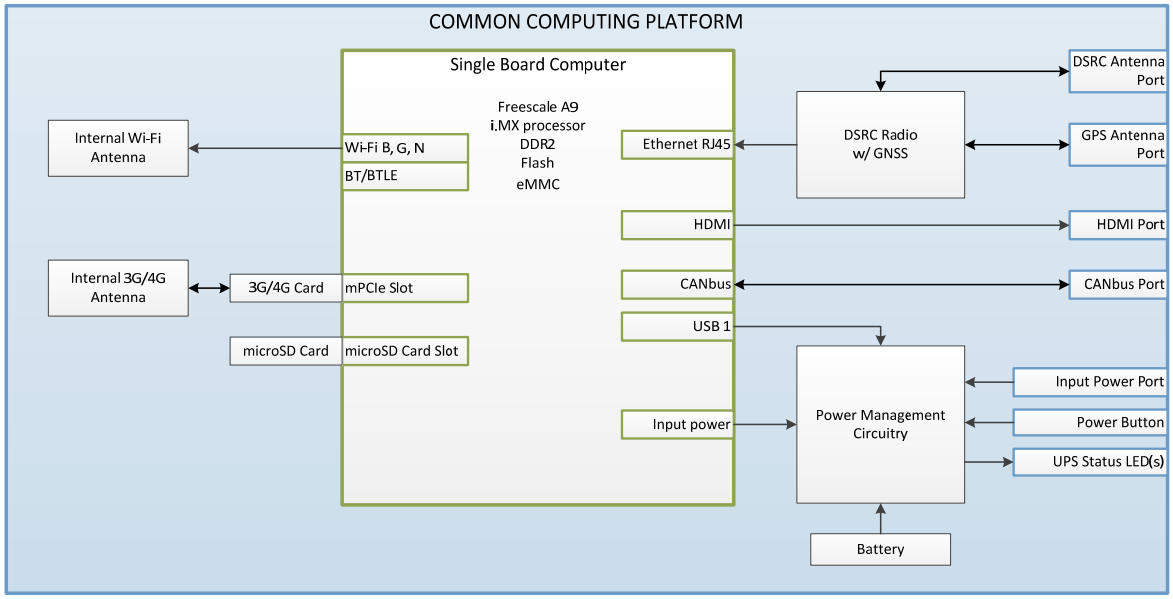
The CCP is effectively a hardened, small form factor, single board computer that serves as the interface to the components of the joint E-TRP and TSPW system. The CCP, shown in concept in Figure 5-1 will be installed in both the transit vehicles and in the roadside infrastructure. The transit vehicle CCP installation is expected to

Source: Battelle

Figure 5-1. Illustration of conceptualized CCP

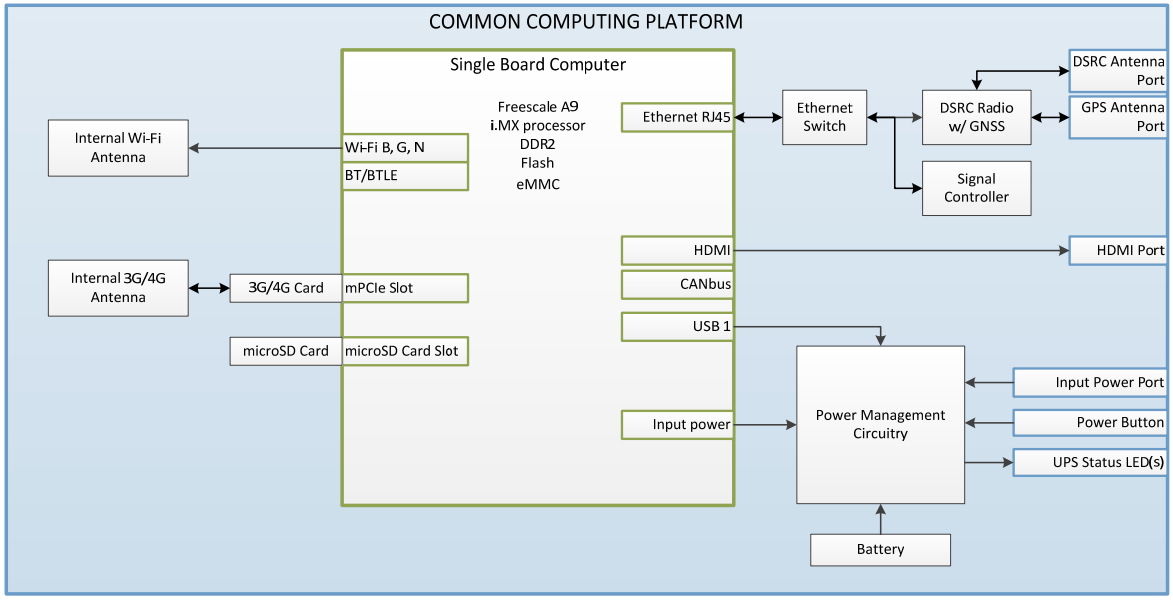
interface to the vehicle data bus, rear-camera, side-mounted proximity sensors, Human Interface System, and power distribution systems. The infrastructure installation is expected to interface to a local power source near the installation location.

The basic hardware architecture for the CCP is shown in Figure 5-2 for the OBE and in Figure 5-3 for the RSE. The TSPW and E-TRP design processes will determine whether the DSRC system and/or cellular modem are incorporated into the CCP enclosure, or installed as a separate component, but for the purposes of this ConOps it is included in Figure 5-2 and Figure 5-3.



Source: Battelle

Figure 5-2. Conceptualized hardware architecture of the CCP and DSRC system communications ports – OBE



Source: Battelle

Figure 5-3. Conceptualized hardware architecture of the CCP and DSRC system communications ports – RSE

DSRC Radio (On-board Unit)

The joint on-board E-TRP and TSPW DSRC radio will be a mature, ready-to-use Commercial-Off-The-Shelf (COTS) DSRC solution. A similar radio will be used for the RSU. Many of today's offerings are a computing and communications platform specifically designed for the development, implementation, testing, and evaluation of 5.9 GHz DSRC V2V/V2I applications. The devices incorporate dual IEEE 802.11 radios, a powerful processor running V2X software stacks and applications, a GPS positioning system providing lane-level accuracy.

Cellular Modem

The cellular modem will likely take the form of an embedded mini PCI express (mPCIe) card and provide a complete, read-to-integrate communications modem likely utilizing 4G LTE standards. The cellular modem will serve as the primary communications method between the CCP and the Cloud-based Management System. The cellular modem will be installed in both the transit vehicle and infrastructure installations.

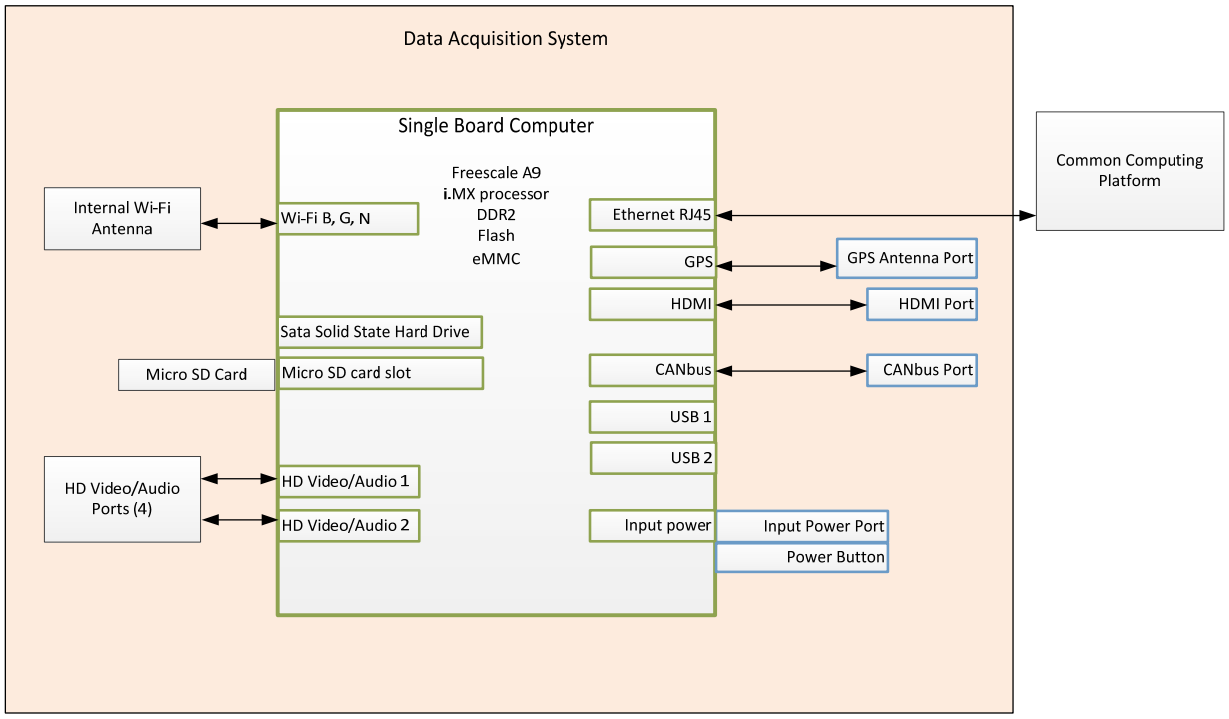
Data Acquisition System

From a configuration management perspective the DAS is a separate assembly from the E-TRP or TSPW systems. The purpose of the DAS is to collect data from the systems during the evaluation portion of this project. The collected data will provide the third party evaluation with "ground truth" data to determine the overall effectiveness and reliability of the system. The DAS is itself a small form factor computer with on-board and cloud-based storage capabilities.

The DAS for the TSPW project will provide the ability to record a variety of vehicle dynamic information at variable sampling rates and/or based on various threshold settings or trigger events. The DAS will also include an integrated video monitoring system capable of recording driver actions,

as well as events outside the vehicle. Finally, the DAS will be capable of recording up to 10 days of operational data before requiring a download.

The DAS is expected to be a small, form factor computer similar to the CCP but separate and distinct from the CCP. The DAS will be expected to operate autonomously from the CCP, though receiving as input information from the CCP, and will serve as the primary mechanism for collection of data to support the evaluation of the TSPW application. Figure 5-4 illustrates a conceptual architecture for the DAS.



Source: Battelle

Figure 5-4. Conceptualized architecture for the data acquisition system

Cloud-Based Management System

The TSPW cloud management system will serve as a remote portal for two primary functions: remote data storage and remote fleet management. Both the transit-based and the infrastructure-based CCPs will be collecting a large amount of data during operations and providing this data to a DAS. Sources of this data include streaming video from cameras, vehicle Controller Area Network (CAN) bus data, and data from the safety applications. Rather than permanently store all of this data locally on each CCP and/or DAS during the entire period of operation, the data will be periodically pushed to a Cloud-based database for collection, storage, archival, and analysis. In addition to sending the collected operational data, the CCP will also periodically send status messages to the CMS to allow for near-real time monitoring of the deployed TSPW application. For example, a system administrator would be able to log into a fleet management portal and view a dashboard of the status of each installed system that would possibly include:

- Operational State (Active, Standby, Offline)
- Last communication with CMS timestamp

- Last time data was uploaded to the CMS
- Subsystem Health (Operational, Unknown)
- Running total of number of informational alerts
- Running total of number of warnings.

In addition to the dashboard, the fleet management portal should also allow for pushing remote software updates to the CCP, reducing the need to service/update the system in-person.

Pedestrian Detection System

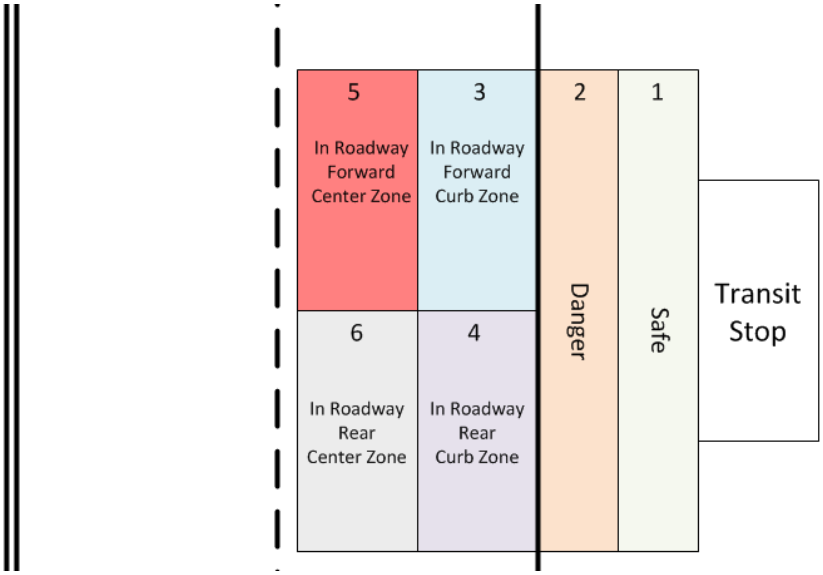
Pedestrian detection will be done at the transit stop utilizing an off the shelf but emerging technology. Ideally, the solution would be capable of discerning between pedestrians, bicyclists and vehicles across a wide operating environment, including below freezing, at night, and in rain and snow. Accurate detection of multiple pedestrians at the same time is required. The system should also be capable of detecting pedestrians that are both in motion (walking across the street in the crosswalk) as well as standing still (waiting in the sidewalk apron).

Figure 5-5 provides an overview of the basic configuration expected at a transit stop with respect to pedestrian zones of interest. As observed in the figure, there are seven zones of interest where pedestrians are expected to be identified with four of these zones in the roadway overlapping the expected path of the transit vehicle. The following briefly describes each of these seven zones:

- **Waiting Zone – Within Transit Stop Shelter:** Pedestrians in this zone are considered to be safe from being struck by vehicles. This zone encompasses the area protected by a shelter house, if provided.
- **Waiting Zone – Safe:** Pedestrians in this zone are considered to be safe from being struck by vehicles. This zone encompasses the area of the sidewalk closest to the transit stop shelter house.
- **Waiting Zone – Danger:** This zone encompasses the area of the sidewalk closest to the roadway. Pedestrians in this zone would be at risk of being struck by a transit vehicle as the vehicle maneuvers into and out of the transit stop and/or from anything protruding from the transit vehicle such as a side mirror.
- **In Roadway Forward Curb Zone:** This zone encompasses the roadway in the lane closest to the transit stop and roughly one-half the width (curb-side) of the transit vehicle and one-half of the total length of the pedestrian zones at the transit stop. Pedestrians in this zone would be considered to be at risk of being struck by vehicles.
- **In Roadway Rear Curb Zone:** This zone encompasses the roadway in the lane closest to the transit stop and roughly one-half of the total width (curb-side) of the transit vehicle and one-half of the total length of the pedestrian zones at the transit stop. Pedestrians in this zone would be considered to be at risk of being struck by vehicles.
- **In Roadway Forward Center Zone:** This zone encompasses the roadway in the lane closest to the transit stop and roughly one-half the width (opposite of curb-side) of the transit vehicle and one-half of the total length of the pedestrian zones at the transit stop. Pedestrians in this zone would be considered to be at risk of being struck by vehicles. These zone may be widened into the adjacent lane(s) to detect

pedestrians crossing the street from the opposite direction (e.g. jaywalking) to catch the bus.

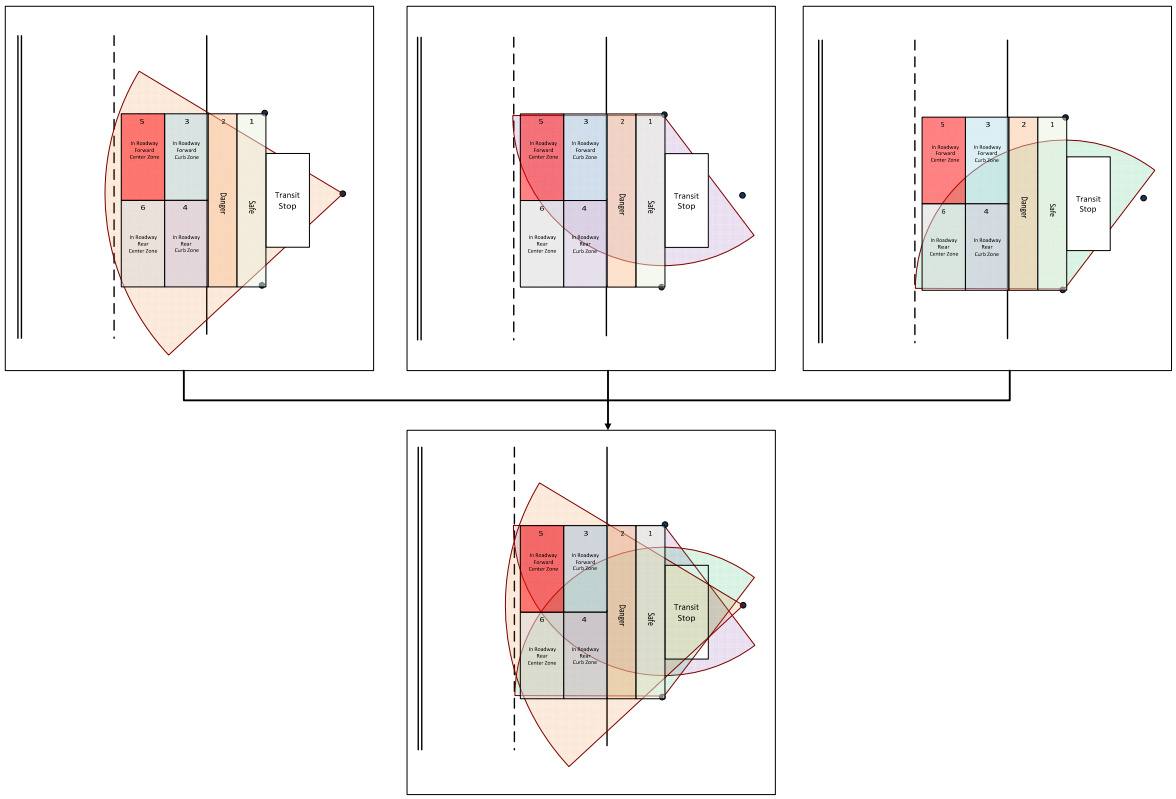
- **In Roadway Rear Center Zone:** This zone encompasses the roadway in the lane closest to the transit stop and roughly one-half of the total width (opposite of curb-side) of the transit vehicle and one-half of the total length of the pedestrian zones at the transit stop. Pedestrians in this zone would be considered to be at risk of being struck by vehicles. These zone may be widened into the adjacent lane(s) to detect pedestrians crossing the street from the opposite direction (e.g. jaywalking) to catch the bus.



Source: Battelle

Figure 5-5. Six pedestrian zones of interest for a typical transit stop

It is envisioned that multiple detectors will be needed at each transit stop to accommodate various fields of view and zones. These detectors would provide overlapping fields of view that collectively would encompass all six pedestrian zones of interest when combined as illustrated in Figure 5-6. In the figure, the six pedestrian zones of interest are covered by three pedestrian detectors. However, more or less detectors may be needed depending upon the range and field of vision for the pedestrian detectors.



Source: Battelle

Figure 5-6. Illustration of using three pedestrian detectors to cover the six pedestrian zones of interest

Human Interface System for Transit Vehicle Operator

The purpose of the HIS for the transit vehicle operator is to provide an indication to the transit vehicle driver that a pedestrian has been detected in the predicted path of the transit vehicle. The exact form, fit, and functionality of the HIS will be determined through the requirements process. However, the overall concept of the HIS is to provide the operator with information in a non-distracting and timely fashion to improve safety by reducing that change of pedestrian collision. Driver interface methods may include the use of LED indicators strategically placed at various spots in the driver's field of view or audible tones, to indicate an alert or warning event with some form of indication of directionality.

Mobile Devices

The TSPW application includes providing alerts to waiting riders and pedestrians in the zones around the transit stop of oncoming, departing, and transit vehicles at the transit stop. This communication is expected to be conducted wirelessly and may consist of "instant message" type notifications that will provide both a visual, audible, and tactile alert to the owner of the mobile device. Other than installation of the application and configuration of the communications interface, no other modifications to the mobile device is expected.

On-Board Transit Vehicle Pedestrian Warning Device

The transit vehicles will include hardware that will enable the vehicle itself to provide a pedestrian walking in front the transit vehicle with a visual and/or audible alert warning the pedestrian of an on-coming vehicle passing the transit vehicle. This mechanism is designed to provide additional protection to pedestrians crossing in front of the transit vehicle who are prevented from seeing on-coming traffic by the transit vehicle.

Infrastructure Based, Pedestrian Warning Device

The purpose of the infrastructure based, pedestrian warning system is to provide pedestrians with an audible and visual alert that they are in danger of being struck by a transit vehicle. It is envisioned that this warning system will consist of a digital message sign capable of displaying text messages, flashing, and emitting an audible tone. Additionally, this digital message sign will provide traveler information about approaching transit vehicles. Figure 5-7 illustrates a typical message that would be displayed on this digital media.

Source: Battelle

Figure 5-7. Illustration of dynamic message sign for waiting rider

Software Components

The TSPW application improves safety of pedestrians by providing informational alerts and warnings to the transit vehicle operator of a pedestrian in danger of being stuck by the transit vehicle. At the same time, the software application notifies waiting riders and pedestrians of on-coming transit vehicles and DSRC-equipped connected vehicles. The functionality of warning transit vehicle operators or pedestrians/waiting riders will be encompassed in a single application, but will be separated by functional components. Effectively, there will be four functional components to the overall TSPW application:

- On-Board Transit Vehicle Component
- Transit Stop Infrastructure Component
- Mobile Device Component
- On-Coming Personally Owned Vehicle (POV) Component.

The following summarizes the functionality of the TSPW components.

Table 5-1. Summary of functionality of the four major software components comprising the TSPW application

Function	Software Component			
	On-Board Transit Vehicle	**Transit Stop Infrastructure**	**Mobile Device**	**On-Coming POV**
Input	• GPS position (Latitude, Longitude, Timestamp, Heading, Speed, Elevation) • DSRC messages (Geometric Intersection Description, Basic Safety Messages, etc.) • J1939 transit vehicle telematics • Transit vehicle proximity sensors (if equipped) • Status and location of pedestrians/waiting riders	• Information from pedestrian detection equipment • Information from mobile devices of waiting riders (location, presence at transit stop) • BSM and Transit Vehicle Tracking DSRC messages	• GPS position • Alerts from Transit Stop Infrastructure	• GPS position • DSRC messages (GID, BSMs) • Status and location of pedestrians and/or waiting riders via DSRC
Processing	Responsible for determining the location, heading, and status of the transit vehicle relative to the transit stop and reporting this information to the Transit Stop Infrastructure component. Receives information from the Transit Stop Infrastructure components regarding the status of pedestrians and/or waiting riders and determines whether to display an alert to the transit vehicle operator and/or activate the on-board transit pedestrian warning hardware.	This component receives information from the pedestrian detection equipment and uses this information to maintain situational awareness of the pedestrian zones. This component controls the infrastructure pedestrian warning system and the digital message board.	This component is responsible for receiving alerts from the Transit Stop Infrastructure component and presenting these to the waiting rider/pedestrian	This component is responsible for determining the location of the on-coming vehicle relative to the transit stop and presenting alerts to the operator.
Output	• DSRC messages (Transit Vehicle Tracking Messages, Basic Safety Messages) • Activation of on-board transit vehicle pedestrian warning	• Activation of pedestrian warning system • Alerts to mobile devices • DSRC messages	• Status and location of pedestrian and/or waiting rider	• DSRC Basic Safety Messages

Source: Battelle

Modes of Operation

The TSPW system has the following modes of operation:

- Transit Standby Mode is where the un-switched battery voltage is powering the joint TSPW and E-TRP system but the battery voltage that is controlled by the ignition switch is removed. In this mode, the common computing platform continues to monitor the vehicle CAN bus but the other peripherals including DSRC, cellular, and the HIS are off.
- Transit Operational Mode is characterized by full TSPW system operation where the common computing platform is monitoring DSRC, CAN bus, GPS, and communicating data to the DAS, HIS, and CMS.
- Transit Stop Infrastructure Operational Mode is characterized by full TSPW system operation where the pedestrian detection equipment and the pedestrian warning systems are in full operation and transmitting information on the status and location of pedestrians to transit vehicles.

User Classes and other Involved Personnel

The user classes and associated personnel are expected to remain very similar to the existing system. The transit agency will continue to operate all in-vehicle systems, but during the evaluation period Battelle will serve as the maintainer of the TSPW in-vehicle system. The City of Cleveland or GCRTA will assist Battelle in the maintenance of the TSPW Infrastructure equipment, based on the ownership of the bus stop infrastructure. Operation consists mainly of supplying both space allocation and power to the equipment. Additionally, pedestrians will be added as data consumers for the TSPW application as they will have a new source of information about their situation. During development transit vehicle operators will be provided an opportunity to provide feedback on the system concept during closed-course training opportunities.

Support Environment

The support environment is largely similar to that of the existing System or Situation. Battelle will initially serve as the provider, installer, and maintainer of the TSPW application throughout the duration of this project. GCRTA will provide transit vehicle maintenance staff to assist in the installation and maintenance of the TSPW application. GCRTA and the City of Cleveland will provide maintenance support for the transit stops, based on who the responsible party is for each location. After the period of performance of this project, Battelle intends to transition all operational and maintenance responsibility of the TSPW application to GCRTA and the City of Cleveland.

Chapter 6 Operational Scenarios

The following scenarios describe how the system will operate, with the primary focus centered on the transit vehicle operator as well as persons at the transit stop either waiting for a transit vehicle or as pedestrians. The differences in the scenario details are summarized in each section.

The TSPW application will generate alerts during dangerous and potentially dangerous situations.

- An "inform alert" refers to an indication that a potentially dangerous situation could occur.
- A "warning alert" refers to an indication that a dangerous situation is likely to occur.

Unless noted, the transit stop infrastructure and the transit vehicle with the TSPW application are in Operational Mode.

Within the scenarios below, graphics are provided indicating the type of feedback, and who the information will be presented to, as the scenario unfolds. The graphics used are for illustrative purposes only as the actual human interface designs will be developed during the system design phase. For the purposes of illustration, color coding is used to indicate that an alert is presented to a specific user group and the nature of the alert. The following color coding schema is used throughout the scenarios:

1. An enable alert to the transit vehicle operator that the transit stop is a TSPW equipped transit stop in the absence of any waiting passengers or pedestrians is indicated in Green.
2. Visual enable alerts will be presented to pedestrians and/or waiting riders via the Infrastructure Based, Pedestrian Warning Device when they are in the Safe Waiting Zone to provide the pedestrians and/or waiting riders with information on the status of the transit vehicle (arriving, at-stop). For the purposes of illustration, these enable alerts are indicated in Green.
3. Inform alerts to pedestrians and/or waiting riders will be issued when they are in the Danger Waiting Zone and are potentially at risk of being struck by a transit vehicle. These inform alerts will consist of audible, visual, and tactile notifications on their individual mobile devices and a visual display on the Infrastructure Based, Pedestrian Warning Device. For the purposes of illustration, these inform alerts are indicated in Yellow.
4. Warning alerts to pedestrians and/or waiting riders will be issued when they are in one of the four Roadway Zones and are at risk of being struck by a moving transit vehicle. These warning alerts will consist of activation of the Infrastructure Based, Pedestrian Warning Device; visual, audible, and tactile warnings on their mobile devices; and in cases where the pedestrian is crossing in front of the transit vehicle with an on-coming DSRC-equipped connected vehicle that is passing the transit vehicle, a visual and audible warning from the transit vehicle. The visual, audible, and tactile warnings on mobile devices may be removed for scenarios when the pedestrian is in the street, based on stakeholder feedback. For the purposes of illustration, these warning alerts are indicated in Red.
5. Inform alerts, indicated in Yellow, will be presented to operators of on-coming DSRC-equipped connected vehicles to indicate that there is a pedestrian present and that this pedestrian may be moving to a position where they could be struck by the on-coming vehicle. A warning alert, indicated in Red will be presented if there is a pedestrian that is in one of the four roadway zones and is at risk of being struck by the on-coming vehicle.

It is expected that the TSPW application will need to assess and determine the conditions and resulting notifications based upon a number of factors. These factors could include aspects such as the:

- Telematics information from the transit vehicle and/or on-coming DSRC-equipped connected vehicle indicating current path of the vehicle as it approaches an intersection.
- Predicated path of the vehicle
- Pedestrian detection status and presence of a person in one of the six zones.

Ultimately, for the purposes of this ConOps, it is assumed that the system will be able to determine, based upon current conditions and other information, the intention, path, and direction of the transit vehicle and DSRC-equipped connected vehicle (remote vehicle) with respect to pedestrians at an equipped transit stop. The specific parameters and observational factors that will be gathered and processed for this analysis will be determined as part of the system design process.

The TSPW application will be developed and deployed in a real-world environment using actual transit vehicles, pedestrians, and transit stops. As such, the application is expected to encounter a wide variety of different scenarios during operation. While it is possible to enumerate all possible scenarios, the following section only provides concepts for a number of expected scenarios that vary based upon the presence or absence of pedestrians, the path of the transit vehicle and/or on-coming DSRC-equipped connected vehicle, and the location pedestrians relative to transit vehicles and other on-coming vehicles.

The scenarios presented in this section involve pedestrians and waiting riders at equipped transit stops. Unequipped transit stops or unequipped transit vehicles are outside of the study boundaries. Within the study boundaries there are many different options and possible scenarios. All possible scenarios involving a single pedestrian or waiting rider are enumerated in Table 6-1. Additional permutations involving multiple pedestrians/waiting riders and/or multiple transit vehicles can be observed and illustrated through combining the appropriate single pedestrian/waiting rider and single transit vehicle scenarios (see Table 6-2 for examples).

Table 6-1. TSPW single pedestrian/waiting rider scenarios with a single transit vehicle

Status of Transit Vehicle	Zone Where Pedestrian/ Waiting Rider Detected	Status of Additional Connected Vehicle	Scenario Reference
Approaching – outside of roadway zones	None	None	Figure 6-1. Scenario 1 – Transit vehicle approaching with no waiting pedestrians/riders
Approaching – outside of roadway zones	Waiting – transit shelter	None	Figure 6-2. Scenario 2 – Transit vehicle approaching with the rider waiting in safe zone inside transit shelter
Approaching – outside of roadway zones	Waiting – safe	None	Figure 6-3. Scenario 3 – Transit vehicle approaching with the rider waiting in safe zone
Approaching – outside of roadway zones	Waiting – danger	None	Figure 6-4. Scenario 4 – Transit vehicle approaching with the rider waiting in danger waiting zone

Table 6-1. TSPW single pedestrian/waiting rider scenarios with a single transit vehicle (continued)

Status of Transit Vehicle	Zone Where Pedestrian/ Waiting Rider Detected	Status of Additional Connected Vehicle	Scenario Reference
Approaching – outside of roadway zones	Roadway – forward curbside	None	Figure 6-5. Scenario 5 – Transit vehicle approaching with a pedestrian in forward curbside roadway zone
Approaching – outside of roadway zones	Roadway – rear curbside	None	Figure 6-6. Scenario 6 – Transit vehicle approaching with a pedestrian in rear curbside roadway zone
Approaching – outside of roadway zones	Roadway – forward center	None	Figure 6-7. Scenario 7 – Transit vehicle approaching with a pedestrian in forward center roadway zone
Approaching – outside of roadway zones	Roadway – rear center	None	Figure 6-8. Scenario 8 – Transit vehicle approaching with a pedestrian in rear roadway zone
Approaching – in rear roadway zone	None	None	Figure 6-9. Scenario 9 – Transit vehicle approaching and has entered the rear roadway zone with no waiting riders at the transit stop
Approaching – in rear roadway zone	Waiting – transit shelter	None	Figure 6-10. Scenario 10 – Transit vehicle approaching and has entered the rear roadway zone with a rider waiting in safe zone inside transit shelter
Approaching – in rear roadway zone	Waiting – safe	None	Figure 6-11. Scenario 11 – Transit vehicle approaching and has entered the rear roadway zone with the rider waiting in safe zone
Approaching – in rear roadway zone	Waiting – danger zone	None	Figure 6-12. Scenario 12 – Transit vehicle approaching and has entered the rear roadway zone with the rider waiting in danger zone
Approaching – in rear roadway zone	Roadway – forward curbside	None	Figure 6-13. Scenario 13 – Transit vehicle approaching and has entered the rear roadway zone and there is a pedestrian in forward curbside roadway zone
Approaching – in rear roadway zone	Roadway – rear curbside	None	Figure 6-14. Scenario 14 – Transit vehicle approaching and has entered the rear roadway zone and there is a pedestrian in rear curbside roadway zone
Approaching – in rear roadway zone	Roadway – forward center	None	Figure 6-15. Scenario 15 – Transit vehicle approaching and has entered the rear roadway zone and there is a pedestrian in forward center roadway zone
Approaching – in rear roadway zone	Roadway – rear center	None	Figure 6-16. Scenario 16 – Transit vehicle approaching and has entered the rear roadway zone and there is a pedestrian in rear center roadway zone
At transit stop	None	None	Figure 6-17. Scenario 17 – Transit vehicle stopped at transit stop with no waiting riders or pedestrians

Table 6-1. TSPW single pedestrian/waiting rider scenarios with a single transit vehicle (continued)

Status of Transit Vehicle	Zone Where Pedestrian/ Waiting Rider Detected	Status of Additional Connected Vehicle	Scenario Reference
At transit stop	Waiting – transit shelter	None	Figure 6-18. Scenario 18 – Transit vehicle stopped at transit stop with waiting rider inside of transit shelter
At transit stop	Waiting – safe	None	Figure 6-19. Scenario 19 – Transit vehicle stopped at transit stop with waiting rider in safe zone
At transit stop	Waiting – danger	None	Figure 6-20. Scenario 20 – Transit vehicle stopped at transit stop with waiting rider inside of the danger zone
At transit stop	Roadway – forward curbside	None	Figure 6-21. Scenario 21 –Transit vehicle stopped at transit stop with pedestrian in the forward curbside roadway zone
At transit stop	Roadway – rear curbside	None	Figure 6-22. Scenario 22 – Transit vehicle stopped at transit stop with pedestrian in the rear curbside roadway zone
At transit stop	Roadway – forward center; in front of transit vehicle	None	Figure 6-23. Scenario 23 – Transit vehicle stopped at transit stop with pedestrian in the forward center roadway zone in front of the stopped transit vehicle
At transit stop	Roadway – rear center	None	Figure 6-24. Scenario 24 – Transit vehicle stopped at transit stop with pedestrian in the rear center roadway zone in front of the stopped transit vehicle
Departing – transit vehicle still in all roadway zones	None	None	Figure 6-25. Scenario 25 – Transit vehicle is departing but is still in all four roadway zones and there are no waiting riders
Departing – transit vehicle still in all roadway zones	Waiting – transit shelter	None	Figure 6-26. Scenario 26 – Transit vehicle is departing but is still in all four roadway zones and there is a rider waiting in safe zone inside transit shelter
Departing – transit vehicle still in all roadway zones	Waiting – safe	None	Figure 6-27. Scenario 27 – Transit vehicle is departing but is still in all four roadway zones and there is a waiting rider in the safe zone
Departing – transit vehicle still in all roadway zones	Waiting – danger	None	Figure 6-28. Scenario 28 – Transit vehicle is departing but is still in all four roadway zones and there is a waiting rider in the danger zone
Departing – transit vehicle still in all roadway zones	Roadway – forward curbside	None	Figure 6-29. Scenario 29 – Transit vehicle is departing but is still in all four roadway zones and there is a pedestrian in the forward curbside roadway zone
Departing – transit vehicle still in all roadway zones	Roadway – rear curbside	None	Figure 6-30. Scenario 30 – Transit vehicle is departing but is still in all four roadway zones and there is a pedestrian in the rear curbside roadway zone

Table 6-1. TSPW single pedestrian/waiting rider scenarios with a single transit vehicle (continued)

Status of Transit Vehicle	Zone Where Pedestrian/ Waiting Rider Detected	Status of Additional Connected Vehicle	Scenario Reference
Departing – transit vehicle still in all roadway zones	Roadway – forward center	None	Figure 6-31. Scenario 31 – Transit vehicle is departing but is still in all four roadway zones and there is a pedestrian in the forward center roadway zone
Departing – transit vehicle still in all roadway zones	Roadway – rear center	None	Figure 6-32. Scenario 32 – Transit vehicle is departing but is still in all four roadway zones and there is a pedestrian in the rear center roadway zone
Departing – transit vehicle still in forward roadway zone	None	None	Figure 6-33. Scenario 33 – Transit vehicle is departing but is still in the forward roadway zones and there are no waiting riders
Departing – transit vehicle still in forward roadway zone	Waiting – transit shelter	None	Figure 6-34. Scenario 34 – Transit vehicle is departing but is still in the forward roadway zones and there is a rider waiting in safe zone inside transit shelter
Departing – transit vehicle still in forward roadway zone	Waiting – safe	None	Figure 6-35. Scenario 35 – Transit vehicle is departing but is still in the forward roadway zones and there is a waiting rider in the safe zone
Departing – transit vehicle still in forward roadway zone	Waiting – danger	None	Figure 6-36. Scenario 36 – Transit vehicle is departing but is still in the forward roadway zones and there is a waiting rider in the danger zone
Departing – transit vehicle still in forward roadway zone	Roadway – forward curbside	None	Figure 6-37. Scenario 37 – Transit vehicle is departing but is still in the forward roadway zones and there is a pedestrian in the forward curbside roadway zone
Departing – transit vehicle still in forward roadway zone	Roadway – rear curbside	None	Figure 6-38. Scenario 38 – Transit vehicle is departing but is still in the forward roadway zones and there is a pedestrian in the rear curbside roadway zone
Departing – transit vehicle still in forward roadway zone	Roadway – forward center	None	Figure 6-39. Scenario 39 – Transit vehicle is departing but is still in the forward roadway zones and there is a pedestrian in the forward center roadway zone
Departing – transit vehicle still in forward roadway zone	Roadway – rear center	None	Figure 6-40. Scenario 40 – Transit vehicle is departing but is still in the forward roadway zones and there is a pedestrian in the rear center roadway zone
Departing – transit vehicle clear of all roadway zones	None	None	Figure 6-41. Scenario 41 – Transit vehicle is departing and has cleared all roadway zones and there are no waiting riders
Departing – transit vehicle clear of all roadway zones	Waiting – transit shelter	None	Figure 6-42. Scenario 42 – Transit vehicle is departing and has cleared all roadway zones and there is a rider waiting in safe zone inside transit shelter

Table 6-1. TSPW single pedestrian/waiting rider scenarios with a single transit vehicle (continued)

Status of Transit Vehicle	Zone Where Pedestrian/ Waiting Rider Detected	Status of Additional Connected Vehicle	Scenario Reference
Departing – transit vehicle clear of all roadway zones	Waiting – safe	None	Figure 6-43. Scenario 43 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the safe zone
Departing – transit vehicle clear of all roadway zones	Waiting – danger	None	Figure 6-44. Scenario 44 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the danger zone
Departing – transit vehicle clear of all roadway zones	Roadway – forward curbside	None	Figure 6-45. Scenario 45 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward curbside roadway zone
Departing – transit vehicle clear of all roadway zones	Roadway – rear curbside	None	Figure 6-46. Scenario 46 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear curbside roadway zone
Departing – transit vehicle clear of all roadway zones	Roadway – forward center	None	Figure 6-47. Scenario 47 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward center roadway zone
Departing – transit vehicle clear of all roadway zones	Roadway – rear center	None	Figure 6-48. Scenario 48 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear center roadway zone
At transit stop	None	Behind transit vehicle	Figure 6-49. Scenario 49 – Transit vehicle stopped at transit stop and there are no waiting riders but there is an oncoming vehicle behind the transit vehicle
At transit stop	Waiting – transit shelter	Behind transit vehicle	Figure 6-50. Scenario 50 – Transit vehicle stopped at transit stop with a waiting rider waiting in the transit shelter and an oncoming vehicle behind the transit vehicle
At transit stop	Waiting – safe	Behind transit vehicle	Figure 6-51. Scenario 51 – Transit vehicle stopped at transit stop with a waiting rider waiting in the safe zone and an oncoming vehicle behind the transit vehicle
At transit stop	Waiting – danger	Behind transit vehicle	Figure 6-52. Scenario 52 – Transit vehicle stopped at transit stop with a waiting rider waiting in the danger zone and an oncoming vehicle behind the transit vehicle
At transit stop	Roadway – forward curbside	Behind transit vehicle	Figure 6-53. Scenario 53 – Transit vehicle stopped at transit stop with a pedestrian in the forward curbside roadside zone and an oncoming vehicle behind the transit vehicle
At transit stop	Roadway – rear curbside	Behind transit vehicle	Figure 6-54. Scenario 54 – Transit vehicle stopped at transit stop with a pedestrian in the rear curbside roadside zone and an oncoming vehicle behind the transit vehicle

Table 6-1. TSPW single pedestrian/waiting rider scenarios with a single transit vehicle (continued)

Status of Transit Vehicle	Zone Where Pedestrian/ Waiting Rider Detected	Status of Additional Connected Vehicle	Scenario Reference
At transit stop	Roadway – forward center; in front of transit vehicle	Behind transit vehicle	Figure 6-55. Scenario 55 – Transit vehicle stopped at transit stop with pedestrian in the forward center roadway zone in front of the stopped transit vehicle and there is an oncoming vehicle behind the transit vehicle
At transit stop	Roadway – rear center	Behind transit vehicle	Figure 6-56. Scenario 56 – Transit vehicle stopped at transit stop with a pedestrian in the rear center roadside zone and an oncoming vehicle behind the transit vehicle
At transit stop	Roadway – forward curbside	Passing the transit vehicle	Figure 6-57. Scenario 57 – Transit vehicle stopped at transit stop with a pedestrian in the forward curbside roadside zone and an oncoming vehicle passing the transit vehicle
At transit stop	Roadway – rear curbside	Passing the transit vehicle	Figure 6-58. Scenario 58 – Transit vehicle stopped at transit stop with a pedestrian in the rear curbside roadside zone and an oncoming vehicle passing the transit vehicle
At transit stop	Roadway – forward center; in front of transit vehicle	Passing the transit vehicle	Figure 6-59. Scenario 59 – Transit vehicle stopped at transit stop with pedestrian in the forward center roadway zone of the stopped transit vehicle and there is an oncoming vehicle passing the transit vehicle
At transit stop	Roadway – rear center	Behind transit vehicle	Figure 6-60. Scenario 60 – Transit vehicle stopped at transit stop with pedestrian in the rear center roadway zone and there is an oncoming vehicle passing the transit vehicle
Departing – transit vehicle clear of all roadway zones	None	Behind transit vehicle	Figure 6-61. Scenario 61 – Transit vehicle is departing and has cleared all roadway zones with no waiting riders and there is an oncoming vehicle behind the transit vehicle
Departing – transit vehicle clear of all roadway zones	Waiting – transit shelter	Behind transit vehicle	Figure 6-62. Scenario 62 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the safe zone inside of the transit shelter and there is an oncoming vehicle behind the transit vehicle
Departing – transit vehicle clear of all roadway zones	Waiting – safe	Behind transit vehicle	Figure 6-63. Scenario 63 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the safe zone and there is an oncoming vehicle behind the transit vehicle
Departing – transit vehicle clear of all roadway zones	Waiting – danger	Behind transit vehicle	Figure 6-64. Scenario 64 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the danger zone and there is an oncoming vehicle behind the transit vehicle

Table 6-1. TSPW single pedestrian/waiting rider scenarios with a single transit vehicle (continued)

Status of Transit Vehicle	Zone Where Pedestrian/ Waiting Rider Detected	Status of Additional Connected Vehicle	Scenario Reference
Departing – transit vehicle clear of all roadway zones	Roadway – forward curbside	Behind transit vehicle	Figure 6-65. Scenario 65 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward curbside roadway zone and a connected vehicle approaching the transit stop
Departing – transit vehicle clear of all roadway zones	Roadway – rear curbside	Behind transit vehicle	Figure 6-66. Scenario 66 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear curbside roadway zone and there is an oncoming vehicle behind the transit vehicle
Departing – transit vehicle clear of all roadway zones	Roadway – forward center	Behind transit vehicle	Figure 6-67. Scenario 67 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward center roadway zone and a connected vehicle approaching the transit stop
Departing – transit vehicle clear of all roadway zones	Roadway – rear center	Behind transit vehicle	Figure 6-68. Scenario 68 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear center roadway zone and there is an oncoming vehicle behind the transit vehicle
Departing – transit vehicle clear of all roadway zones	Roadway – forward curbside	Passing transit vehicle	Figure 6-69. Scenario 69 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the foreward curbside roadway zone and there is an oncoming vehicle passing the transit vehicle
Departing – transit vehicle clear of all roadway zones	Roadway – rear curbside	Behind transit vehicle	Figure 6-70. Scenario 70 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear curbside roadway zone and there is an oncoming vehicle passing the transit vehicle
Departing – transit vehicle clear of all roadway zones	Roadway – forward center	Passing transit vehicle	Figure 6-71. Scenario 71 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward center roadway zone and there is an oncoming vehicle passing the transit vehicle
Departing – transit vehicle clear of all roadway zones	Roadway – rear center	Behind transit vehicle	Figure 6-72. Scenario 72 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear center roadway zone and there is an oncoming vehicle passing the transit vehicle

Source: Battelle

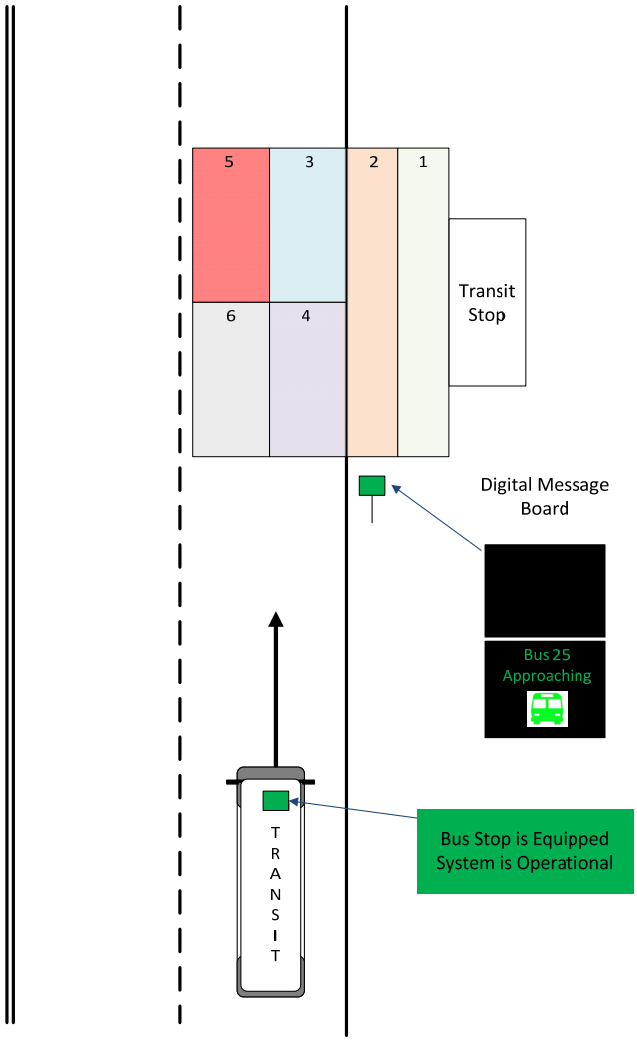
Table 6-2. TSPW multiple waiting rider/pedestrians with multiple transit vehicle scenarios

Status of Transit Vehicles	Zone Where Pedestrians/ Waiting Riders Detected	Scenario Reference
Transit Vehicle #1 is departing but still in the forward roadway zone Transit Vehicle #2 is approaching but has not yet entered the rear roadway zone	Riders are waiting in the safe zone	Figure 6-73. Scenario 73 – First transit vehicle is departing but still in forward roadway zone with the second transit vehicle approaching the transit stop and multiple riders are waiting in the safe zone
Transit Vehicle #1 is departing but still in the forward roadway zone Transit Vehicle #2 is approaching but has not yet entered the rear roadway zone	One waiting rider is in the safe zone with the second pedestrian in the rear roadway zone	Figure 6-74. Scenario 74 – First transit vehicle is departing but still in forward roadway zone with the second transit vehicle approaching the transit stop and one rider is waiting in the safe zone while a pedestrian is in the rear roadway zone

Source: Battelle

Scenario 1 – Transit vehicle approaching with no waiting pedestrians/riders

- The transit vehicle is approaching the transit stop but has not entered any of the roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with an audible and visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Green message.

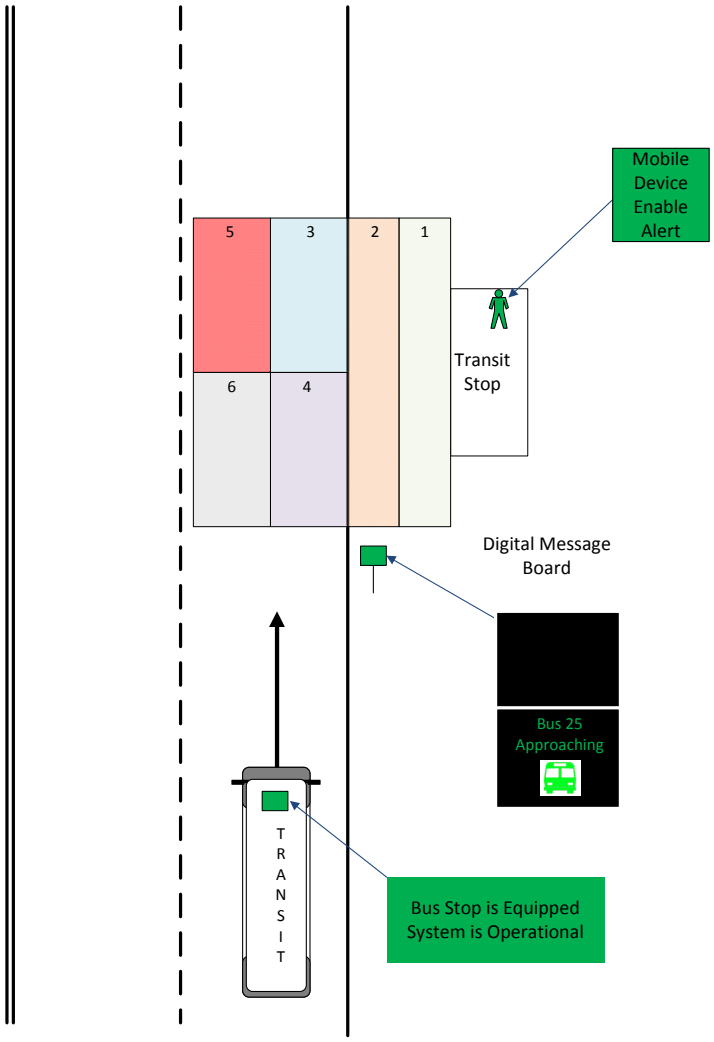


Source: Battelle

Figure 6-1. Scenario 1 – Transit vehicle approaching with no waiting pedestrians/riders

Scenario 2 – Transit vehicle approaching with the rider waiting in safe zone inside transit shelter

- The transit vehicle is approaching the transit stop but has not entered any of the roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a Green visual enabled alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Green message.
- The waiting rider inside the safe zone created by the transit shelter receives a Green enabled alert via a mobile device that indicates that the transit vehicle is approaching.

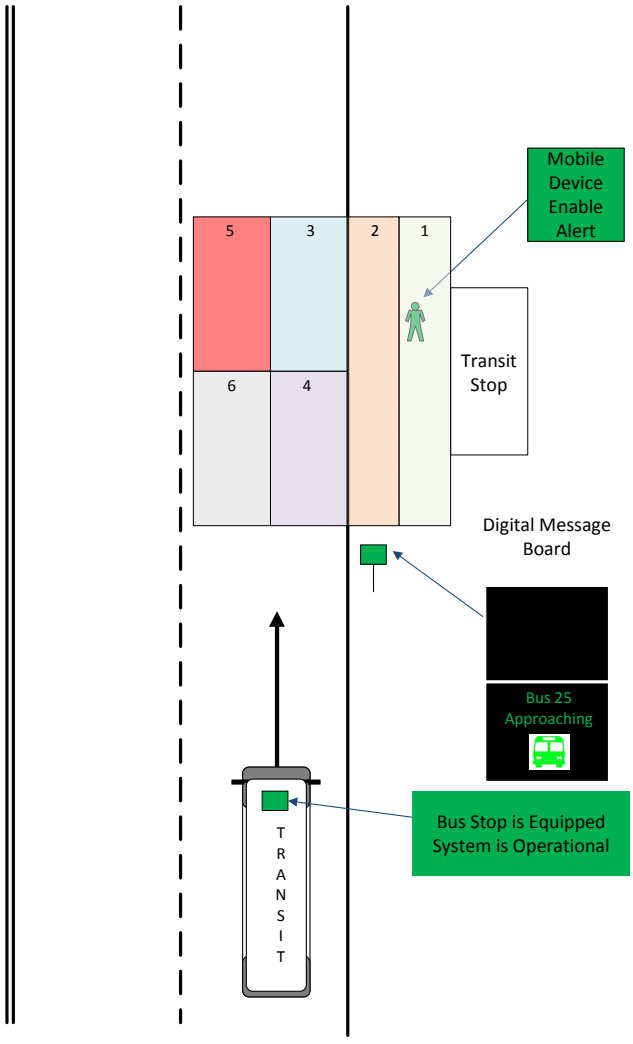


Source: Battelle

Figure 6-2. Scenario 2 – Transit vehicle approaching with the rider waiting in safe zone inside transit shelter

Scenario 3 – Transit vehicle approaching with the rider waiting in safe zone

- The transit vehicle is approaching the transit stop but has not entered any of the roadway zones.
- The TSPW application indicates to the transit vehicle operator with a Green visual enabled alert that there is a waiting rider in the safe zone.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Green message.
- The waiting rider in the safe zone receives a Green enabled alert via a mobile device that indicates that the transit vehicle is approaching.

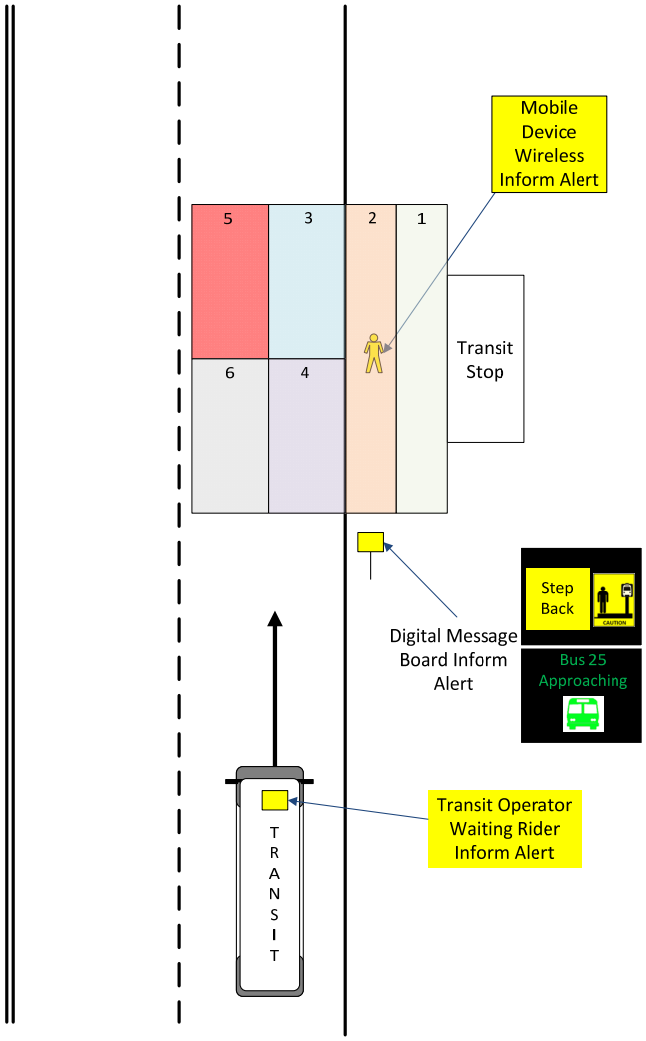


Source: Battelle

Figure 6-3. Scenario 3 – Transit vehicle approaching with the rider waiting in safe zone

Scenario 4 – Transit vehicle approaching with the rider waiting in danger waiting zone

- The transit vehicle is approaching the transit stop but has not entered any of the roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a waiting rider in the danger zone with a Yellow audible and visual inform alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Yellow message.
- The waiting rider in the danger zone receives a Yellow inform alert via a mobile device that indicates that the transit vehicle is approaching.

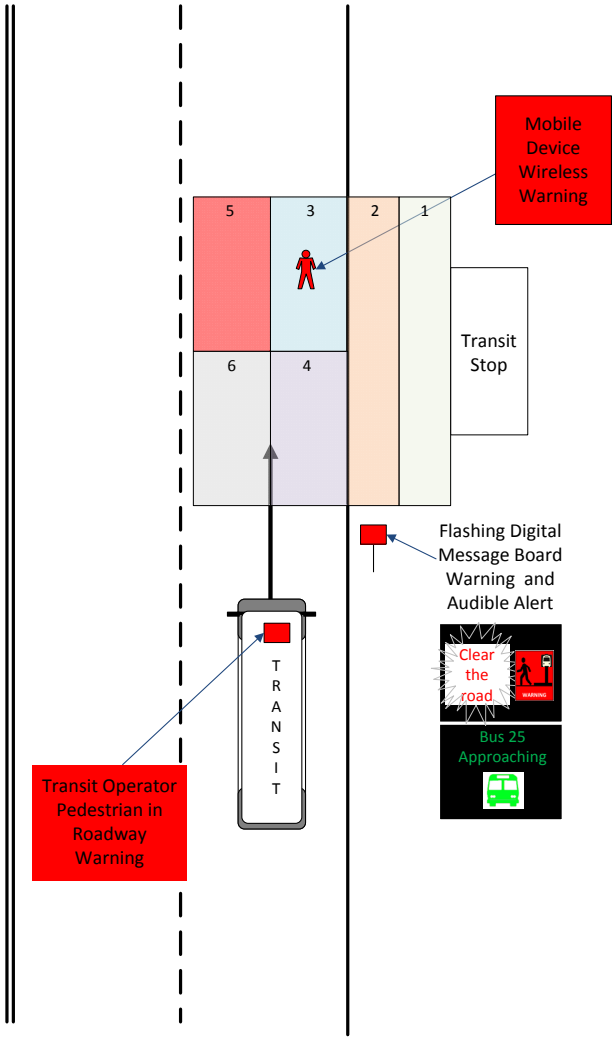


Source: Battelle

Figure 6-4. Scenario 4 – Transit vehicle approaching with the rider waiting in danger waiting zone

Scenario 5 – Transit vehicle approaching with a pedestrian in forward curbside roadway zone

- The transit vehicle is approaching the transit stop but has not entered any of the roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the forward curbside roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Red message that flashes and emits an audible tone.
- The pedestrian in the forward curbside roadway zone receives a Red warning alert via a mobile device that indicates that the transit vehicle is approaching.

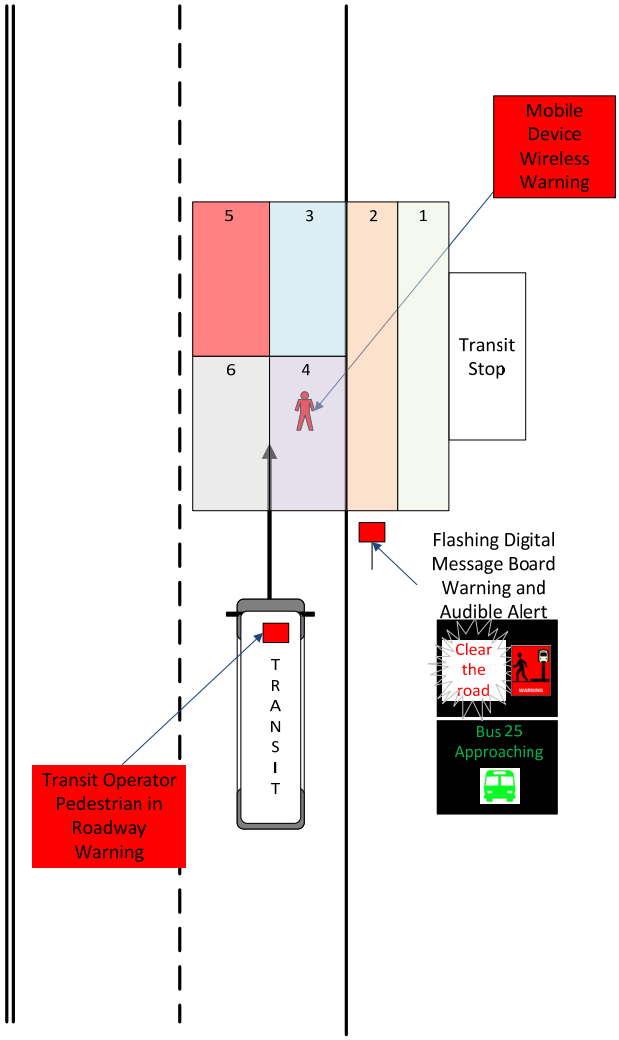


Source: Battelle

Figure 6-5. Scenario 5 – Transit vehicle approaching with a pedestrian in forward curbside roadway zone

Scenario 6 – Transit vehicle approaching with a pedestrian in rear curbside roadway zone

- The transit vehicle is approaching the transit stop but has not entered any of the roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the rear curbside roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Red message that flashes and emits an audible tone.
- The pedestrian in the rear curbside roadway zone receives a Red warning alert via a mobile device that indicates that the transit vehicle is approaching.

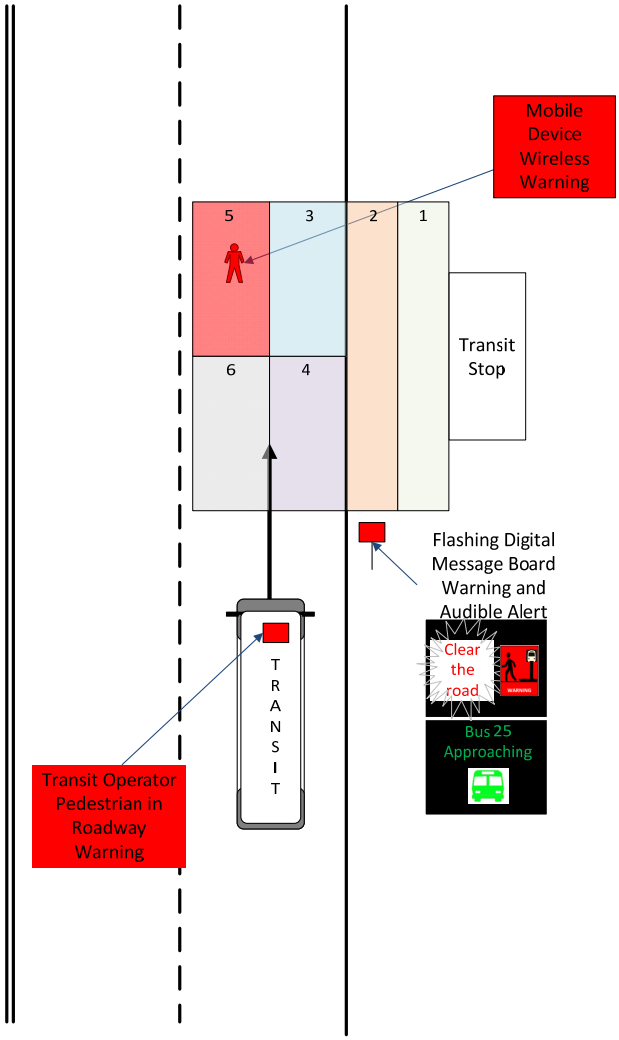


Source: Battelle

Figure 6-6. Scenario 6 – Transit vehicle approaching with a pedestrian in rear curbside roadway zone

Scenario 7 – Transit vehicle approaching with a pedestrian in forward center roadway zone

- The transit vehicle is approaching the transit stop but has not entered any of the roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the forward center roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Red message that flashes and emits an audible tone.
- The pedestrian in the forward center roadway zone receives a Red warning alert via a mobile device that indicates that the transit vehicle is approaching.

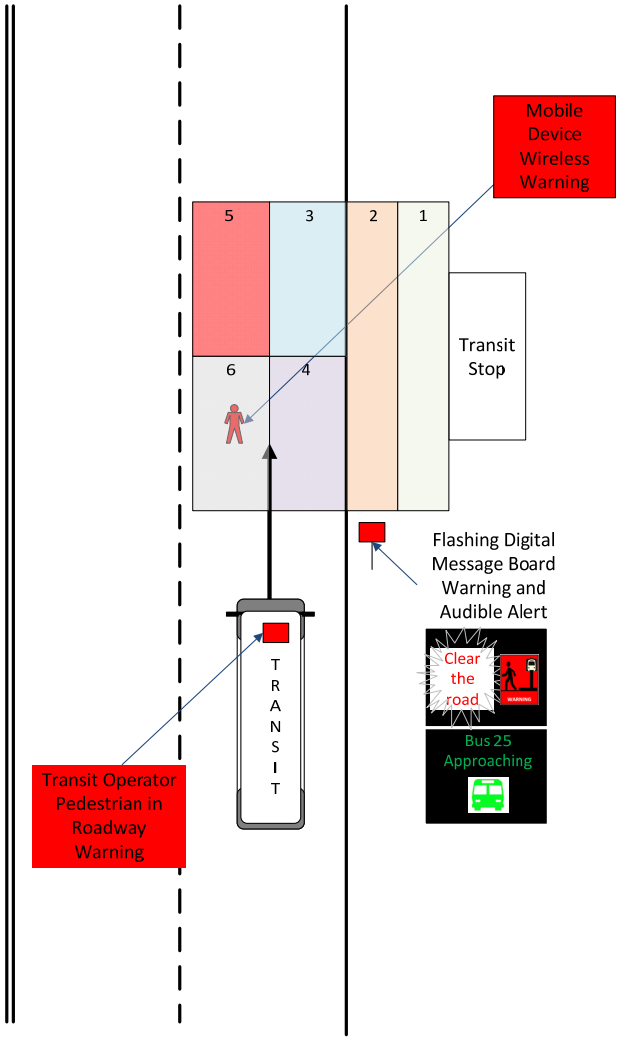


Source: Battelle

Figure 6-7. Scenario 7 – Transit vehicle approaching with a pedestrian in forward center roadway zone

Scenario 8 – Transit vehicle approaching with a pedestrian in rear center roadway zone

- The transit vehicle is approaching the transit stop but has not entered any of the roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the rear center roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Red message that flashes and emits an audible tone.
- The pedestrian in the rear roadway zone receives a Red warning alert via a mobile device that indicates that the transit vehicle is approaching.

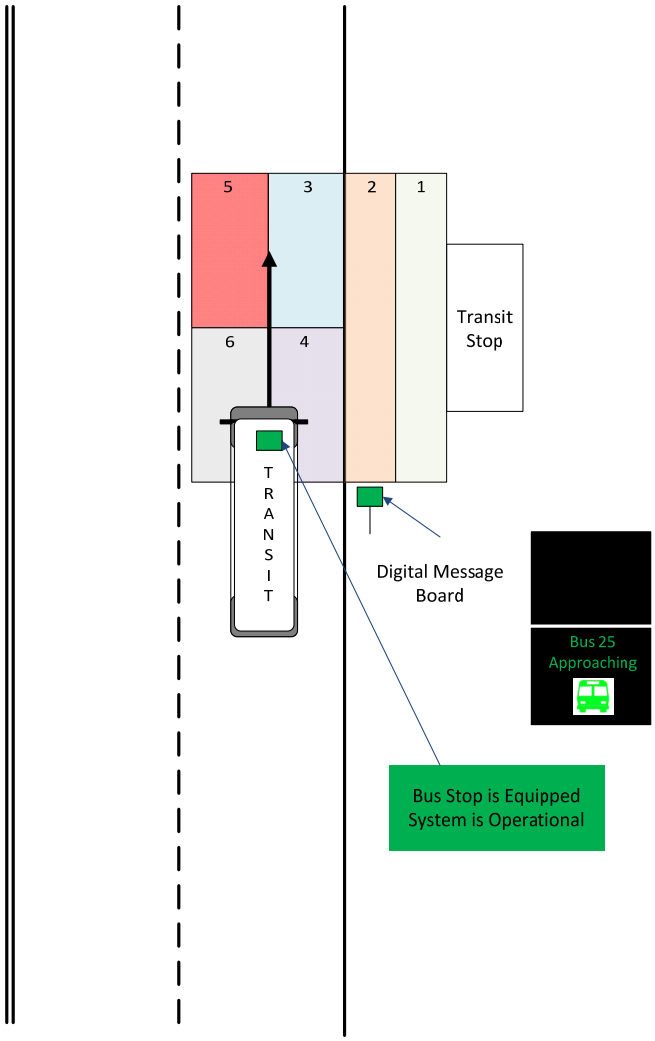


Source: Battelle

Figure 6-8. Scenario 8 – Transit vehicle approaching with a pedestrian in rear roadway zone

Scenario 9 – Transit vehicle approaching and has entered the rear roadway zone with no waiting riders at the transit stop

- The transit vehicle is approaching the transit stop and has entered the rear roadway zone.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Green message.
- There are no waiting riders or pedestrians.

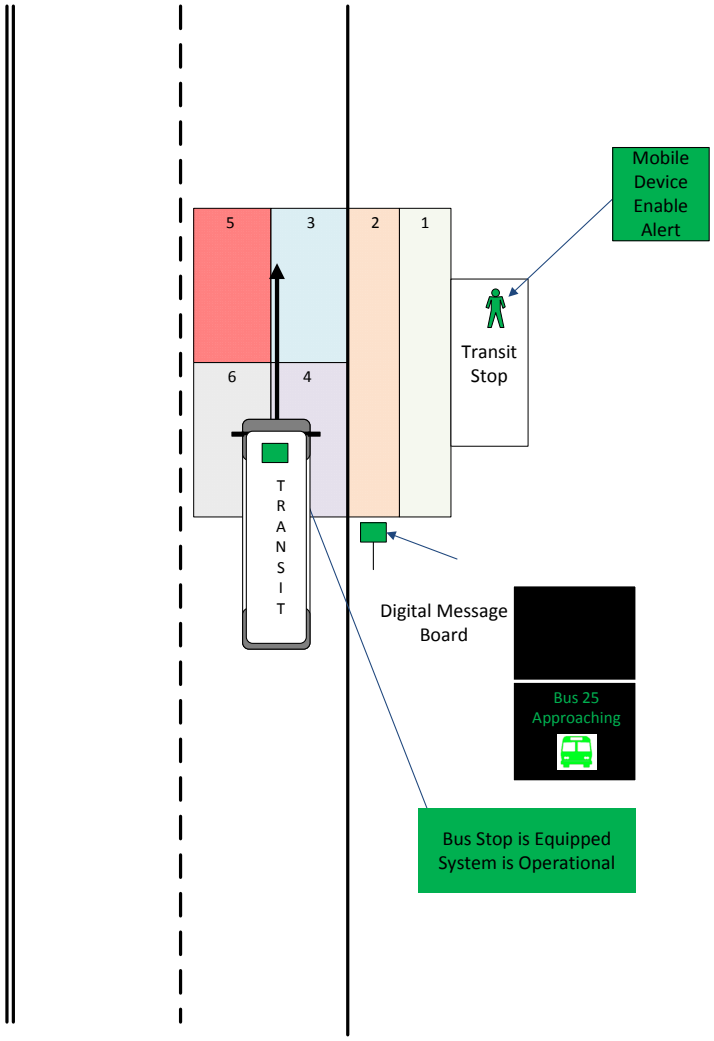


Source: Battelle

Figure 6-9. Scenario 9 – Transit vehicle approaching and has entered the rear roadway zone with no waiting riders at the transit stop

Scenario 10 – Transit vehicle approaching and has entered the rear roadway zone with a rider waiting in safe zone inside transit shelter

- The transit vehicle is approaching the transit stop and has entered the rear roadway zone.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Green message.
- The waiting rider inside the safe zone created by the transit shelter receives a Green enabled alert via a mobile device that indicates that the transit vehicle is approaching.

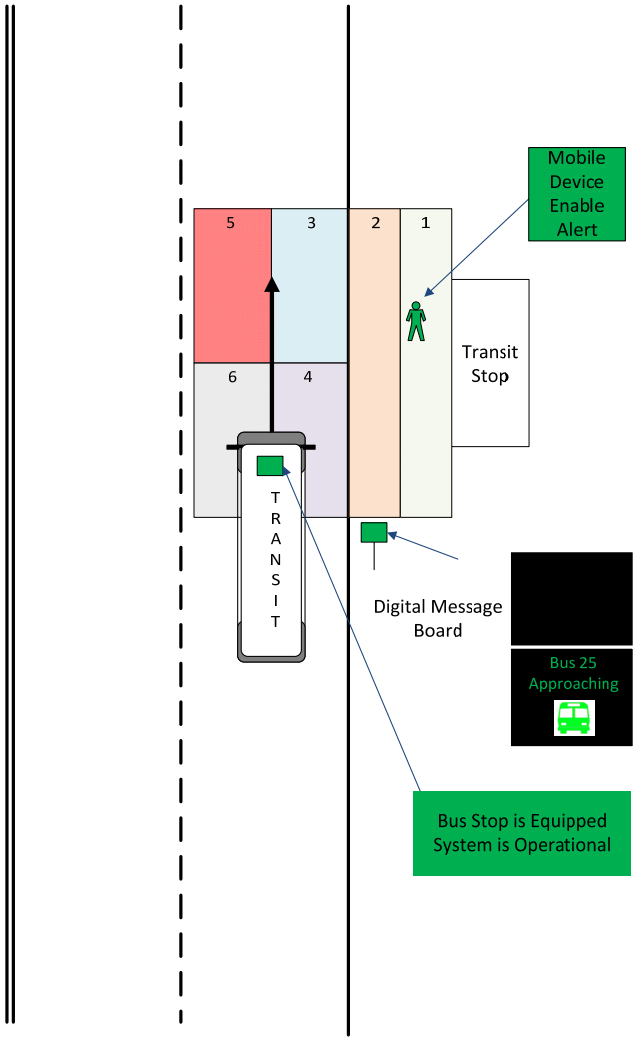


Source: Battelle

Figure 6-10. Scenario 10 – Transit vehicle approaching and has entered the rear roadway zone with a rider waiting in safe zone inside transit shelter

Scenario 11 – Transit vehicle approaching and has entered the rear roadway zone with the rider waiting in safe zone

- The transit vehicle is approaching the transit stop and has entered the rear roadway zone.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Green message.
- The waiting rider inside the safe zone receives a Green enabled alert via a mobile device that indicates that the transit vehicle is approaching.

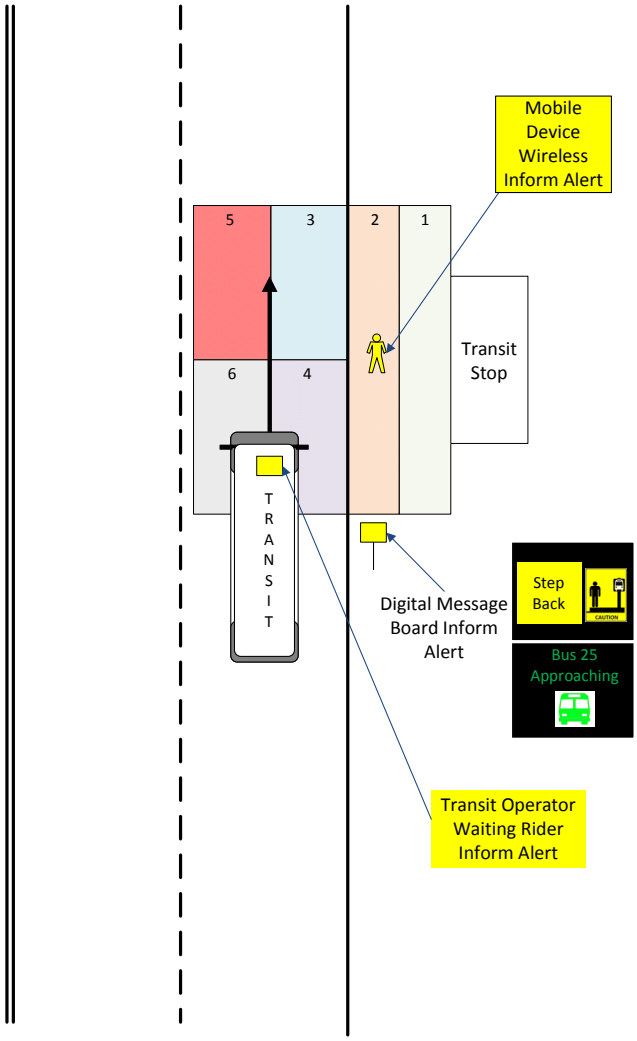


Source: Battelle

Figure 6-11. Scenario 11 – Transit vehicle approaching and has entered the rear roadway zone with the rider waiting in safe zone

Scenario 12 – Transit vehicle approaching and has entered the rear roadway zone with the rider waiting in danger zone

- The transit vehicle is approaching the transit stop and has entered the rear roadway zone.
- The TSPW application indicates to the transit vehicle operator that there is a waiting rider in the danger zone with a Yellow audible and visual inform alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Yellow message.
- The waiting rider in the danger zone receives a Yellow inform alert via a mobile device that indicates that the transit vehicle is approaching.

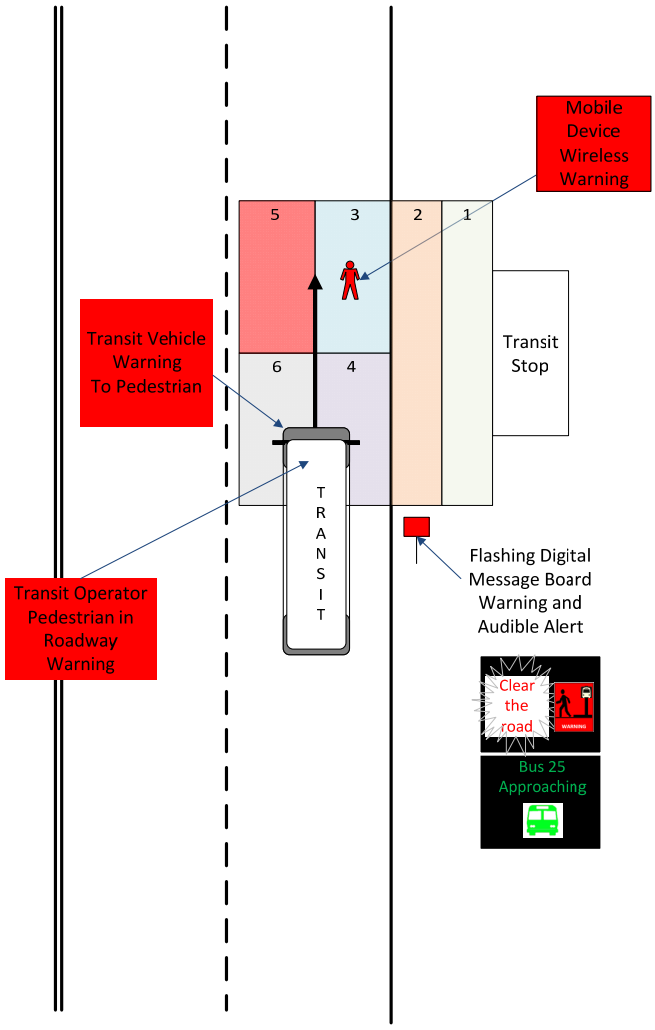


Source: Battelle

Figure 6-12. Scenario 12 – Transit vehicle approaching and has entered the rear roadway zone with the rider waiting in danger zone

Scenario 13 – Transit vehicle approaching and has entered the rear roadway zone and there is a pedestrian in forward curbside roadway zone

- The transit vehicle is approaching the transit stop and has entered the rear roadway zone.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the forward curbside roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Red message that flashes and emits an audible tone.
- The pedestrian in the forward curbside roadway zone receives a Red warning alert via a mobile device that indicates that the transit vehicle is approaching.
- The transit vehicle provides a visual and audible warning to the pedestrian in the roadway through an on-board system.

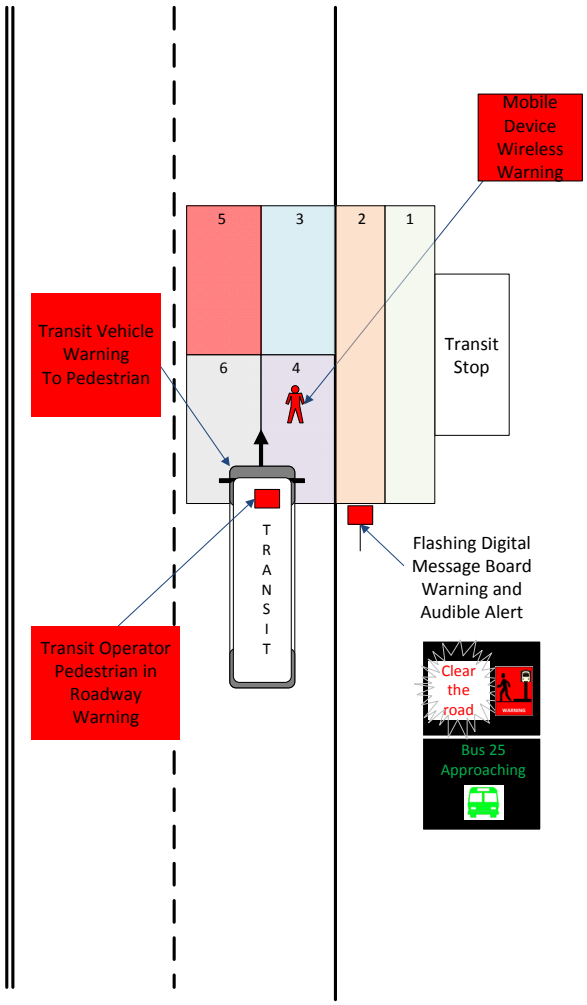


Source: Battelle

Figure 6-13. Scenario 13 – Transit vehicle approaching and has entered the rear roadway zone and there is a pedestrian in forward curbside roadway zone

Scenario 14 – Transit vehicle approaching and has entered the rear curbside roadway zone and there is a pedestrian in rear curbside roadway zone

- The transit vehicle is approaching the transit stop and has entered the rear roadway zone.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the rear curbside roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Red message that flashes and emits an audible tone.
- The pedestrian in the rear curbside roadway zone receives a Red warning alert via a mobile device that indicates that the transit vehicle is approaching.
- The transit vehicle provides a visual and audible warning to the pedestrian in the roadway through an on-board system.

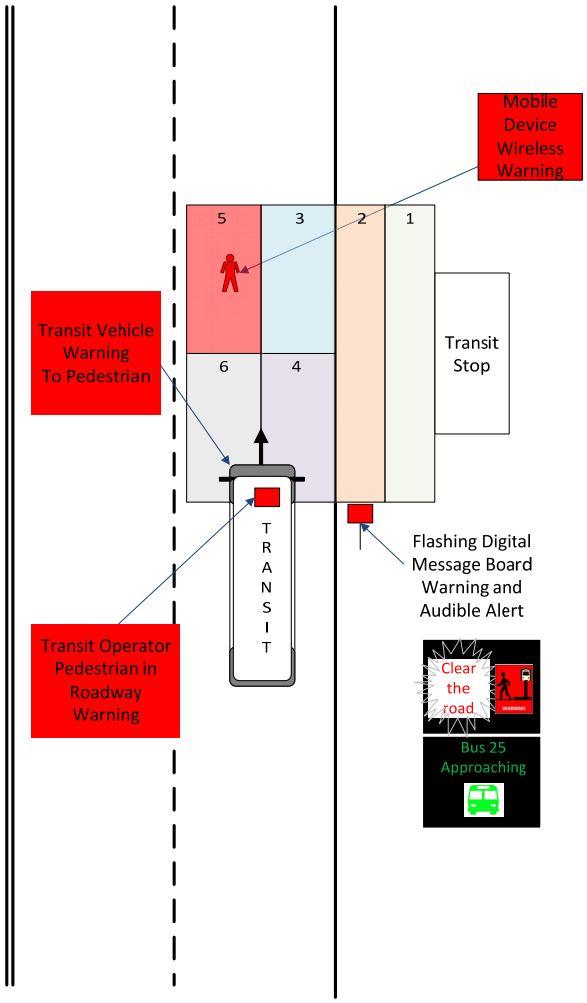


Source: Battelle

Figure 6-14. Scenario 14 – Transit vehicle approaching and has entered the rear roadway zone and there is a pedestrian in rear curbside roadway zone

Scenario 15 – Transit vehicle approaching and has entered the rear roadway zone and there is a pedestrian in forward center roadway zone

- The transit vehicle is approaching the transit stop and has entered the rear roadway zone.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the forward center roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Red message that flashes and emits an audible tone.
- The pedestrian in the forward center roadway zone receives a Red warning alert via a mobile device that indicates that the transit vehicle is approaching.
- The transit vehicle provides a visual and audible warning to the pedestrian in the roadway through an on-board system.

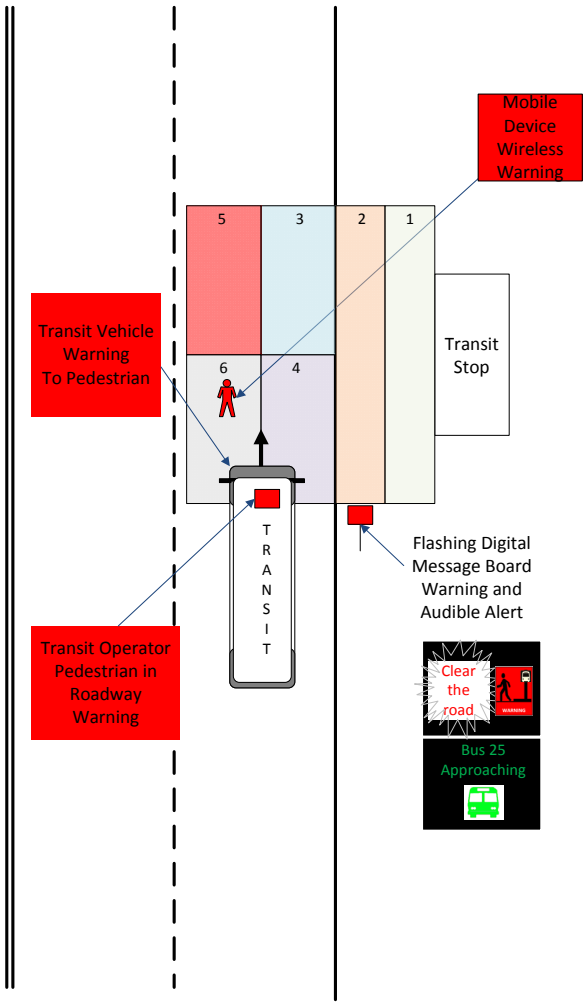


Source: Battelle

Figure 6-15. Scenario 15 – Transit vehicle approaching and has entered the rear roadway zone and there is a pedestrian in forward center roadway zone

Scenario 16 – Transit vehicle approaching and has entered the rear curbside roadway zone and there is a pedestrian in rear center roadway zone

- The transit vehicle is approaching the transit stop and has entered the rear center roadway zone.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the rear center roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Red message that flashes and emits an audible tone.
- The pedestrian in the rear center roadway zone receives a Red warning alert via a mobile device that indicates that the transit vehicle is approaching.
- The transit vehicle provides a visual and audible warning to the pedestrian in the roadway through an on-board system.

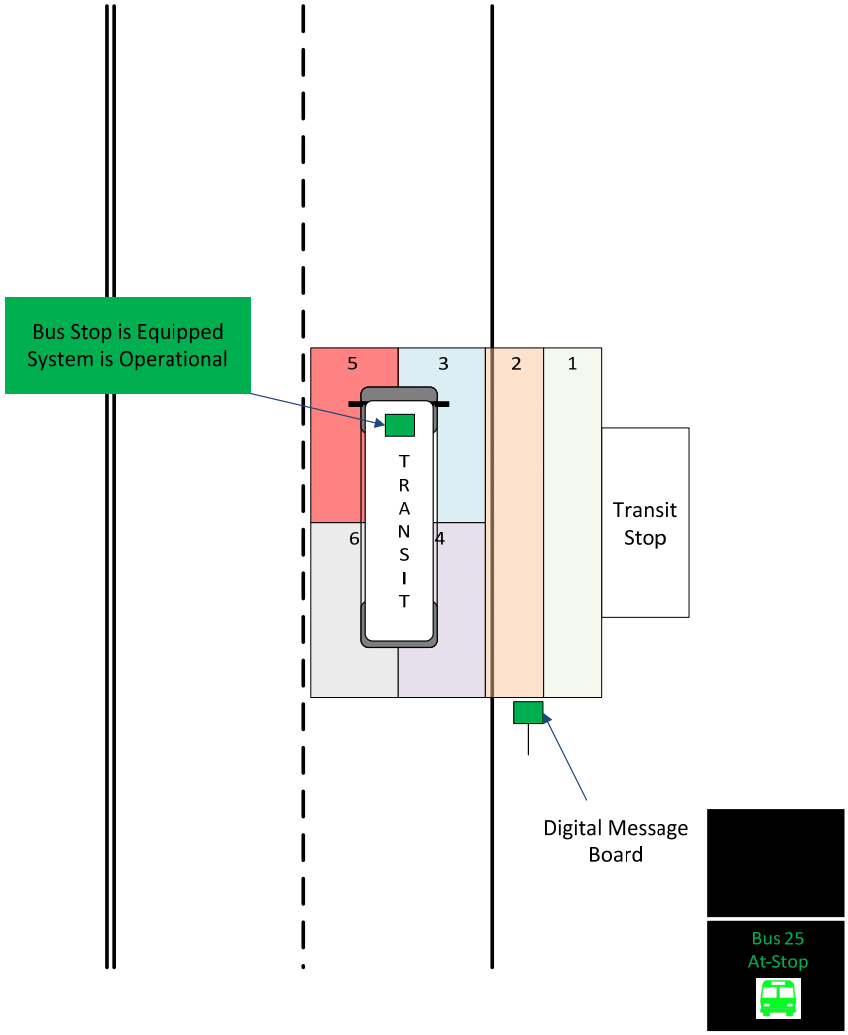


Source: Battelle

Figure 6-16. Scenario 16 – Transit vehicle approaching and has entered the rear roadway zone and there is a pedestrian in rear center roadway zone

Scenario 17 – Transit vehicle stopped at transit stop with no waiting riders or pedestrians

- The transit vehicle is stopped at the transit stop and is in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop using a Green message.

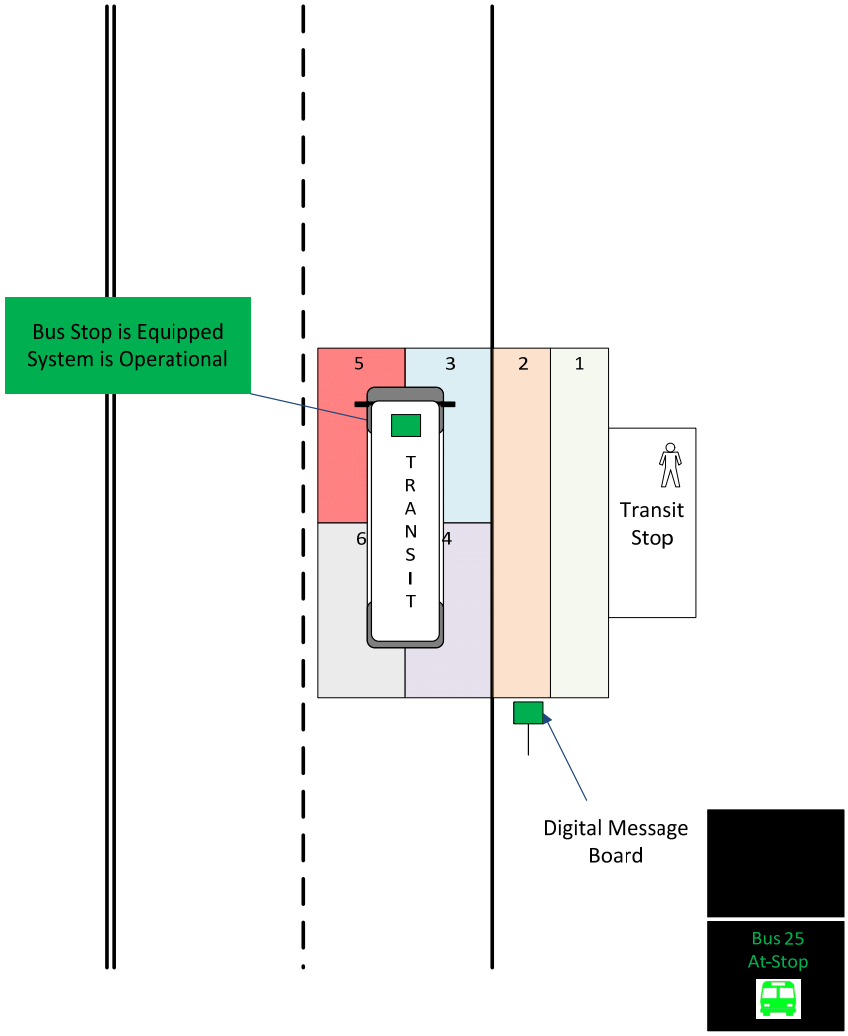


Source: Battelle

Figure 6-17. Scenario 17 – Transit vehicle stopped at transit stop with no waiting riders or pedestrians

Scenario 18 – Transit vehicle stopped at transit stop with waiting rider inside of transit shelter

- The transit vehicle is stopped at the transit stop and is in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop using a Green message.
- The waiting rider in the safe zone created by the transit shelter does not receive an alert.

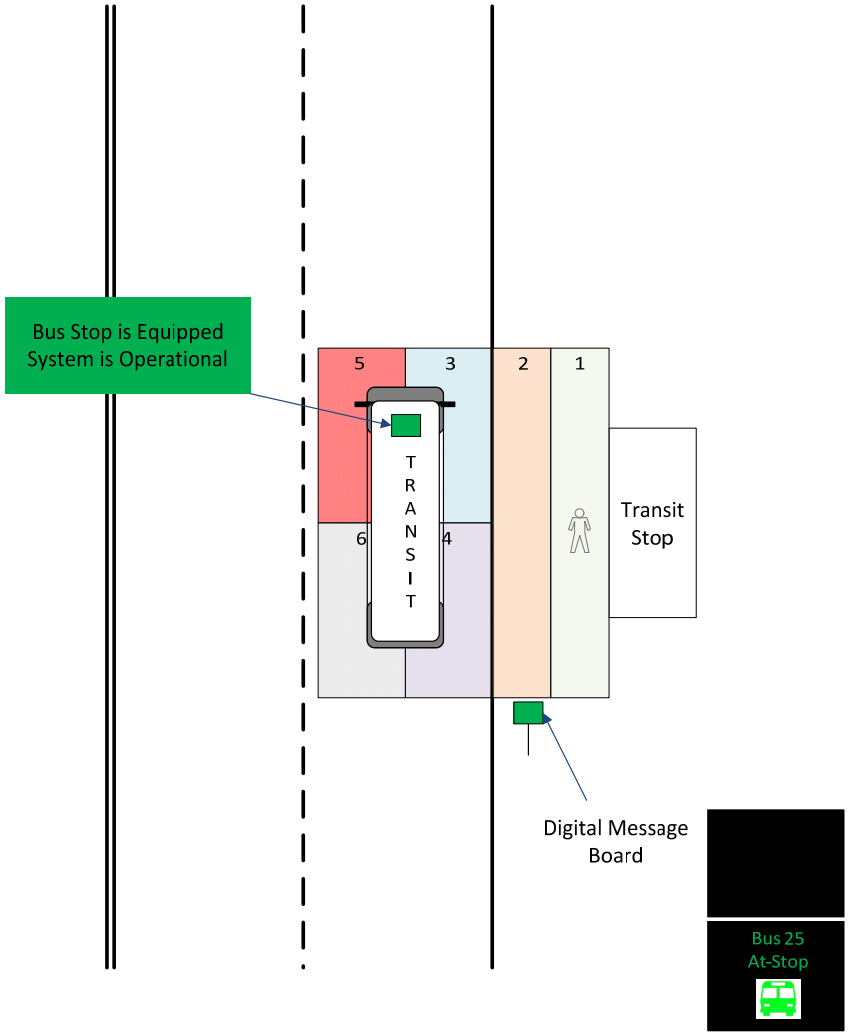


Source: Battelle

Figure 6-18. Scenario 18 – Transit vehicle stopped at transit stop with waiting rider inside of transit shelter

Scenario 19 – Transit vehicle stopped at transit stop with waiting rider in safe zone

- The transit vehicle is stopped at the transit stop and is in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with an audible and visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop using a Green message.
- The waiting rider in the safe zone does not receive an alert.

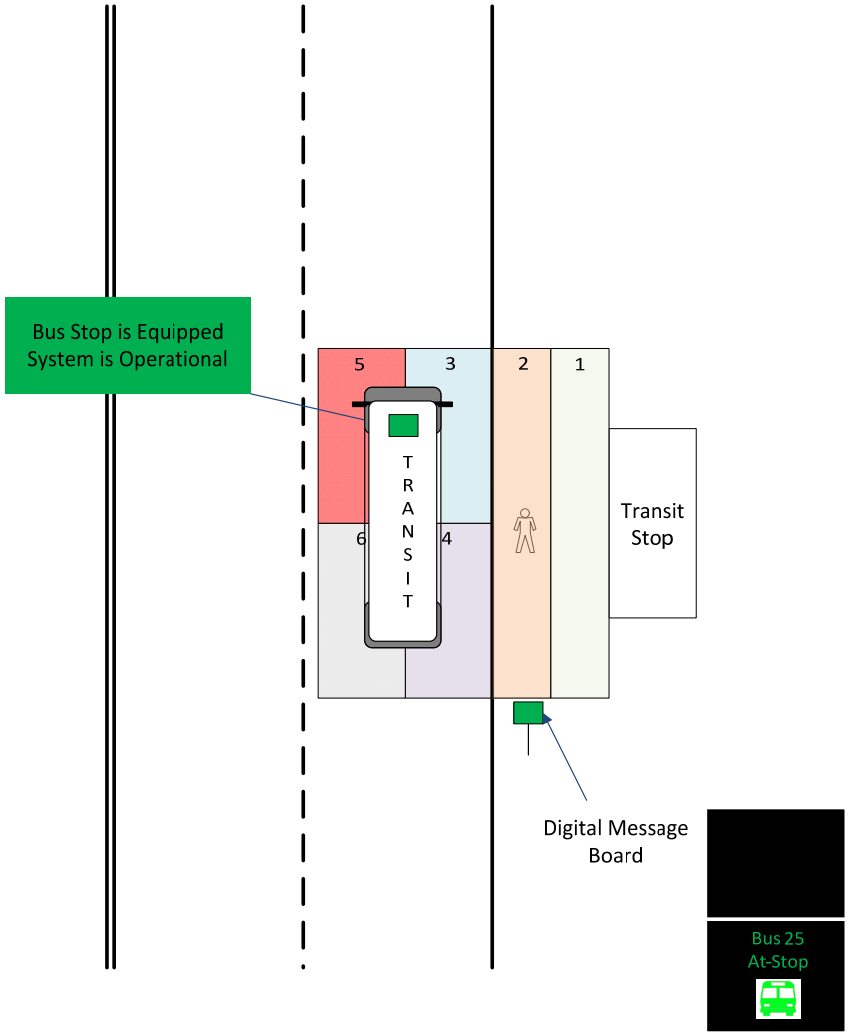


Source: Battelle

Figure 6-19. Scenario 19 – Transit vehicle stopped at transit stop with waiting rider in safe zone

Scenario 20 – Transit vehicle stopped at transit stop with waiting rider inside of the danger zone

- The transit vehicle is stopped at the transit stop and is in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with an audible and visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop using a Green message.
- The waiting rider in the danger zone created does not receive an alert.

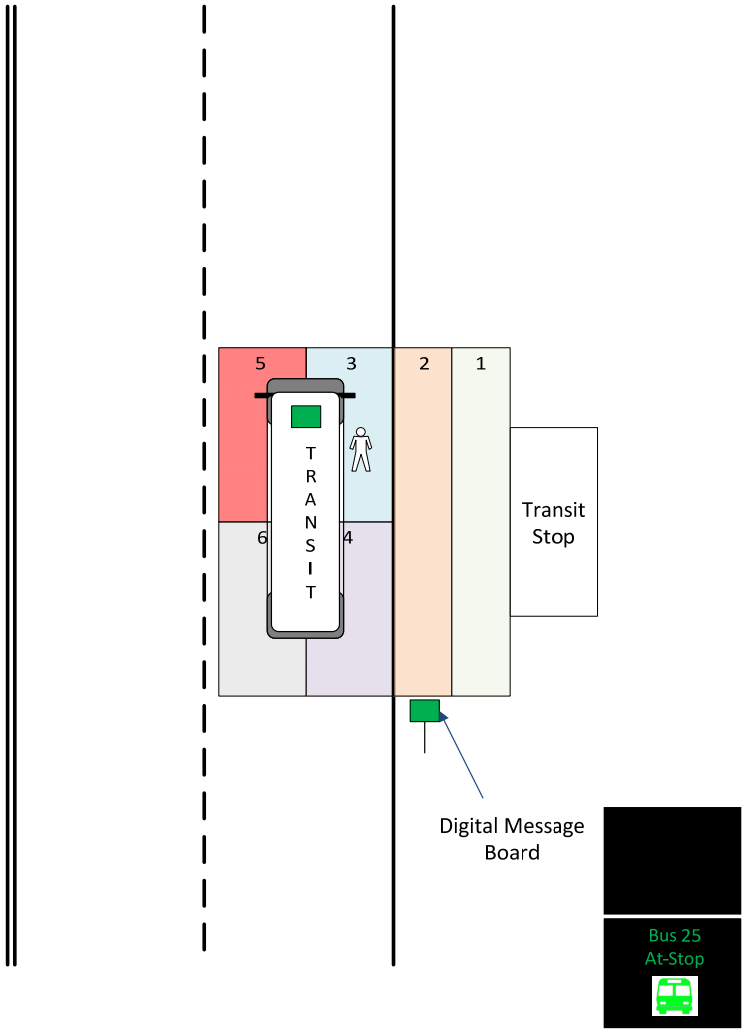


Source: Battelle

Figure 6-20. Scenario 20 – Transit vehicle stopped at transit stop with waiting rider inside of the danger zone

Scenario 21 –Transit vehicle stopped at transit stop with pedestrian in the forward curbside roadway zone

- The transit vehicle is stopped at the transit stop and is in all four roadway zones.
- The waiting rider crosses into the forward curbside roadway zone to board the transit vehicle.
- Since the transit vehicle is stopped, and pedestrians are expected to cross into the curb-side zones to board the vehicle, no warnings are issued.

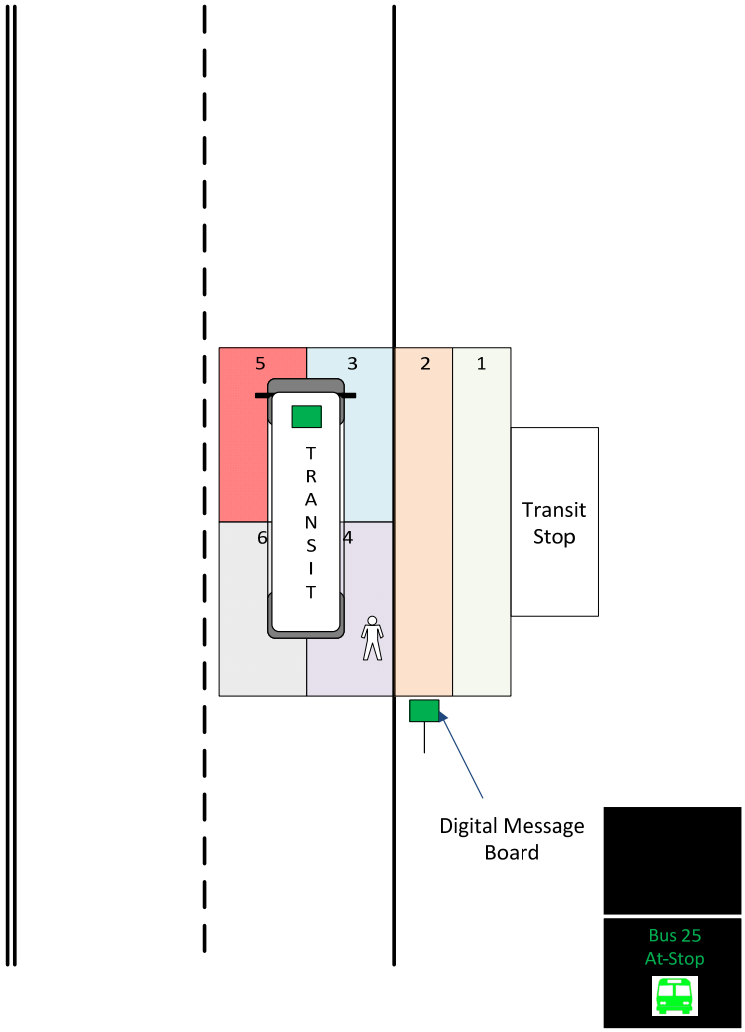


Source: Battelle

Figure 6-21. Scenario 21 –Transit vehicle stopped at transit stop with pedestrian in the forward curbside roadway zone

Scenario 22 – Transit vehicle stopped at transit stop with pedestrian in the rear curbside roadway zone

- The transit vehicle is stopped at the transit stop and is in all four roadway zones.
- The waiting rider crosses into the rear curbside roadway zone to board the transit vehicle.
- Since the transit vehicle is stopped, and pedestrians are expected to cross into the curb-side zones to board the vehicle, no warnings are issued.

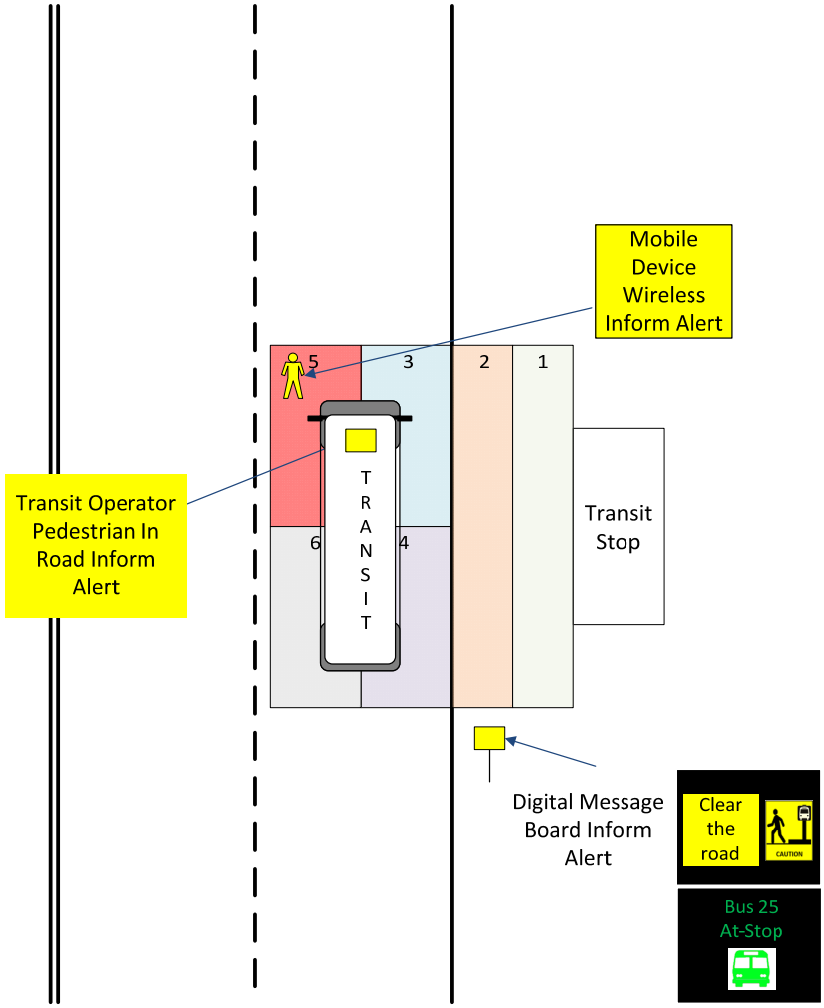


Source: Battelle

Figure 6-22. Scenario 22 – Transit vehicle stopped at transit stop with pedestrian in the rear curbside roadway zone

Scenario 23 – Transit vehicle stopped at transit stop with pedestrian in the forward center roadway zone in front of the stopped transit vehicle

- The transit vehicle is stopped at the transit stop and is in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the forward roadway zone with a Yellow visual inform alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop and a pedestrian is present within the forward center roadway zone using a Yellow message.
- The pedestrian in the forward roadway zone in front of the transit vehicle receives a Yellow inform alert via a mobile device.

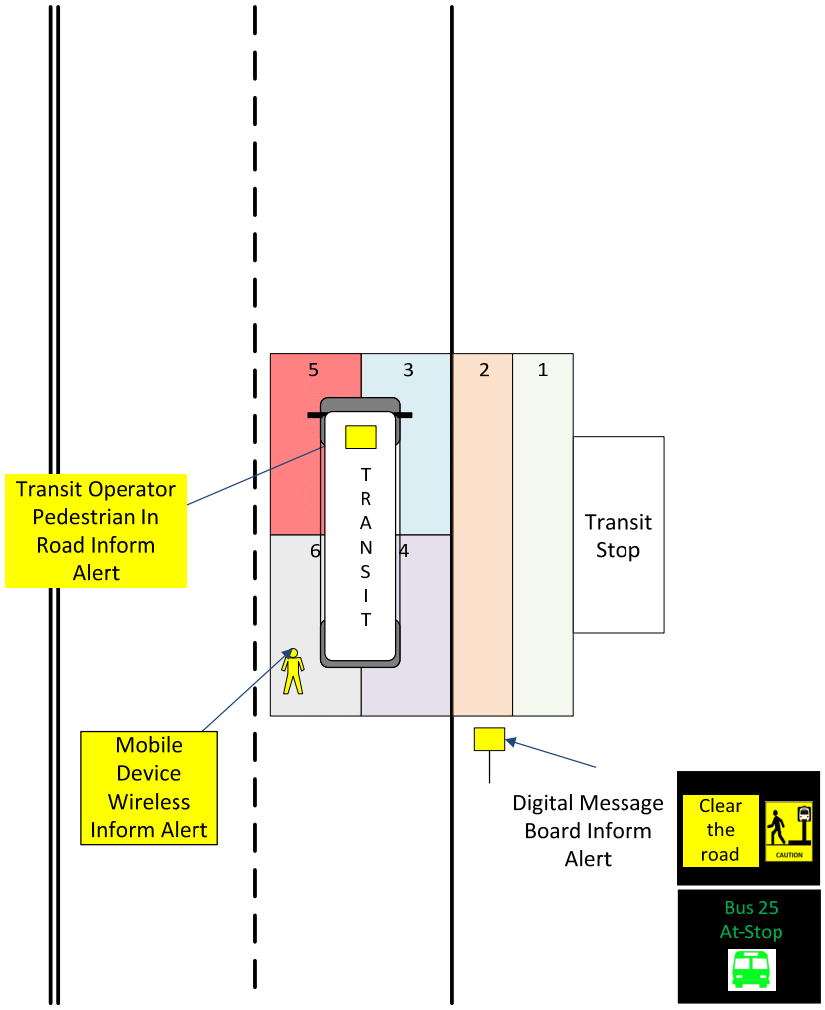


Source: Battelle

Figure 6-23. Scenario 23 – Transit vehicle stopped at transit stop with pedestrian in the forward center roadway zone in front of the stopped transit vehicle

Scenario 24 – Transit vehicle stopped at transit stop with pedestrian in the rear center roadway zone behind the stopped transit vehicle

- The transit vehicle is stopped at the transit stop and is in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the rear center roadway zone with a Yellow visual inform alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop and a pedestrian is present within the rear center roadway zone using a Yellow message.
- The pedestrian in the rear center roadway zone in front of the transit vehicle receives a Yellow inform alert via a mobile device.

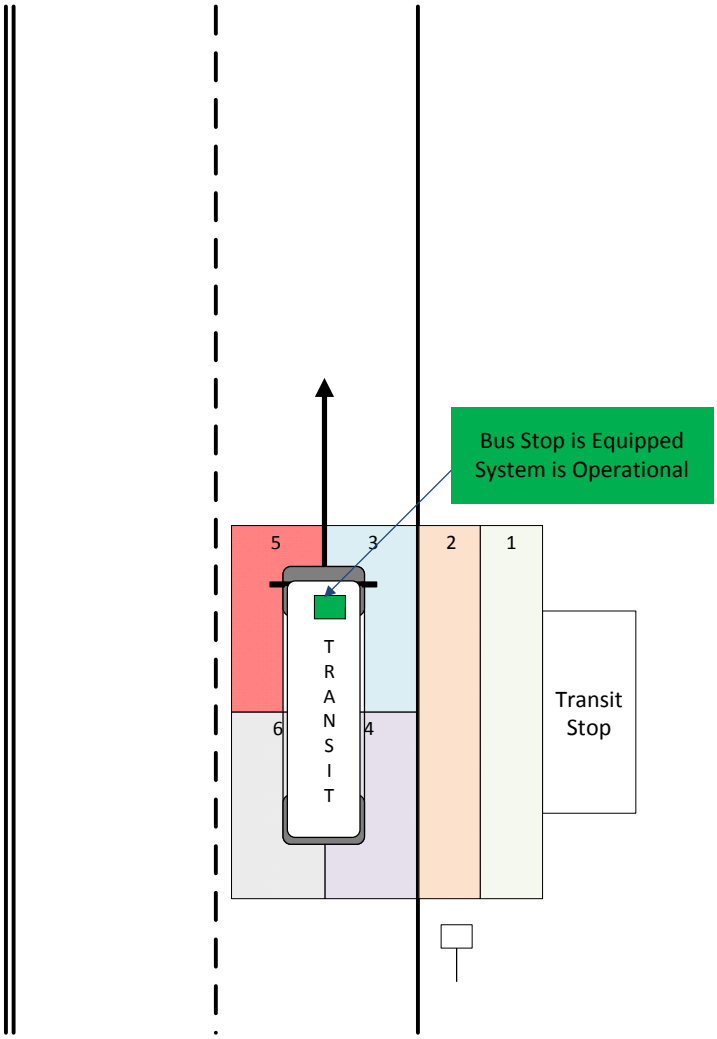


Source: Battelle

Figure 6-24. Scenario 24 – Transit vehicle stopped at transit stop with pedestrian in the rear center roadway zone in front of the stopped transit vehicle

Scenario 25 – Transit vehicle is departing but is still in all four roadway zones and there are no waiting riders

- The transit vehicle is departing the transit stop but is still in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.

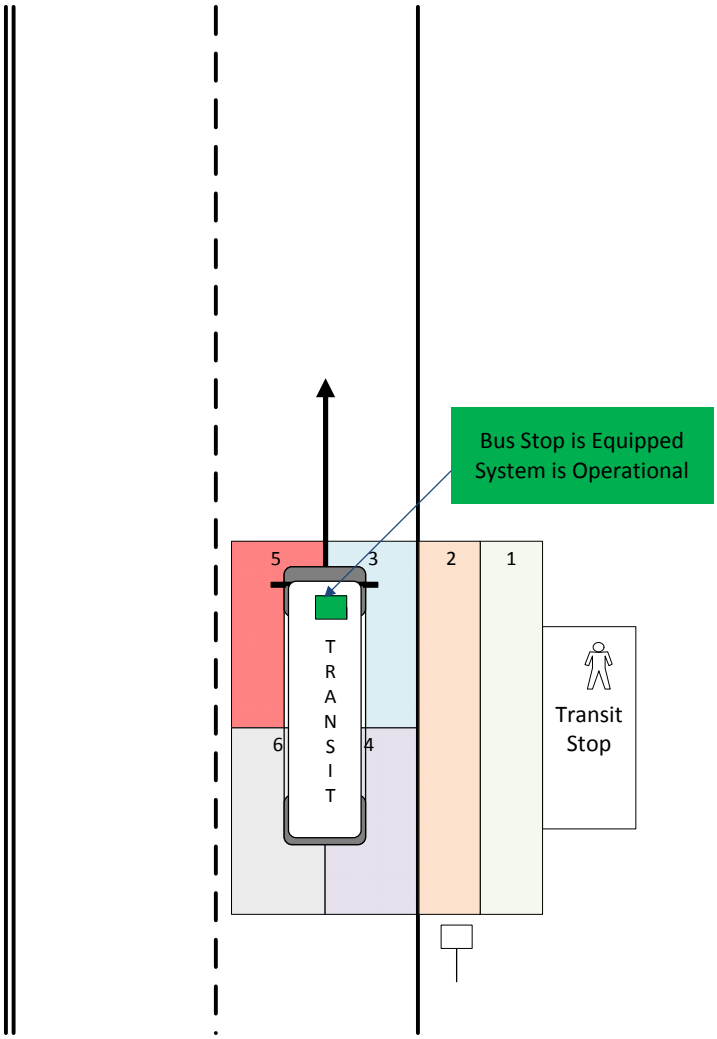


Source: Battelle

Figure 6-25. Scenario 25 – Transit vehicle is departing but is still in all four roadway zones and there are no waiting riders

Scenario 26 – Transit vehicle is departing but is still in all four roadway zones and there is a rider waiting in safe zone inside transit shelter

- The transit vehicle is departing the transit stop but is still in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The waiting rider in the transit shelter does not receive an alert.

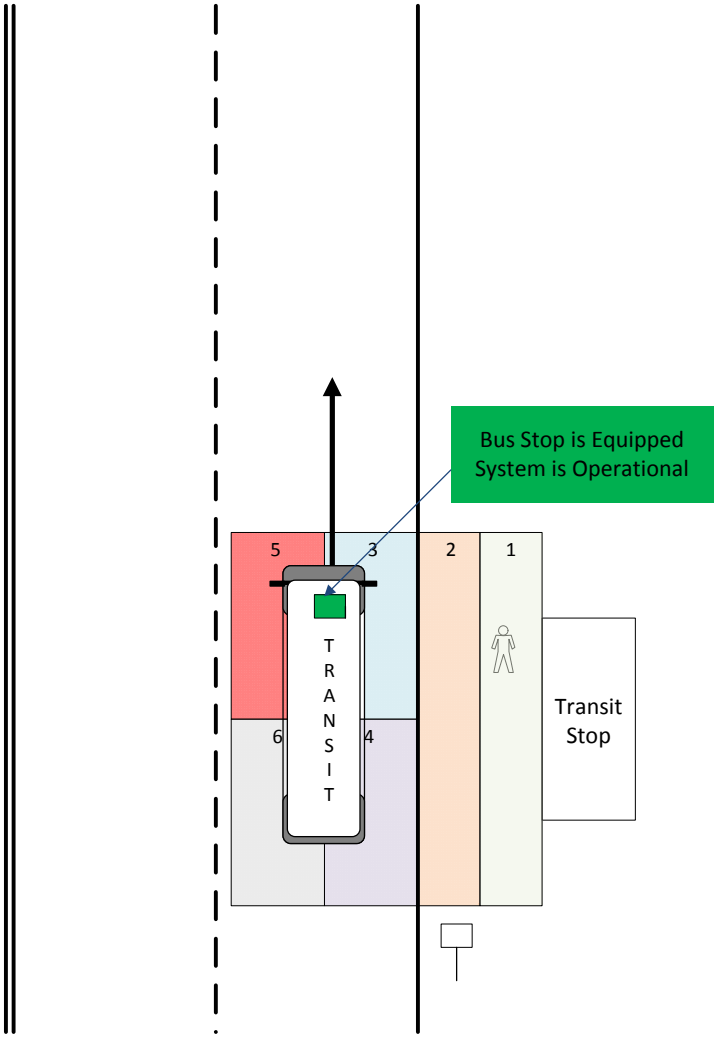


Source: Battelle

Figure 6-26. Scenario 26 – Transit vehicle is departing but is still in all four roadway zones and there is a rider waiting in safe zone inside transit shelter

Scenario 27 – Transit vehicle is departing but is still in all four roadway zones and there is a waiting rider in the safe zone

- The transit vehicle is departing the transit stop but is still in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The waiting rider does not receive an alert.

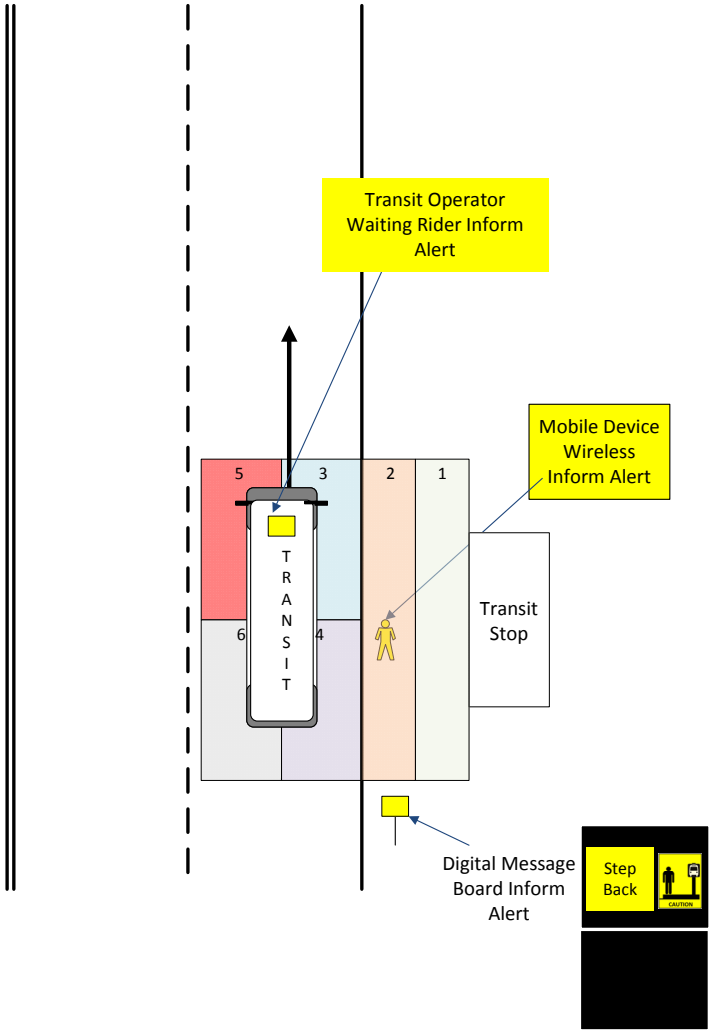


Source: Battelle

Figure 6-27. Scenario 27 – Transit vehicle is departing but is still in all four roadway zones and there is a waiting rider in the safe zone

Scenario 28 – Transit vehicle is departing but is still in all four roadway zones and there is a waiting rider in the danger zone

- The transit vehicle is departing the transit stop but is still in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a waiting rider in the danger zone with a Yellow visual inform alert.
- The infrastructure based pedestrian warning device indicates that that there is a waiting rider in the danger zone with a Yellow visual inform alert.
- The waiting rider in the danger zone receives a Yellow inform alert via a mobile device.

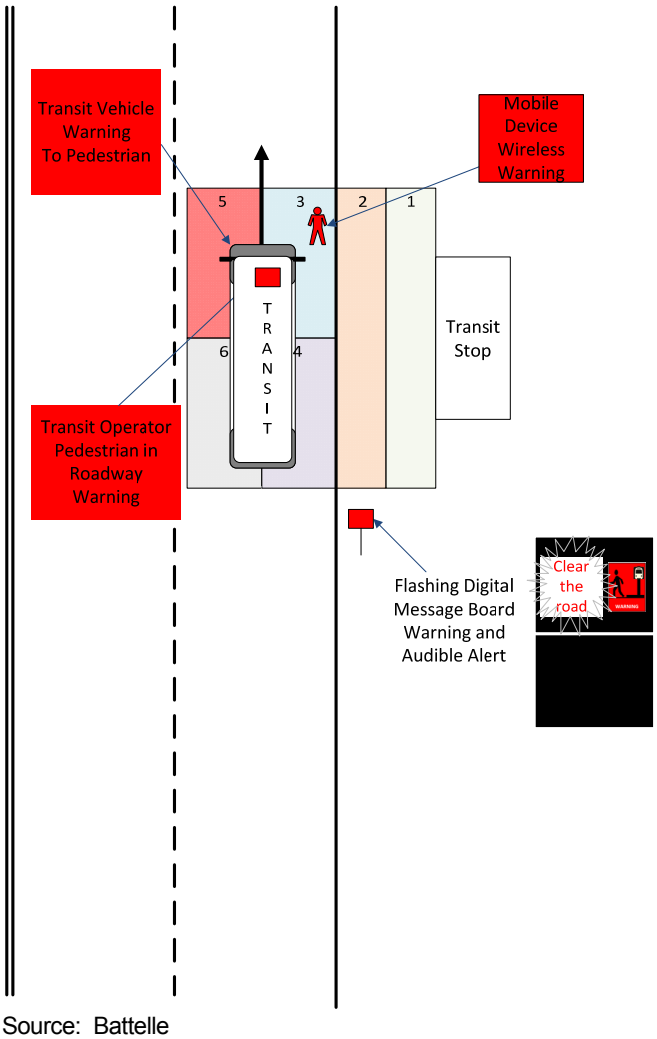


Source: Battelle

Figure 6-28. Scenario 28 – Transit vehicle is departing but is still in all four roadway zones and there is a waiting rider in the danger zone

Scenario 29 – Transit vehicle is departing but is still in all four roadway zones and there is a pedestrian in the forward curbside roadway zone

- The transit vehicle is departing the transit stop but is still in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the forward curbside roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates that there is a pedestrian in the forward curbside roadway zone with a Red message that flashes and emits an audible tone.
- The pedestrian in the forward curbside roadway zone receives a Red warning alert via a mobile device.
- The transit vehicle provides a visual and audible warning to the pedestrian in the roadway through an on-board system.

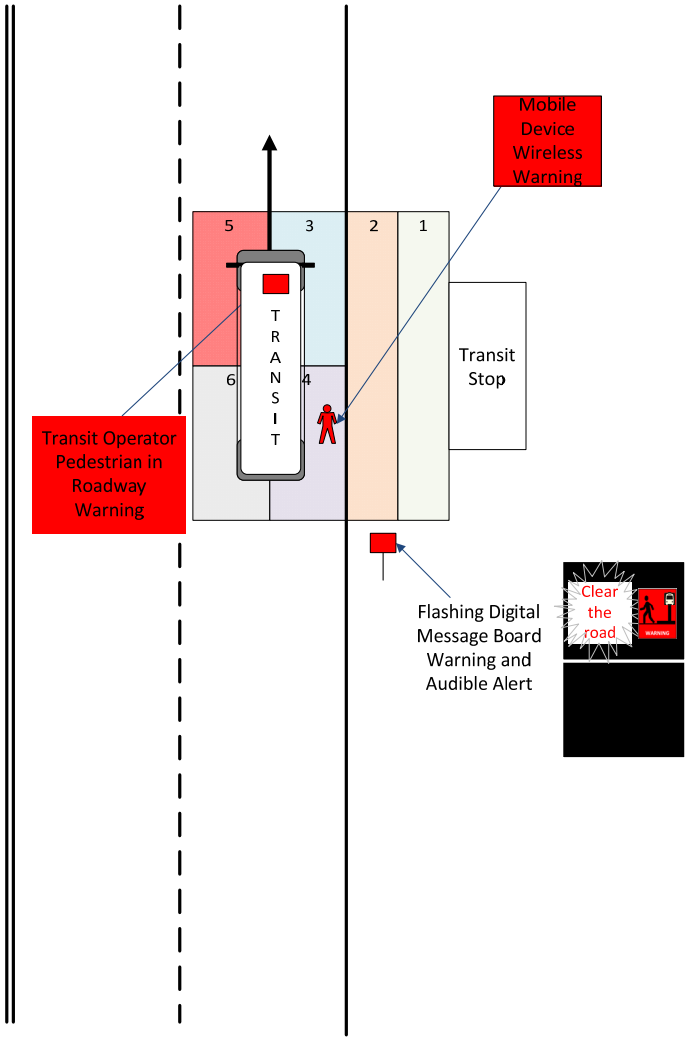


Source: Battelle

Figure 6-29. Scenario 29 – Transit vehicle is departing but is still in all four roadway zones and there is a pedestrian in the forward curbside roadway zone

Scenario 30 – Transit vehicle is departing but is still in all four roadway zones and there is a pedestrian in the rear curbside roadway zone

- The transit vehicle is departing the transit stop but is still in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the rear curbside roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates there is a pedestrian in the rear curbside roadway zone using a Red message that flashes and emits an audible tone.
- The pedestrian in the rear curbside roadway zone receives a Red warning alert via a mobile device.

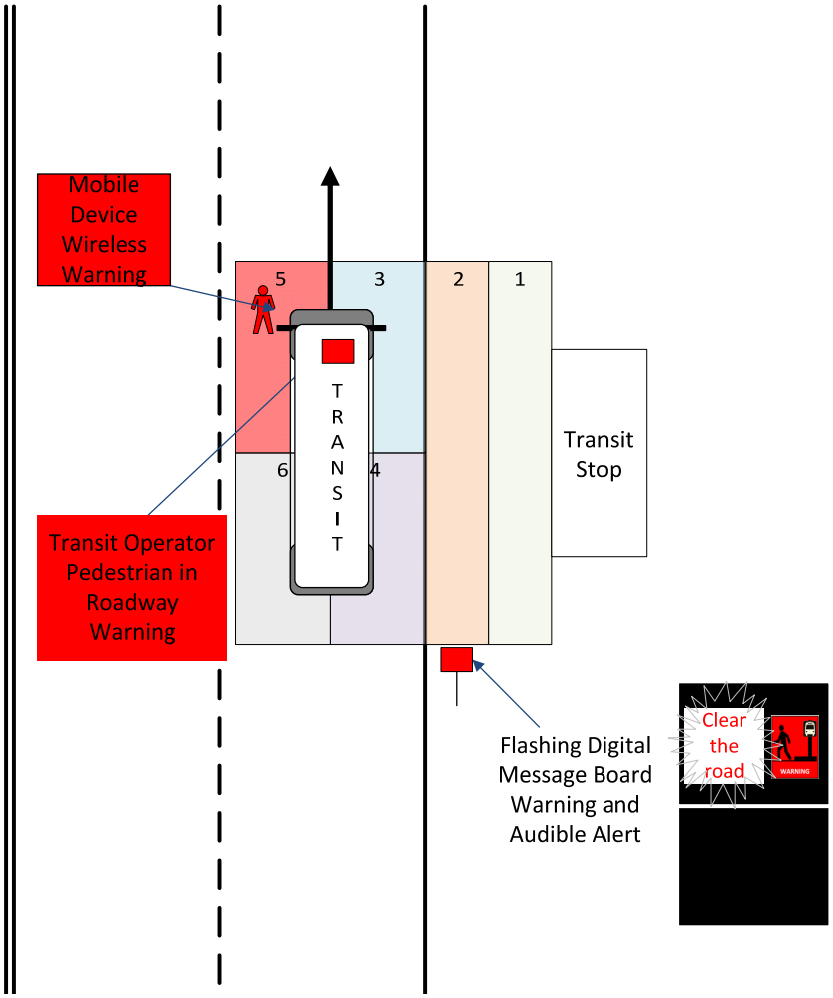


Source: Battelle

Figure 6-30. Scenario 30 – Transit vehicle is departing but is still in all four roadway zones and there is a pedestrian in the rear curbside roadway zone

Scenario 31 – Transit vehicle is departing but is still in all four roadway zones and there is a pedestrian in the forward center roadway zone

- The transit vehicle is departing the transit stop but is still in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the forward center roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates that there is a pedestrian in the forward center roadway zone with a Red message that flashes and emits an audible tone.
- The pedestrian in the forward center roadway zone receives a Red warning alert via a mobile device.
- The transit vehicle provides a visual and audible warning to the pedestrian in the roadway through an on-board system.

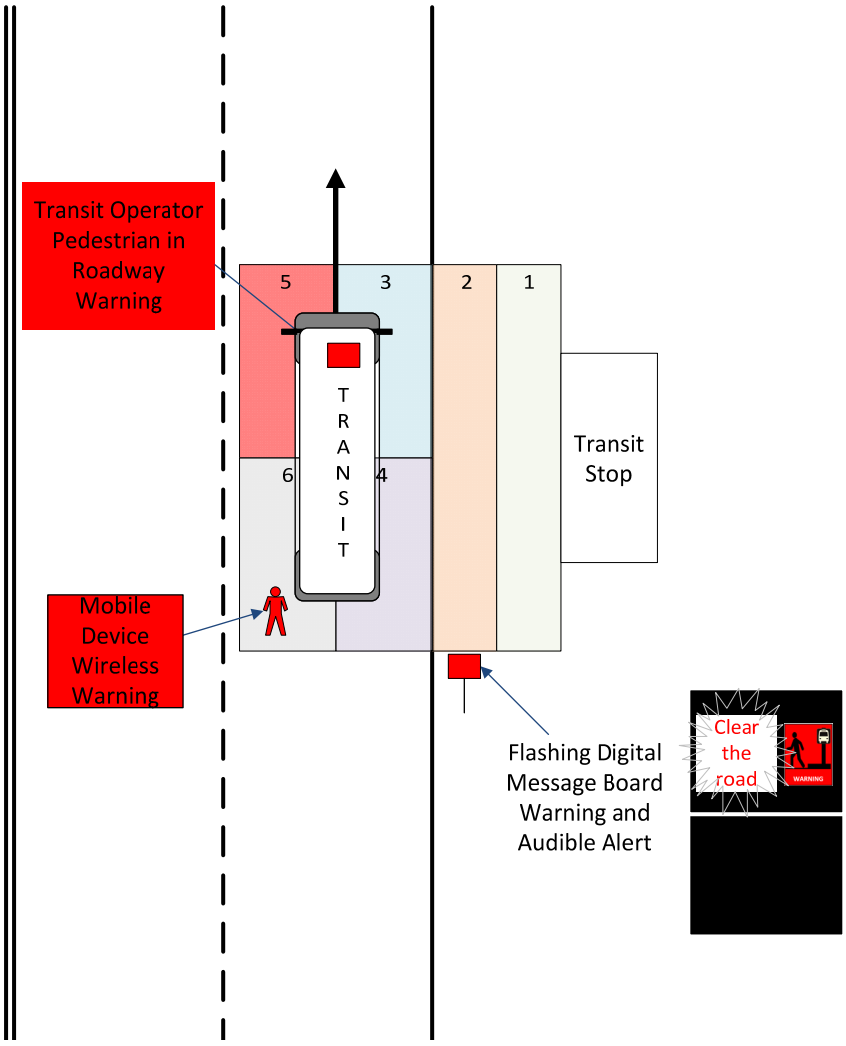


Source: Battelle

Figure 6-31. Scenario 31 – Transit vehicle is departing but is still in all four roadway zones and there is a pedestrian in the forward center roadway zone

Scenario 32 – Transit vehicle is departing but is still in all four roadway zones and there is a pedestrian in the rear center roadway zone

- The transit vehicle is departing the transit stop but is still in all four roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the rear center roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates there is a pedestrian in the rear center roadway zone using a Red message that flashes and emits an audible tone.
- The pedestrian in the rear center roadway zone receives a Red warning alert via a mobile device.

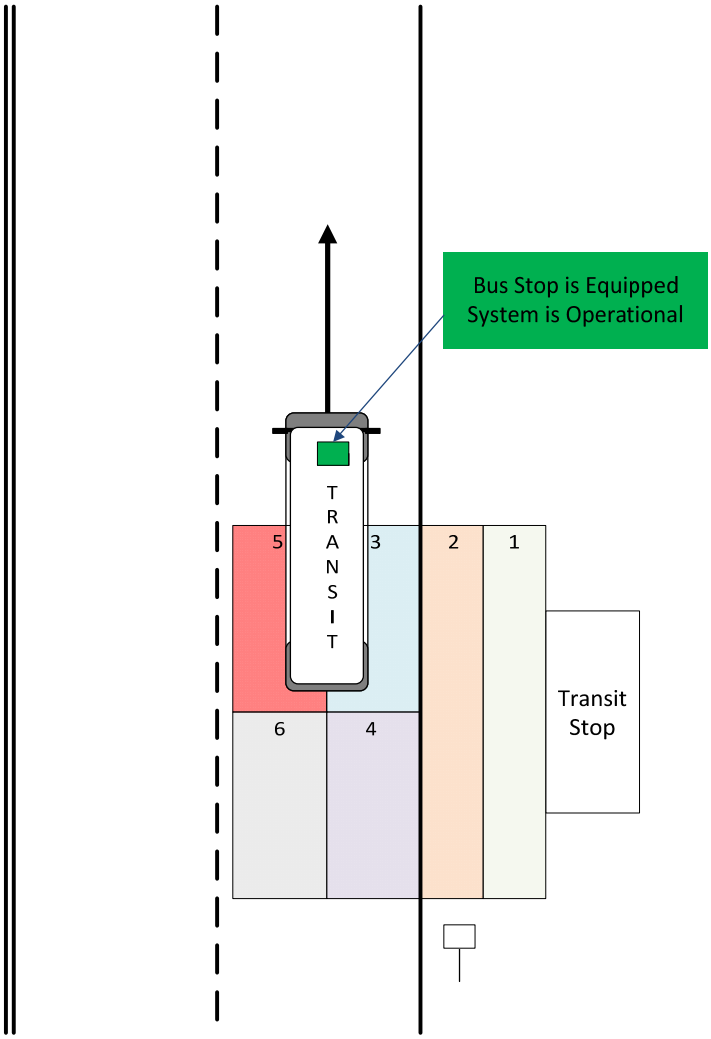


Source: Battelle

Figure 6-32. Scenario 32 – Transit vehicle is departing but is still in all four roadway zones and there is a pedestrian in the rear center roadway zone

Scenario 33 – Transit vehicle is departing but is still in the forward roadway zones and there and there are no waiting riders

- The transit vehicle is departing the transit stop but is still in the forward roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.

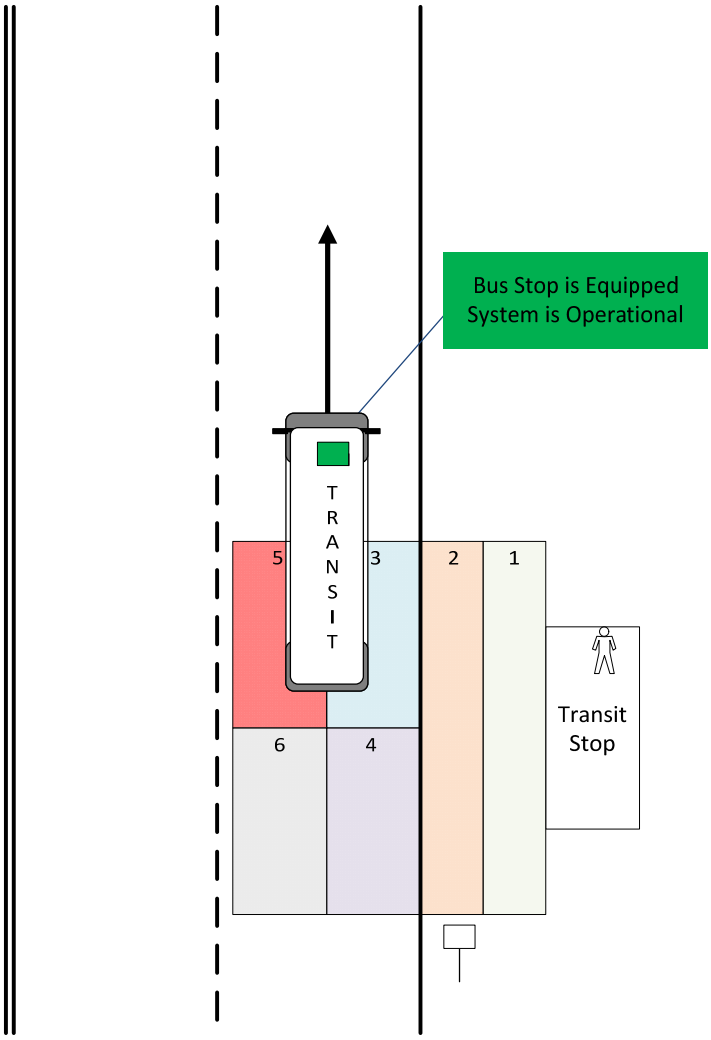


Source: Battelle

Figure 6-33. Scenario 33 – Transit vehicle is departing but is still in the forward roadway zones and there are no waiting riders

Scenario 34 – Transit vehicle is departing but is still in the forward roadway zones and there is a rider waiting in safe zone inside transit shelter

- The transit vehicle is departing the transit stop but is still in the forward roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The waiting rider does not receive an alert.

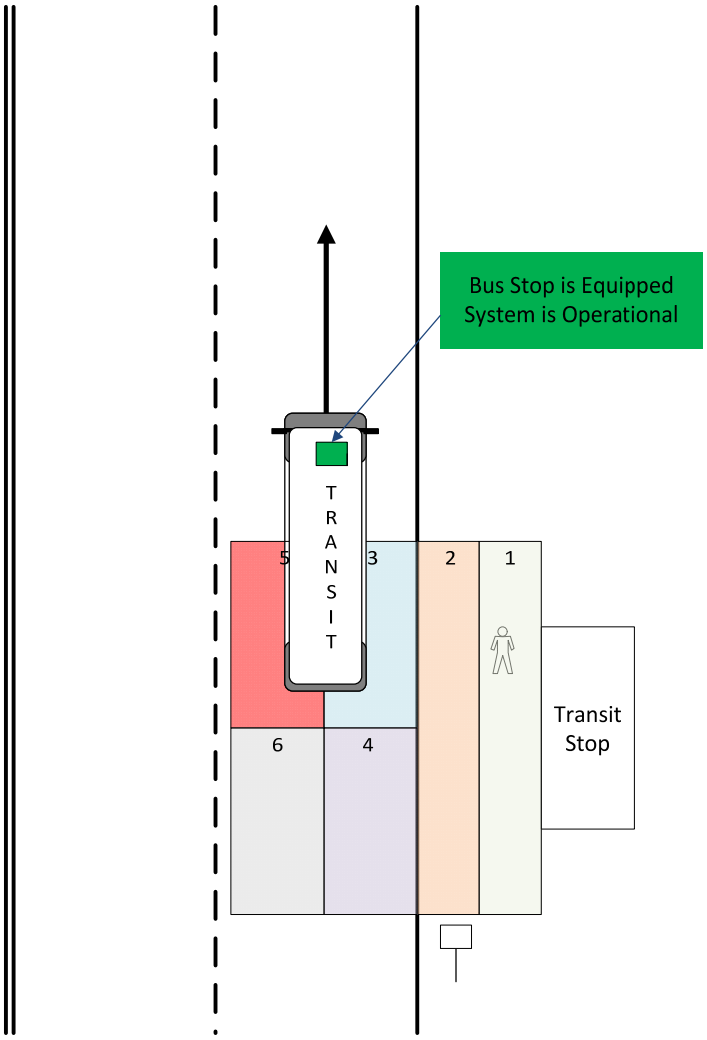


Source: Battelle

Figure 6-34. Scenario 34 – Transit vehicle is departing but is still in the forward roadway zones and there is a rider waiting in safe zone inside transit shelter

Scenario 35 – Transit vehicle is departing but is still in the forward roadway zones and there is a waiting rider in the safe zone

- The transit vehicle is departing the transit stop but is still in the forward roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The waiting rider does not receive an alert.

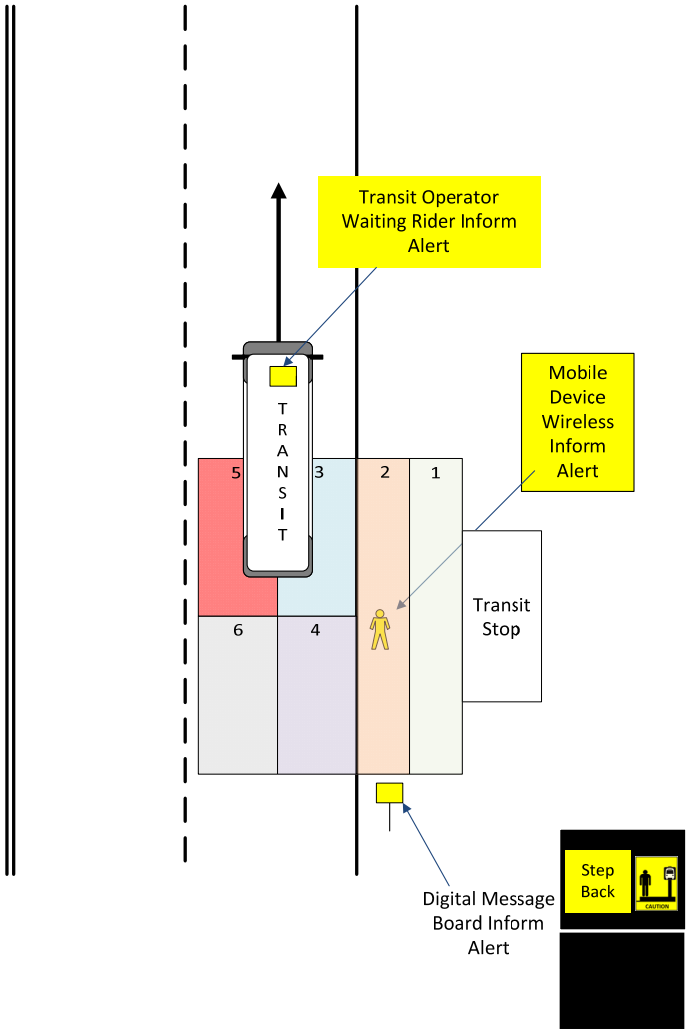


Source: Battelle

Figure 6-35. Scenario 35 – Transit vehicle is departing but is still in the forward roadway zones and there is a waiting rider in the safe zone

Scenario 36 – Transit vehicle is departing but is still in the forward roadway zones and there is a waiting rider in the danger zone

- The transit vehicle is departing the transit stop but is still in the forward roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a waiting rider in the danger zone with a Yellow visual inform alert.
- The infrastructure based pedestrian warning device indicates there is a waiting rider in the danger zone using a Yellow message.
- The waiting rider in the danger zone receives a Yellow inform alert via a mobile device.

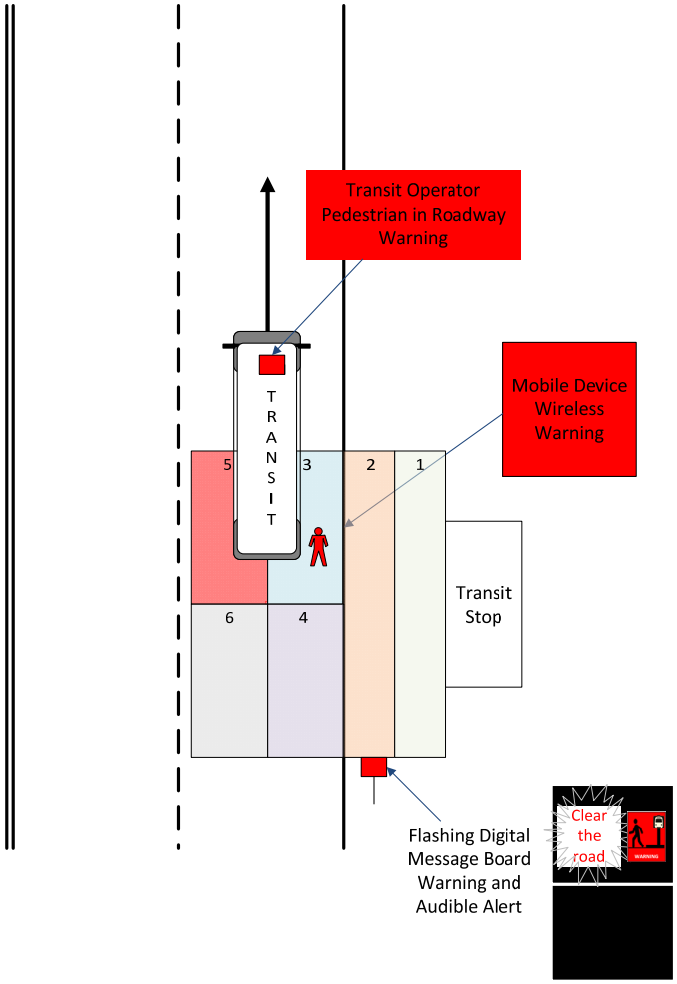


Source: Battelle

Figure 6-36. Scenario 36 – Transit vehicle is departing but is still in the forward roadway zones and there is a waiting rider in the danger zone

Scenario 37 – Transit vehicle is departing but is still in the forward roadway zones and there is a pedestrian in the forward curbside roadway zone

- The transit vehicle is departing the transit stop but is still in the forward curbside roadway zone.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the forward curbside roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates that that there is a pedestrian in the forward curbside roadway zone using a Red message that flashes and emits an audible tone.
- The pedestrian in the forward curbside roadway zone receives a Red warning alert via a mobile device.

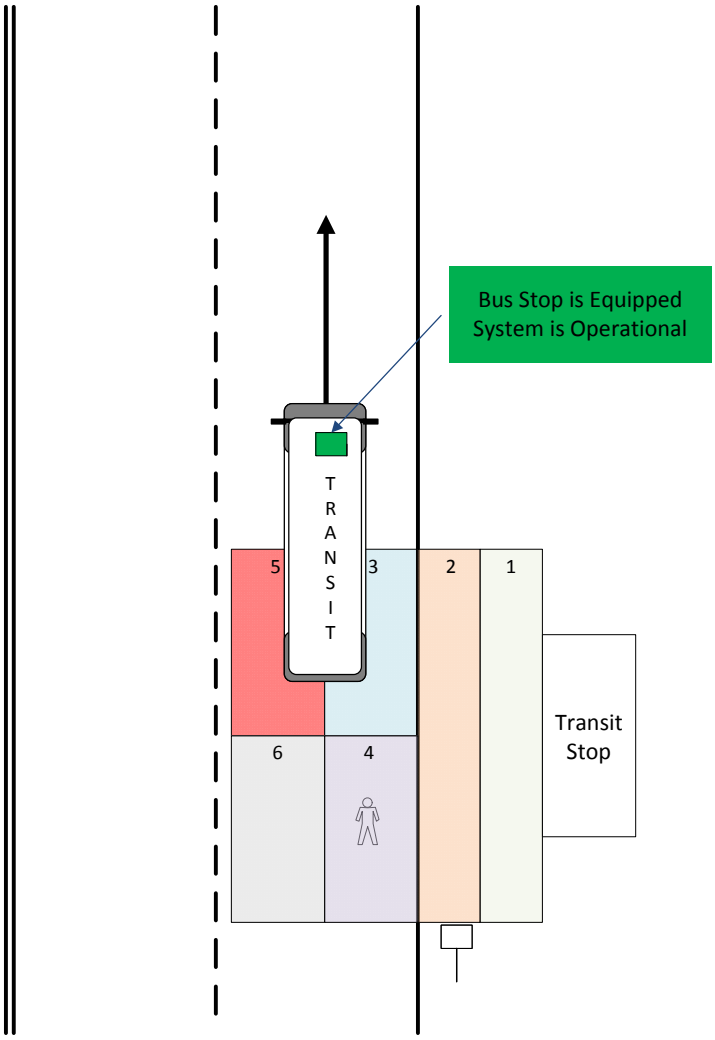


Source: Battelle

Figure 6-37. Scenario 37 – Transit vehicle is departing but is still in the forward roadway zones and there is a pedestrian in the forward curbside roadway zone

Scenario 38 – Transit vehicle is departing but is still in the forward roadway zones and there is a pedestrian in the rear curbside roadway zone

- The transit vehicle is departing the transit stop but is still in the forward roadway zone.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The pedestrian does not receive an alert.

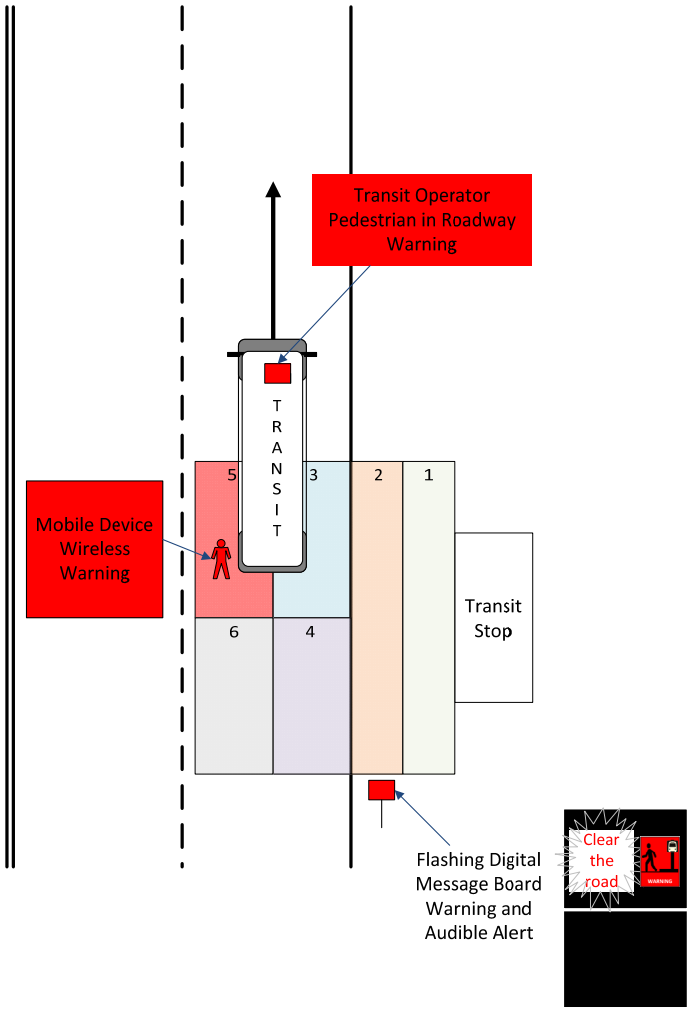


Source: Battelle

Figure 6-38. Scenario 38 – Transit vehicle is departing but is still in the forward roadway zones and there is a pedestrian in the rear curbside roadway zone

Scenario 39 – Transit vehicle is departing but is still in the forward roadway zones and there is a pedestrian in the forward center roadway zone

- The transit vehicle is departing the transit stop but is still in the forward curbside roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the forward center roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates that that there is a pedestrian in the forward center roadway zone using a Red message that flashes and emits an audible tone.
- The pedestrian in the forward curbside roadway zone receives a Red warning alert via a mobile device.

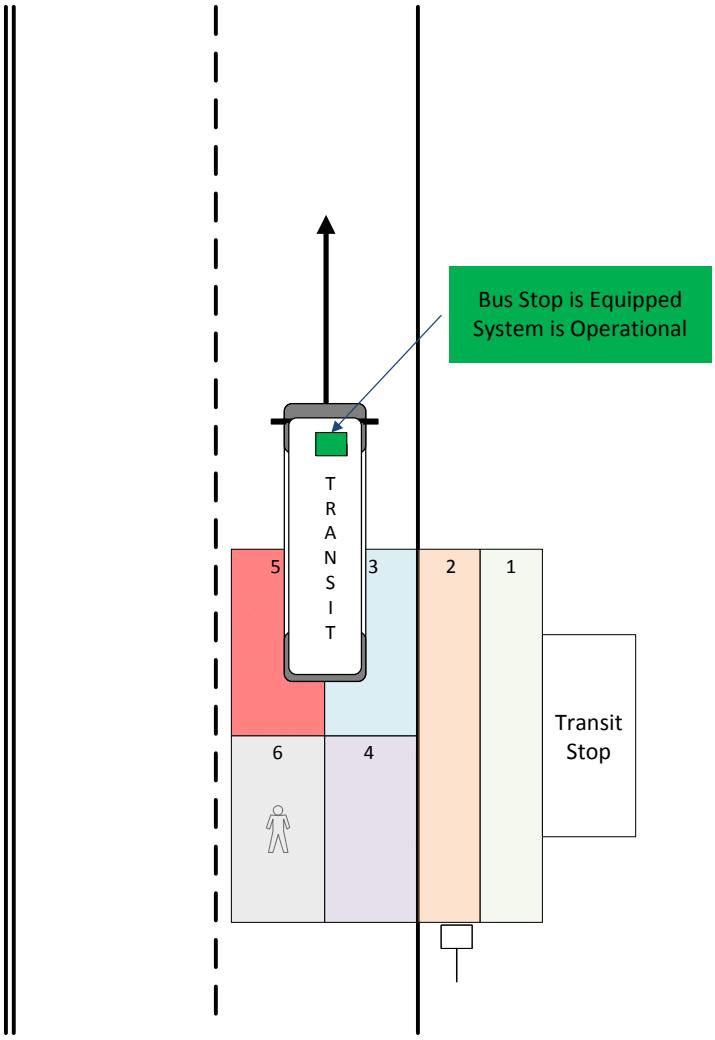


Source: Battelle

Figure 6-39. Scenario 39 – Transit vehicle is departing but is still in the forward roadway zones and there is a pedestrian in the forward center roadway zone

Scenario 40 – Transit vehicle is departing but is still in the forward roadway zones and there is a pedestrian in the rear center roadway zone

- The transit vehicle is departing the transit stop but is still in the forward roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The pedestrian does not receive an alert.

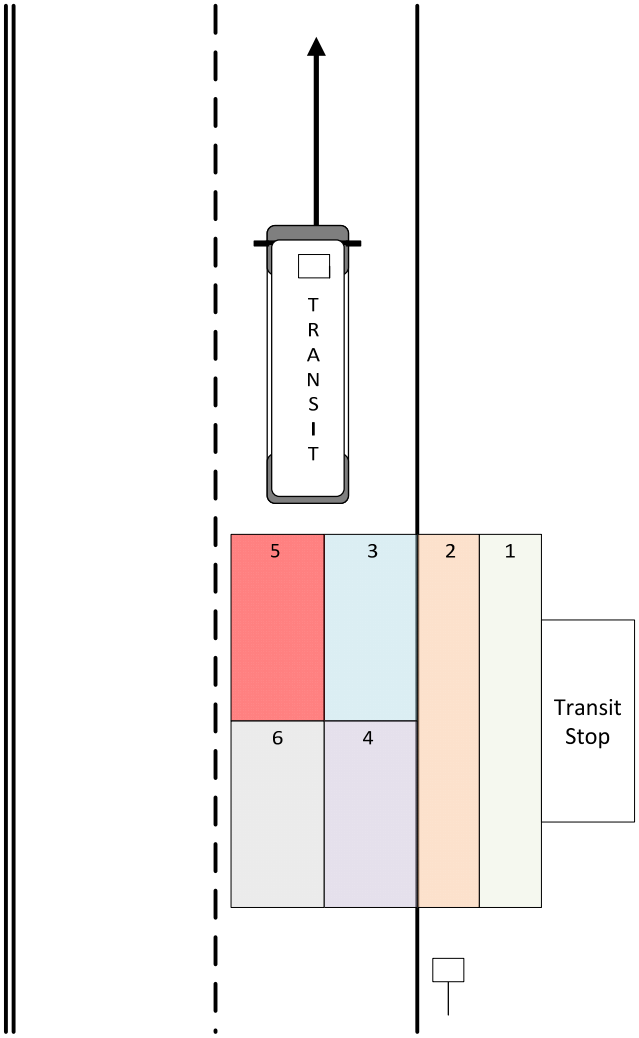


Source: Battelle

Figure 6-40. Scenario 40 – Transit vehicle is departing but is still in the forward roadway zones and there is a pedestrian in the rear center roadway zone

Scenario 41 – Transit vehicle is departing and has cleared all roadway zones and there are no waiting riders

- The transit vehicle is departing the transit stop and has cleared all roadway zones.

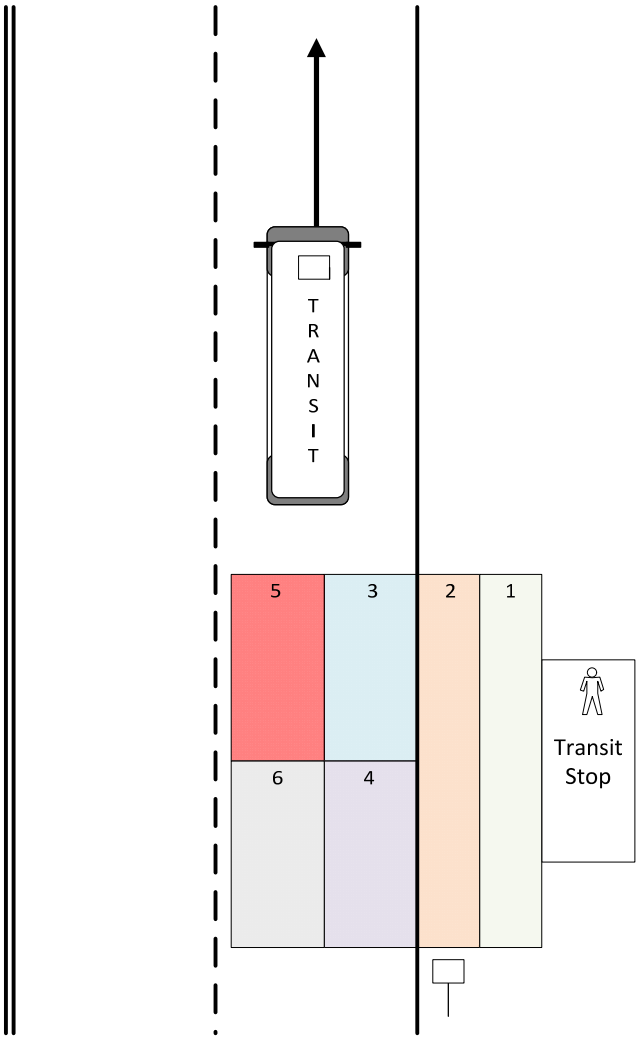


Source: Battelle

Figure 6-41. Scenario 41 – Transit vehicle is departing and has cleared all roadway zones and there are no waiting riders

Scenario 42 – Transit vehicle is departing and has cleared all roadway zones and there is a rider waiting in safe zone inside transit shelter

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The waiting rider does not receive an alert.

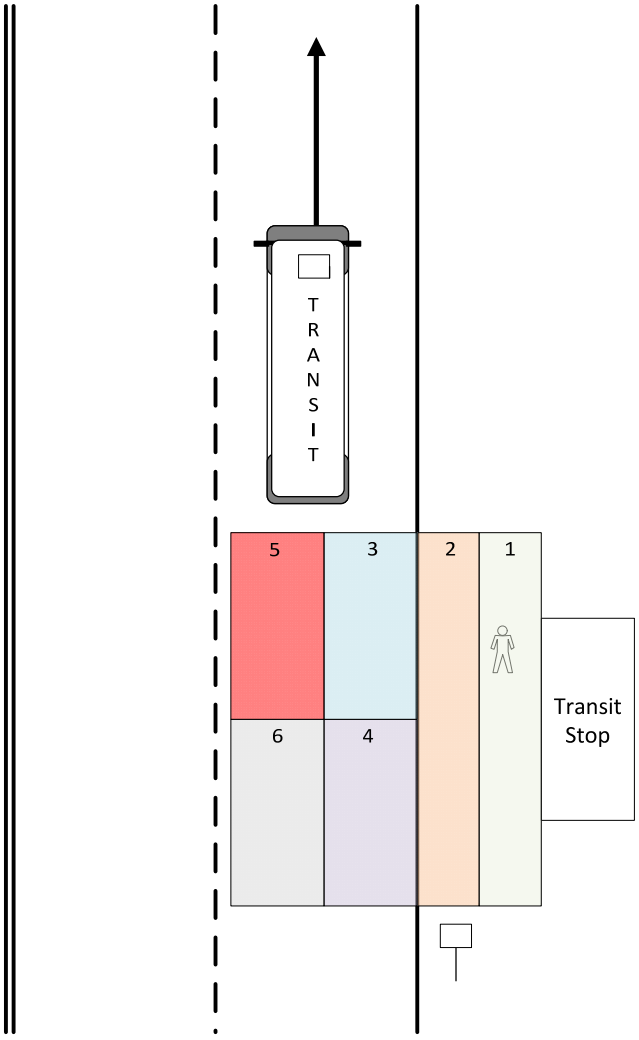


Source: Battelle

Figure 6-42. Scenario 42 – Transit vehicle is departing and has cleared all roadway zones and there is a rider waiting in safe zone inside transit shelter

Scenario 43 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the safe zone

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The waiting rider does not receive an alert.

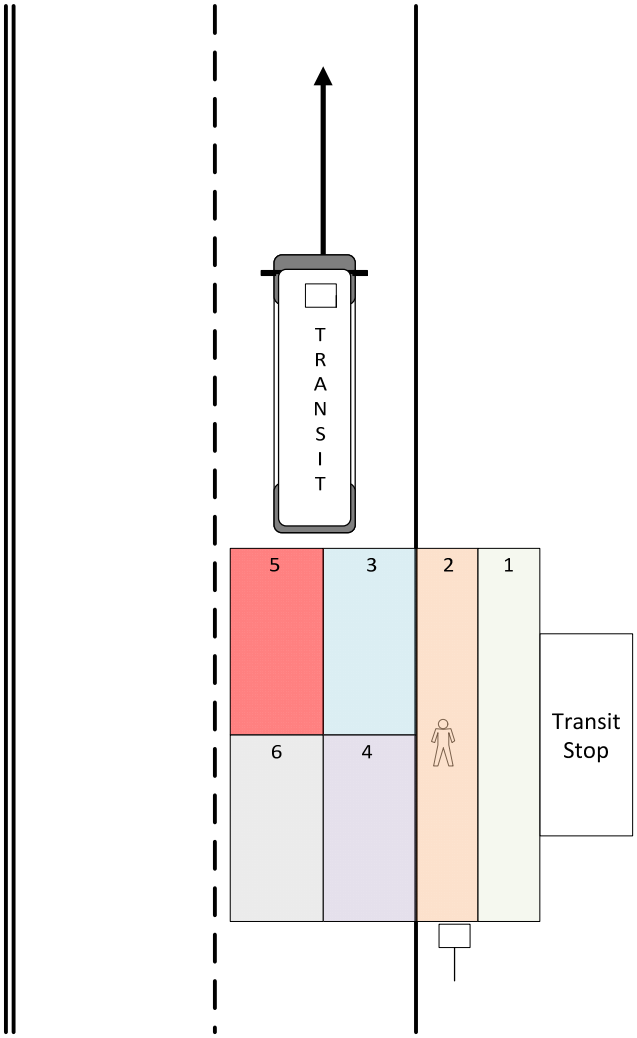


Source: Battelle

Figure 6-43. Scenario 43 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the safe zone

Scenario 44 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the danger zone

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The waiting rider does not receive an alert.

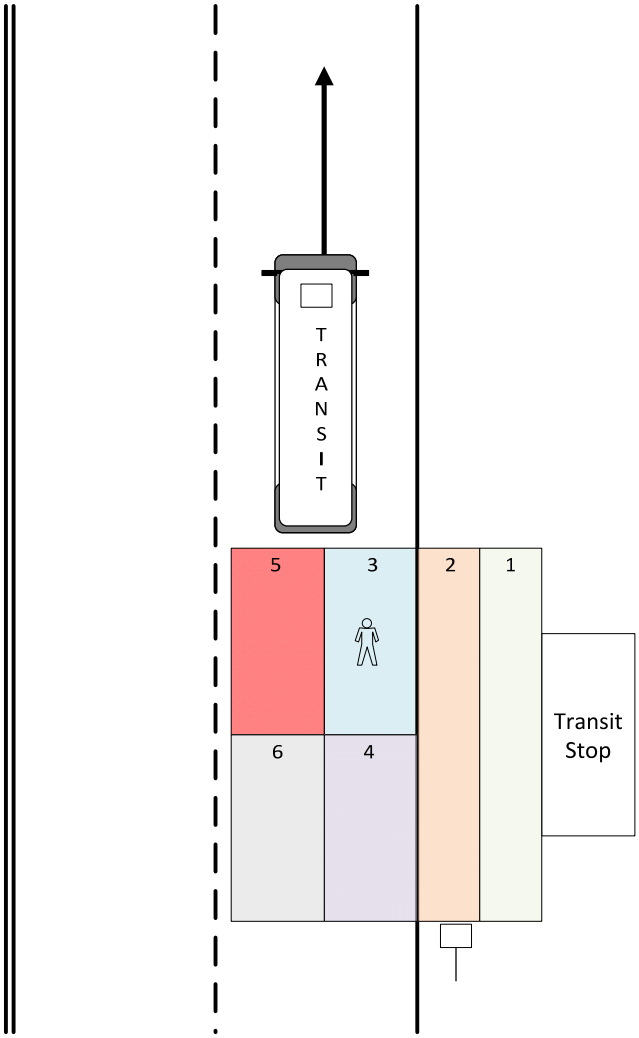


Source: Battelle

Figure 6-44. Scenario 44 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the danger zone

Scenario 45 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward roadway zone

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The pedestrian in the forward curbside roadway zone does not receive an alert.

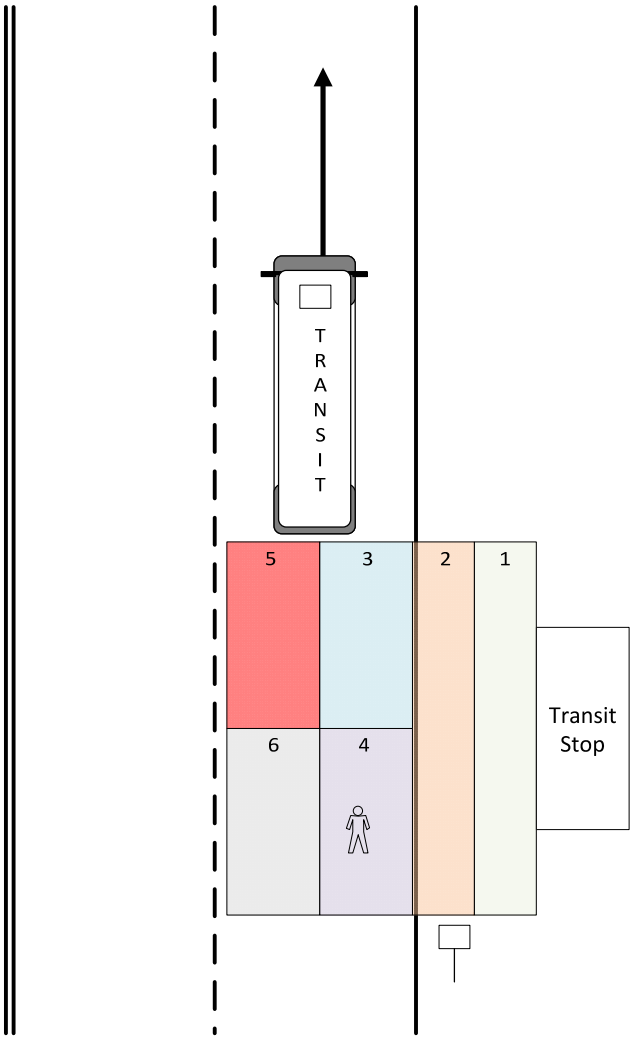


Source: Battelle

Figure 6-45. Scenario 45 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward curbside roadway zone

Scenario 46 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear curbside roadway zone

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The pedestrian in the rear curbside roadway zone does not receive an alert.

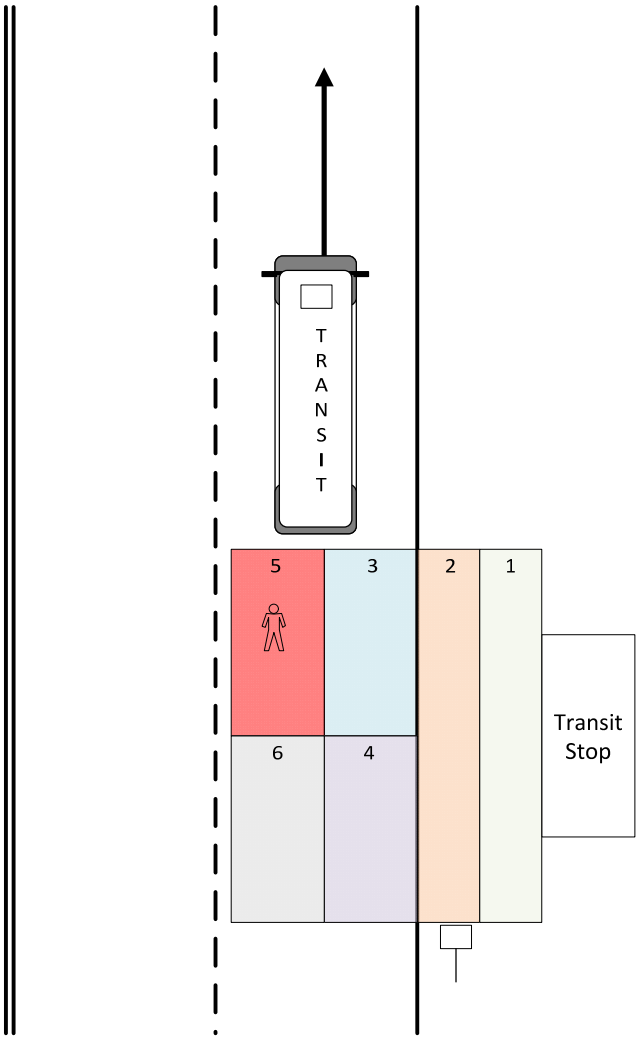


Source: Battelle

Figure 6-46. Scenario 46 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear curbside roadway zone

Scenario 47 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward center roadway zone

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The pedestrian in the forward center roadway zone does not receive an alert.

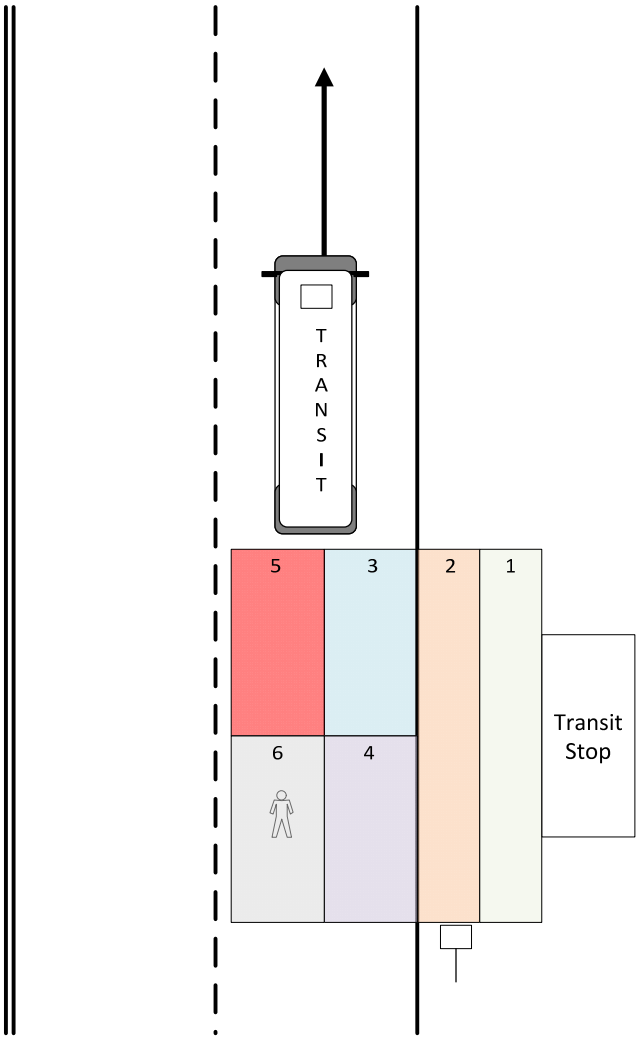


Source: Battelle

Figure 6-47. Scenario 47 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward center roadway zone

Scenario 48 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear center roadway zone

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The pedestrian in the rear center roadway zone does not receive an alert.

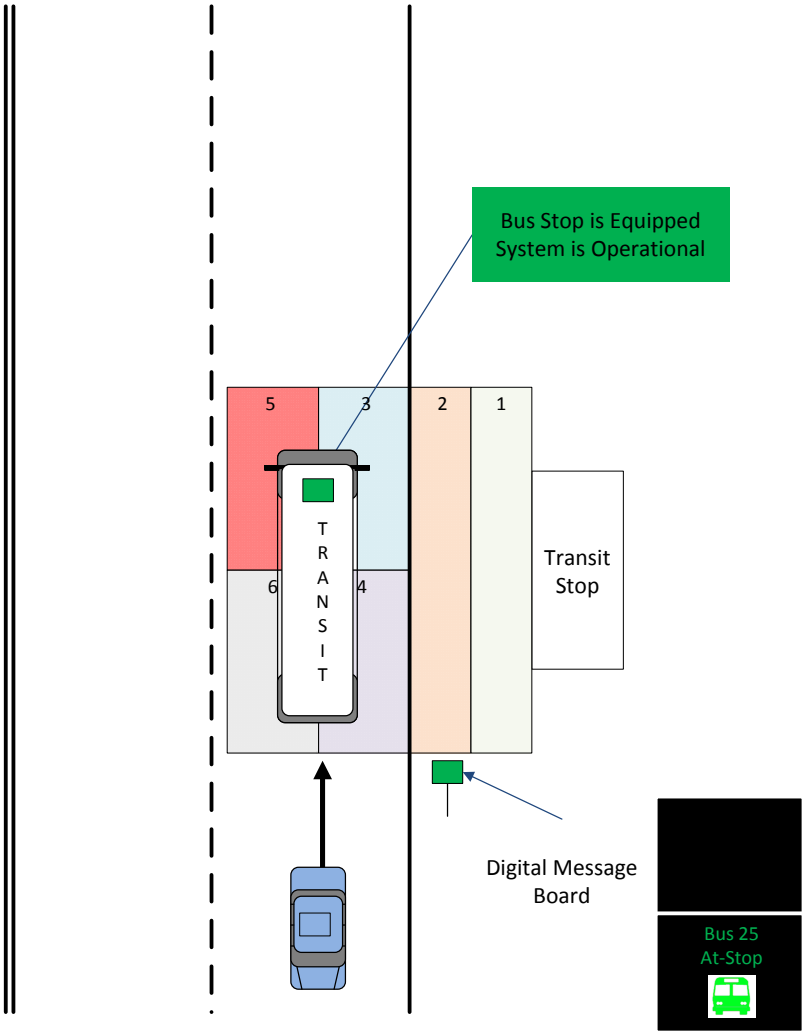


Source: Battelle

Figure 6-48. Scenario 48 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear center roadway zone

Scenario 49 – Transit vehicle stopped at transit stop with no waiting riders but there is an oncoming vehicle behind the transit vehicle

- The transit vehicle is stopped at the transit stop in all roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop using a Green message.
- The oncoming vehicle behind the stationary transit vehicle does not receive an alert.

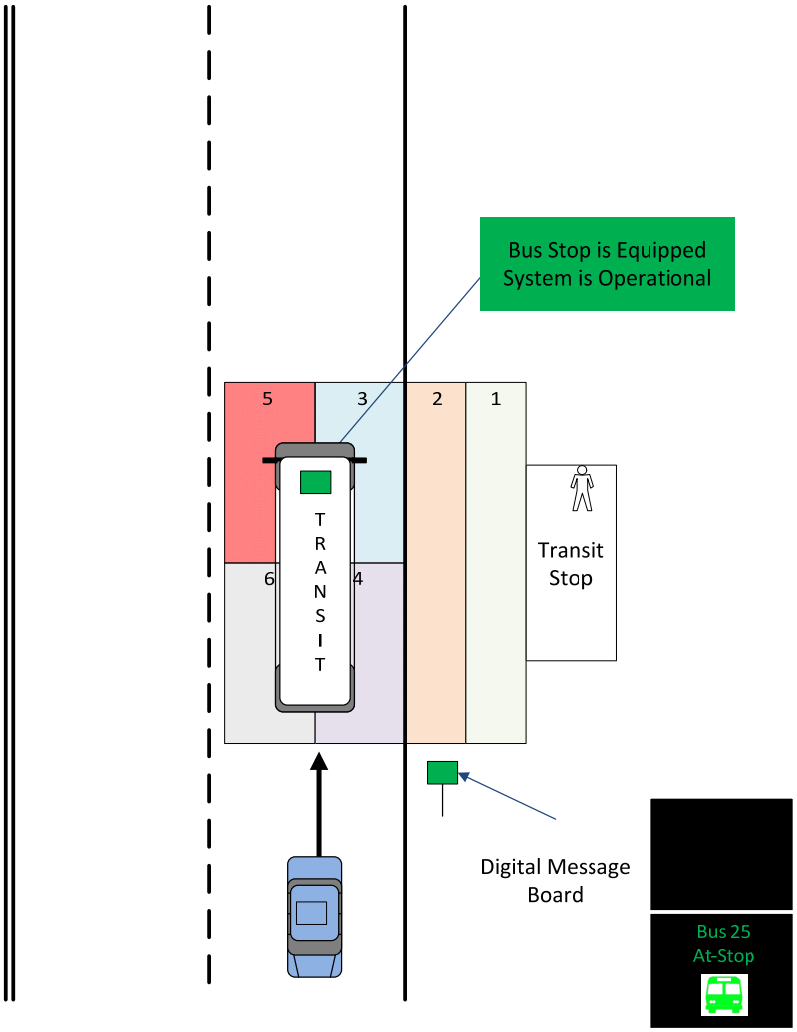


Source: Battelle

Figure 6-49. Scenario 49 – Transit vehicle stopped at transit stop and there are no waiting riders but there is an oncoming vehicle behind the transit vehicle

Scenario 50 – Transit vehicle stopped at transit stop with a waiting rider waiting in the transit shelter and an oncoming vehicle behind the transit vehicle

- The transit vehicle is stopped at the transit stop in all roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop using a Green message.
- The oncoming vehicle behind the stationary transit vehicle does not receive an alert.
- The pedestrian does not receive and alert

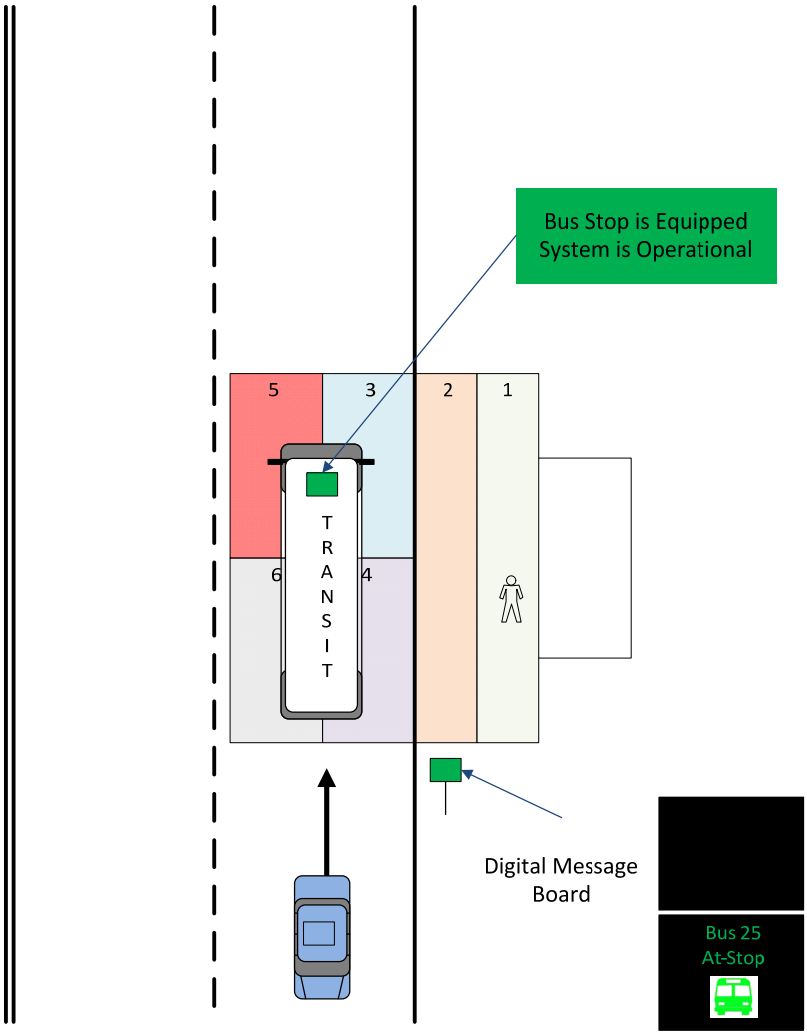


Source: Battelle

Figure 6-50. Scenario 50 – Transit vehicle stopped at transit stop with a waiting rider waiting in the transit shelter and an oncoming vehicle behind the transit vehicle

Scenario 51 – Transit vehicle stopped at transit stop with a waiting rider waiting in the safe zone and an oncoming vehicle behind the transit vehicle

- The transit vehicle is stopped at the transit stop in all roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop using a Green message.
- The oncoming vehicle behind the stationary transit vehicle does not receive an alert.
- The pedestrian does not receive an alert.

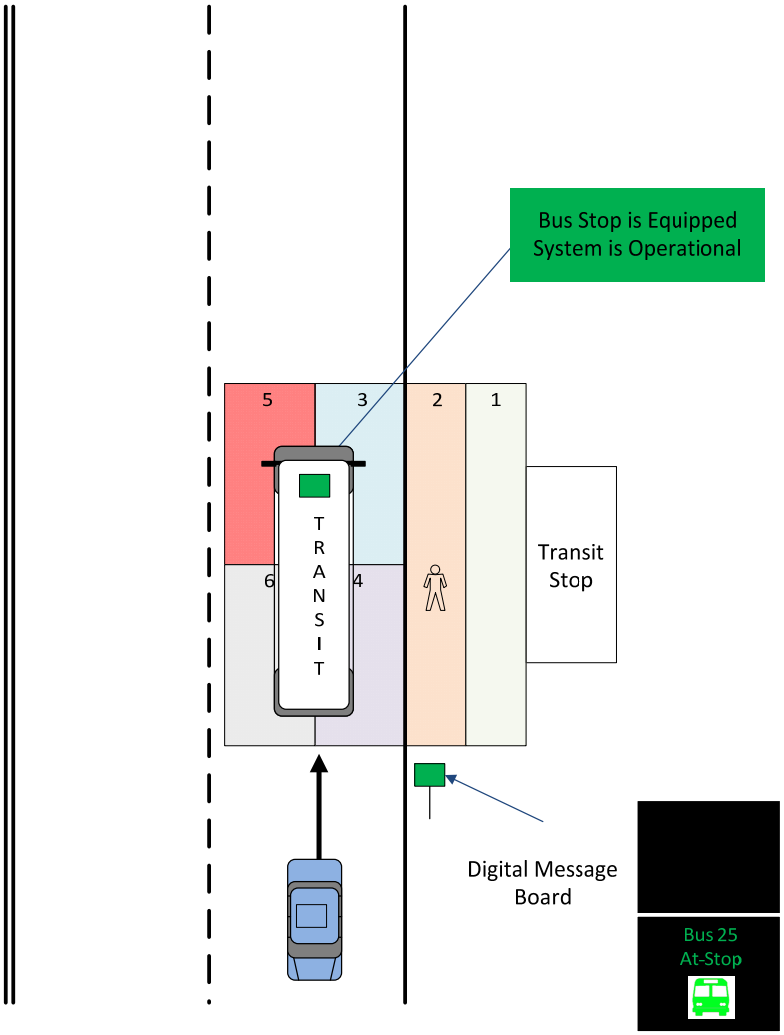


Source: Battelle

Figure 6-51. Scenario 51 – Transit vehicle stopped at transit stop with a waiting rider waiting in the safe zone and an oncoming vehicle behind the transit vehicle

Scenario 52 – Transit vehicle stopped at transit stop with a waiting rider waiting in the danger zone and an oncoming vehicle behind the transit vehicle

- The transit vehicle is stopped at the transit stop in allh roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop using a Green message.
- The oncoming vehicle behind the stationary transit vehicle does not receive an alert.
- The pedestrian does not receive an alert.

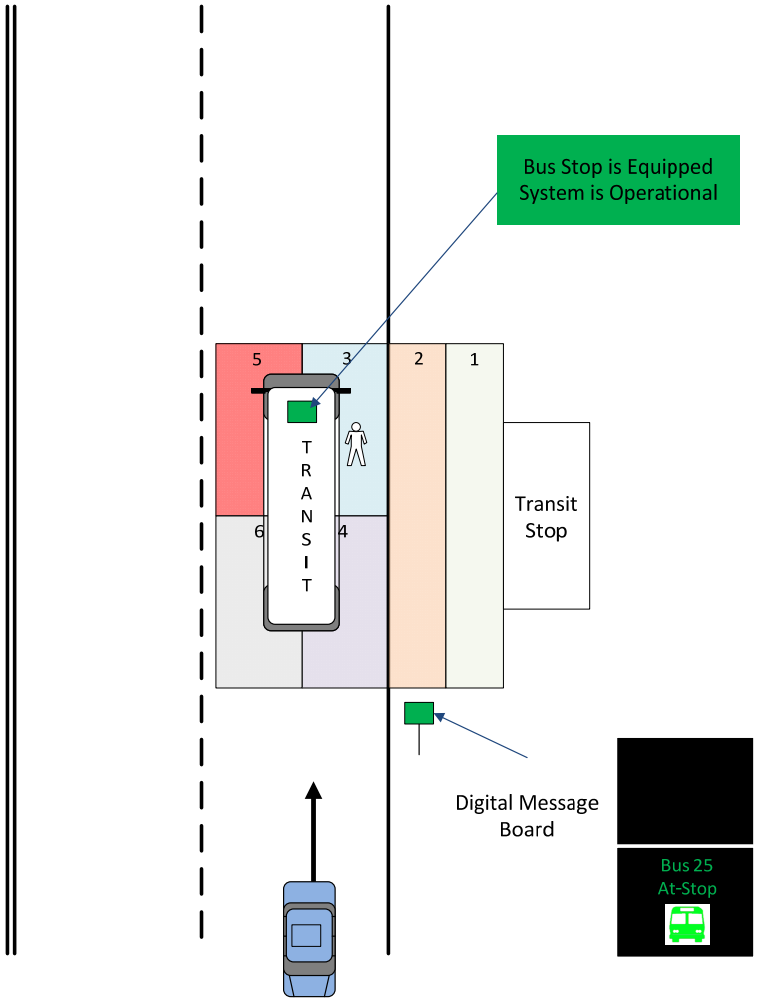


Source: Battelle

Figure 6-52. Scenario 52 – Transit vehicle stopped at transit stop with a waiting rider waiting in the danger zone and an oncoming vehicle behind the transit vehicle

Scenario 53 – Transit vehicle stopped at transit stop with a pedestrian in the forward curbside roadside zone and an oncoming vehicle behind the transit vehicle

- The transit vehicle is stopped at the transit stop in all roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop using a Green message.
- The oncoming vehicle behind the stationary transit vehicle does not receive an alert.
- The pedestrian does not receive an alert.

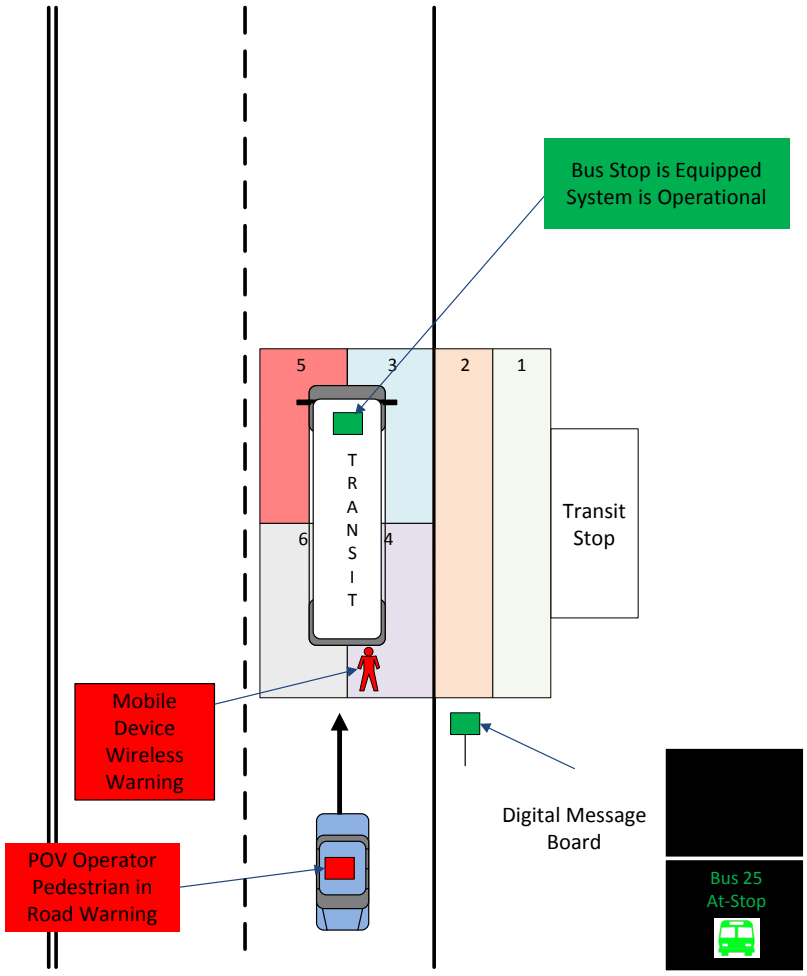


Source: Battelle

Figure 6-53. Scenario 53 – Transit vehicle stopped at transit stop with a pedestrian in the forward curbside roadside zone and an oncoming vehicle behind the transit vehicle

Scenario 54 – Transit vehicle stopped at transit stop with a pedestrian in the rear curbside roadside zone and an oncoming vehicle behind the transit vehicle

- The transit vehicle is stopped at the transit stop in all roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop using a Green message.
- The pedestrian in the rear curbside roadway zone behind the transit vehicle receives a Red warning alert via a mobile device due to the approach of the oncoming vehicle.
- The oncoming vehicle behind the stationary transit vehicle receives a Red warning alert indicating that there is a pedestrian in the roadway.

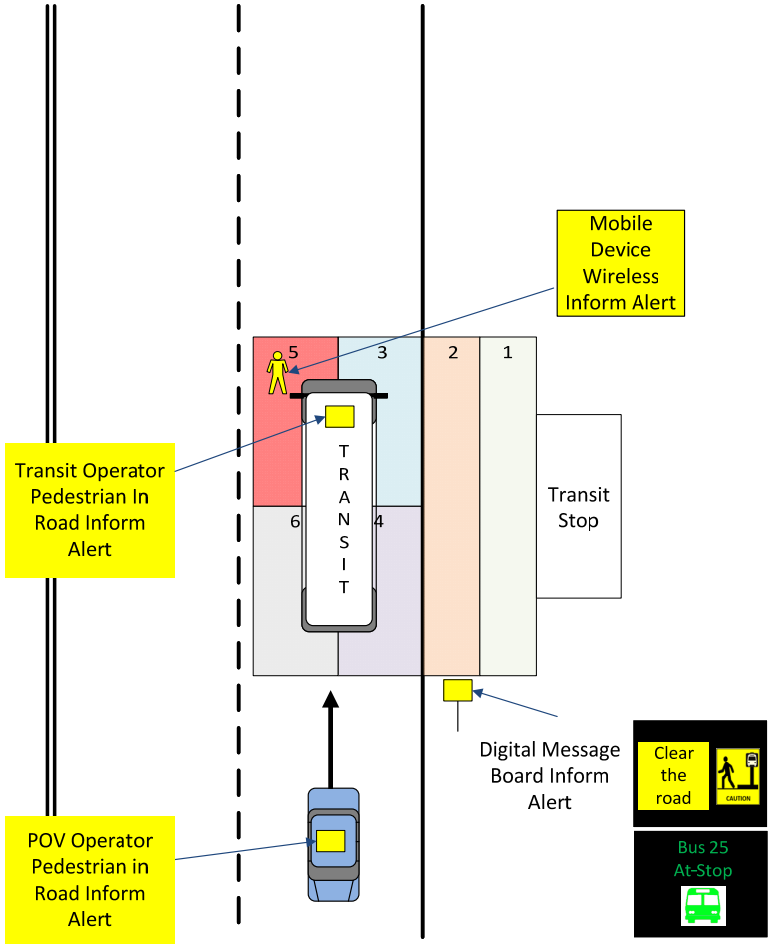


Source: Battelle

Figure 6-54. Scenario 54 – Transit vehicle stopped at transit stop with a pedestrian in the rear curbside roadside zone and an oncoming vehicle behind the transit vehicle

Scenario 55 – Transit vehicle stopped at transit stop with pedestrian in the forward center roadway zone and an oncoming vehicle behind the transit vehicle

- The transit vehicle is stopped at the transit stop and is in all roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the forward center roadway zone with a Yellow audible and visual inform alert.
- The infrastructure based pedestrian warning device indicates that there is a pedestrian in the forward center roadway zone using a Yellow message.
- The pedestrian in the forward center roadway zone in front of the transit vehicle receives a Yellow warning alert via a mobile device.
- The oncoming vehicle behind the stationary transit vehicle receives a Yellow inform alert indicating that there is a pedestrian in the roadway.

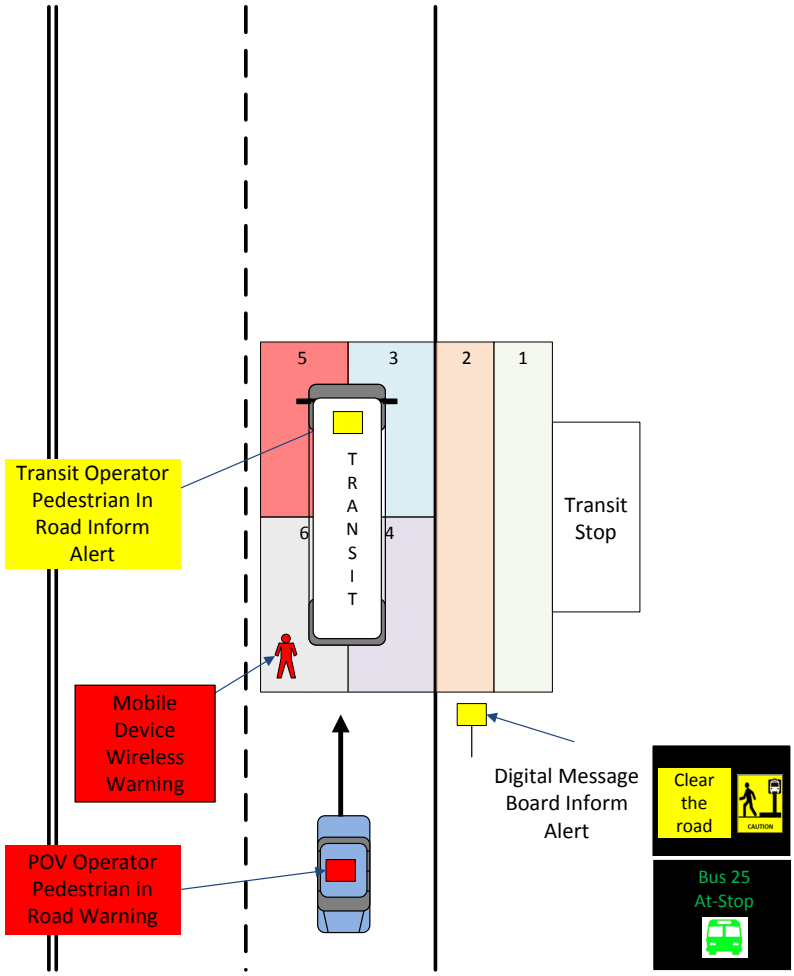


Source: Battelle

Figure 6-55. Scenario 55 – Transit vehicle stopped at transit stop with pedestrian in the forward center roadway zone in front of the stopped transit vehicle and there is an oncoming vehicle behind the transit vehicle

Scenario 56 – Transit vehicle stopped at transit stop with a pedestrian in the rear center roadside zone and an oncoming vehicle behind the transit vehicle

- The transit vehicle is stopped at the transit stop in all roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the rear center roadway zone with a Yellow audible and visual inform alert.
- The infrastructure based pedestrian warning device indicates that there is a pedestrian in the rear center roadway zone using a Yellow message.
- The pedestrian in the rear center roadway zone behind the transit vehicle receives a Red warning alert via a mobile device due to the approach of the oncoming vehicle.
- The oncoming vehicle behind the stationary transit vehicle receives a Red warning alert indicating that there is a pedestrian in the roadway.

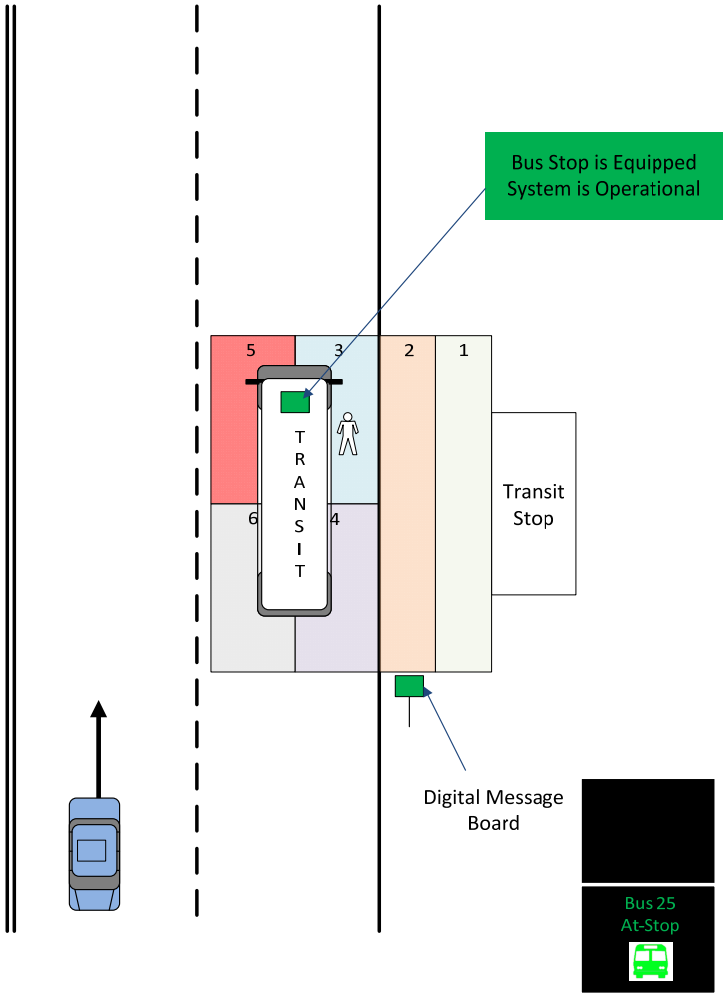


Source: Battelle

Figure 6-56. Scenario 56 – Transit vehicle stopped at transit stop with a pedestrian in the rear center roadside zone and an oncoming vehicle behind the transit vehicle

Scenario 57 – Transit vehicle stopped at transit stop with a pedestrian in the forward curbside roadside zone and an oncoming vehicle passing the transit vehicle

- The transit vehicle is stopped at the transit stop in all roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop using a Green message.
- The oncoming vehicle behind the stationary transit vehicle does not receive an alert.
- The pedestrian does not receive an alert.

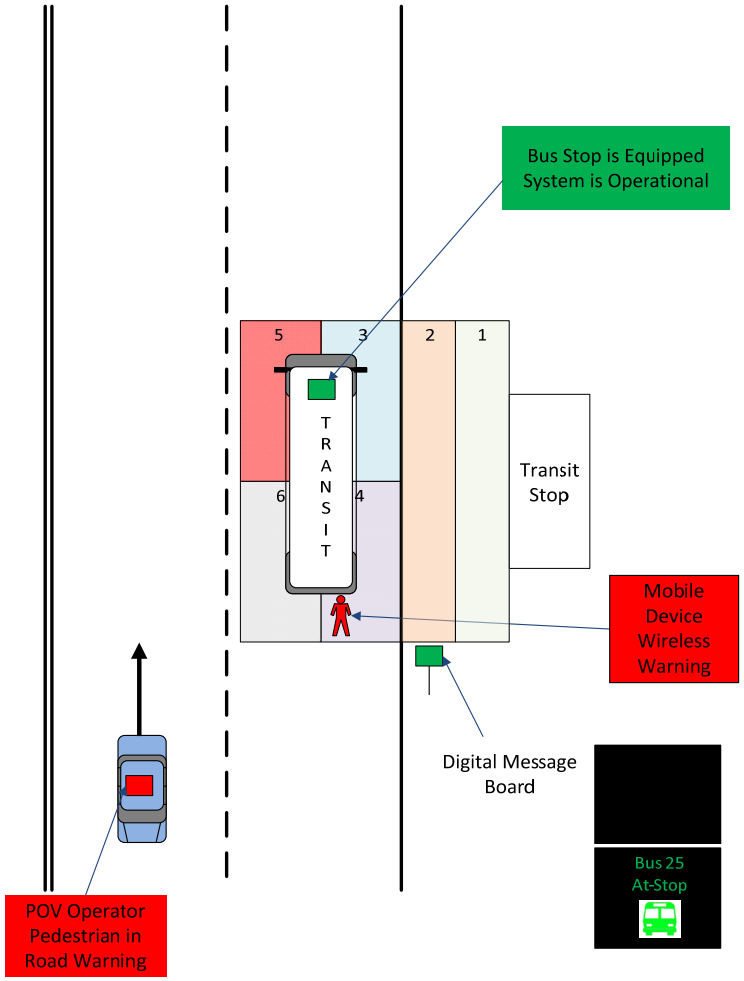


Source: Battelle

Figure 6-57. Scenario 57 – Transit vehicle stopped at transit stop with a pedestrian in the forward curbside roadside zone and an oncoming vehicle passing the transit vehicle

Scenario 58 – Transit vehicle stopped at transit stop with a pedestrian in the rear curbside roadside zone and an oncoming vehicle passing the transit vehicle

- The transit vehicle is stopped at the transit stop in all roadway zones.
- The TSPW application indicates to the transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop using a Green message.
- The pedestrian in the rear curbside roadway zone behind the transit vehicle receives a Red warning alert via a mobile device due to the approach of the oncoming vehicle.
- The oncoming vehicle behind the stationary transit vehicle receives a Red warning alert indicating that there is a pedestrian in the roadway.

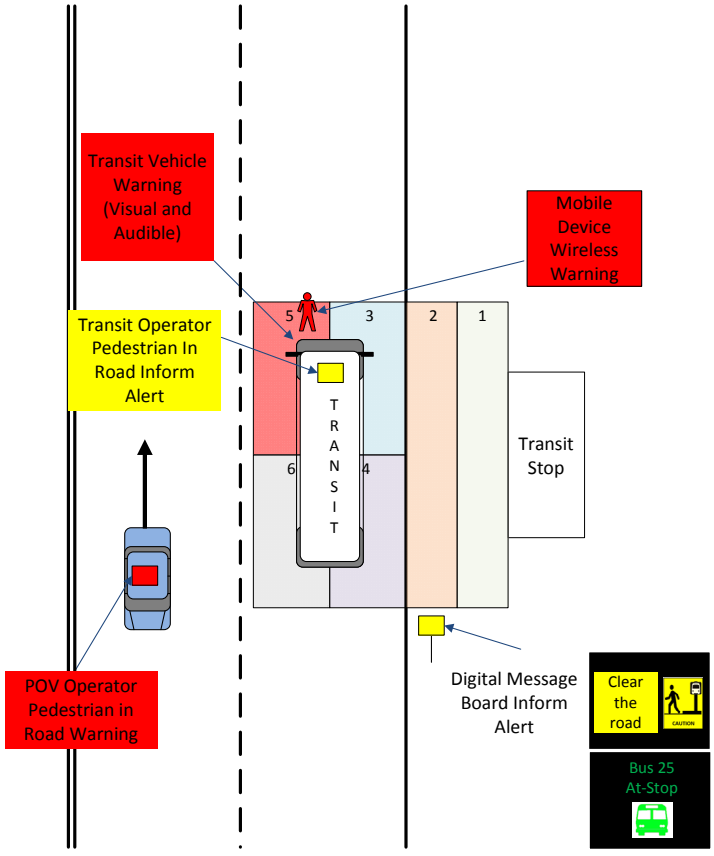


Source: Battelle

Figure 6-58. Scenario 58 – Transit vehicle stopped at transit stop with a pedestrian in the rear curbside roadside zone and an oncoming vehicle passing the transit vehicle

Scenario 59 – Transit vehicle stopped at transit stop with pedestrian in the forward center roadway zone and there is an oncoming vehicle passing the transit vehicle

- The transit vehicle is stopped at the transit stop and is in all roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the forward center roadway zone with a Yellow audible and visual inform alert.
- The infrastructure based pedestrian warning device indicates that there is a pedestrian in the forward center roadway zone using a Yellow message.
- The pedestrian in the forward center roadway zone in front of the transit vehicle receives a Red warning alert via a mobile device due to the passing vehicle.
- The oncoming vehicle passing the stationary transit vehicle receives a Red warning alert indicating that there is a pedestrian in the roadway.
- The transit vehicle provides a visual and audible warning to the pedestrian in the roadway through an on-board system.

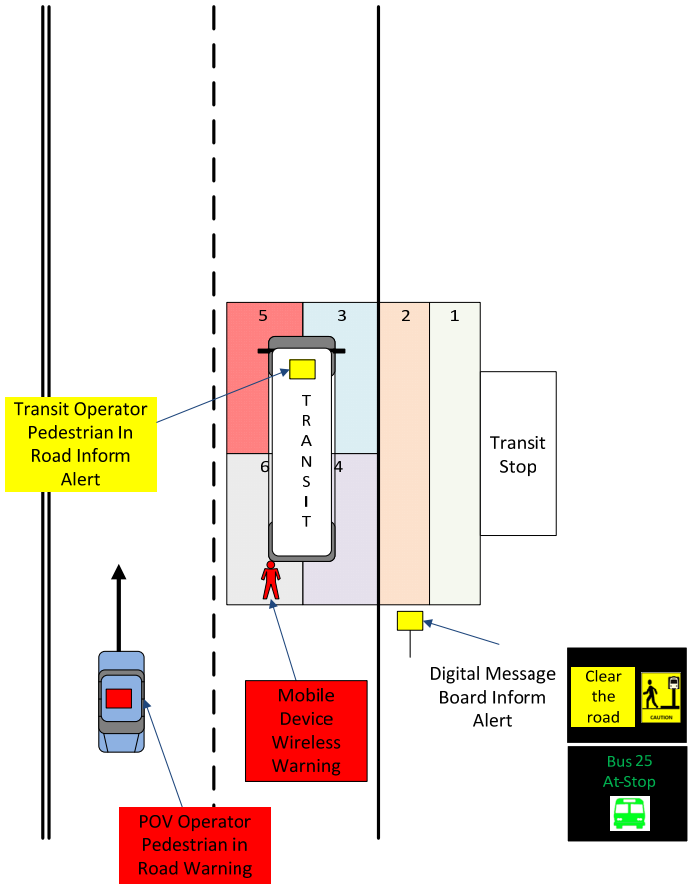


Source: Battelle

Figure 6-59. Scenario 59 – Transit vehicle stopped at transit stop with pedestrian in the forward center roadway zone of the stopped transit vehicle and there is an oncoming vehicle passing the transit vehicle

Scenario 60 – Transit vehicle stopped at transit stop with pedestrian in the rear center roadway zone and there is an oncoming vehicle passing the transit vehicle

- The transit vehicle is stopped at the transit stop and is in all roadway zones.
- The TSPW application indicates to the transit vehicle operator that there is a pedestrian in the rear roadway zone with a Yellow audible and visual inform alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is at the stop using a Yellow message.
- The pedestrian in the rear roadway zone behind the transit vehicle receives a Red warning alert via a mobile device due to the oncoming vehicle.
- The oncoming vehicle passing the stationary transit vehicle receives a Red warning alert indicating that there is a pedestrian in the roadway.

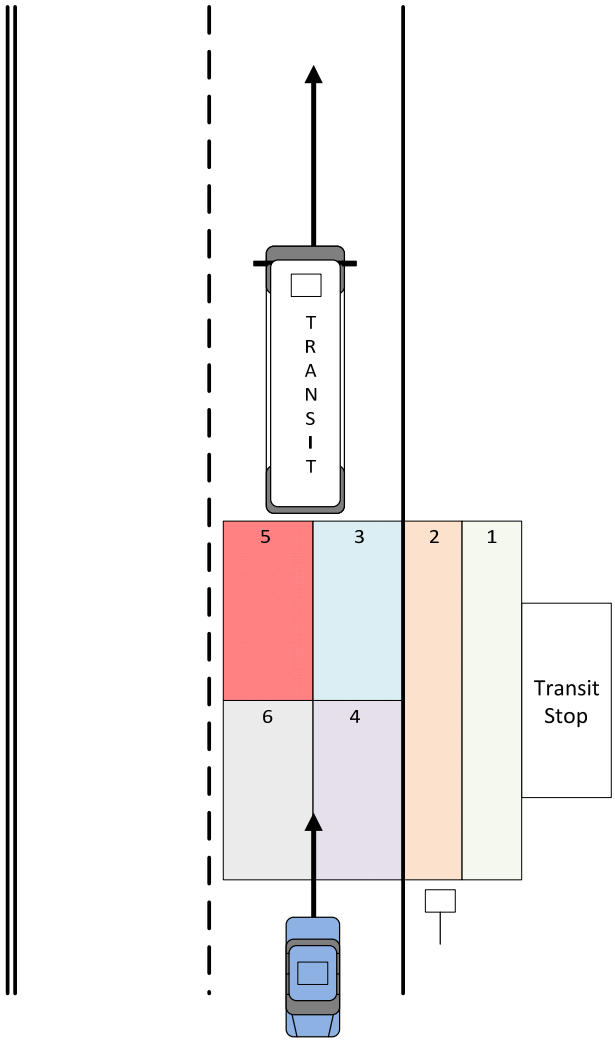


Source: Battelle

Figure 6-60. Scenario 60 – Transit vehicle stopped at transit stop with pedestrian in the rear center roadway zone and there is an oncoming vehicle passing the transit vehicle

Scenario 61 – Transit vehicle is departing and has cleared all roadway zones with no waiting riders and there is an oncoming vehicle behind the transit vehicle

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The on-coming vehicle behind the transit vehicle does not receive an alert.

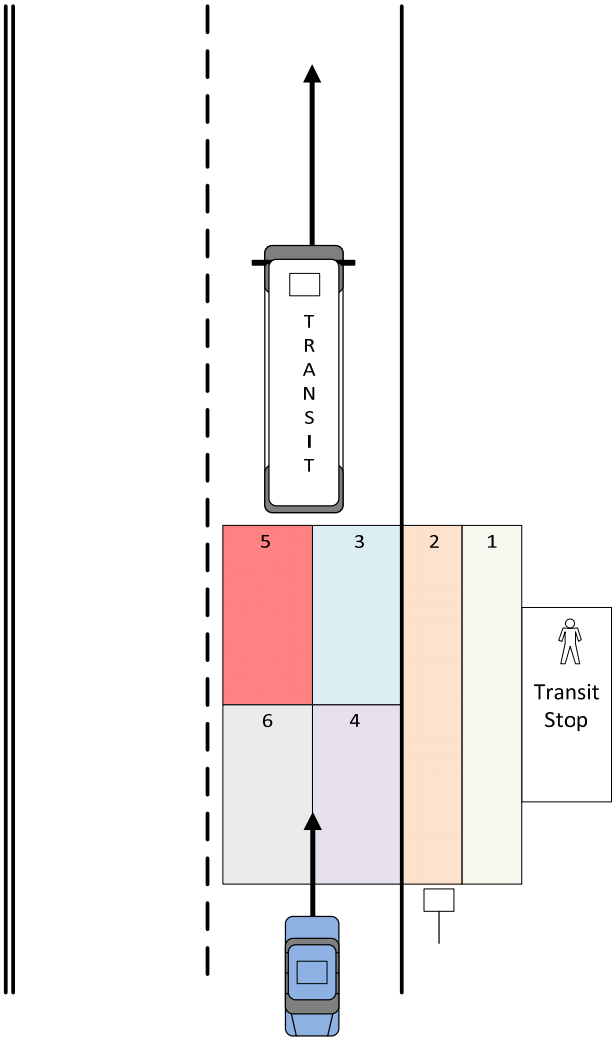


Source: Battelle

Figure 6-61. Scenario 61 – Transit vehicle is departing and has cleared all roadway zones with no waiting riders and there is an oncoming vehicle behind the transit vehicle

Scenario 62 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the safe zone inside of the transit shelter and there is an oncoming vehicle behind the transit vehicle

- The transit vehicle is departing the transit stop and has cleared both roadway zones.
- The waiting rider does not receive an alert.
- The on-coming vehicle behind the transit vehicle does not receive an alert.

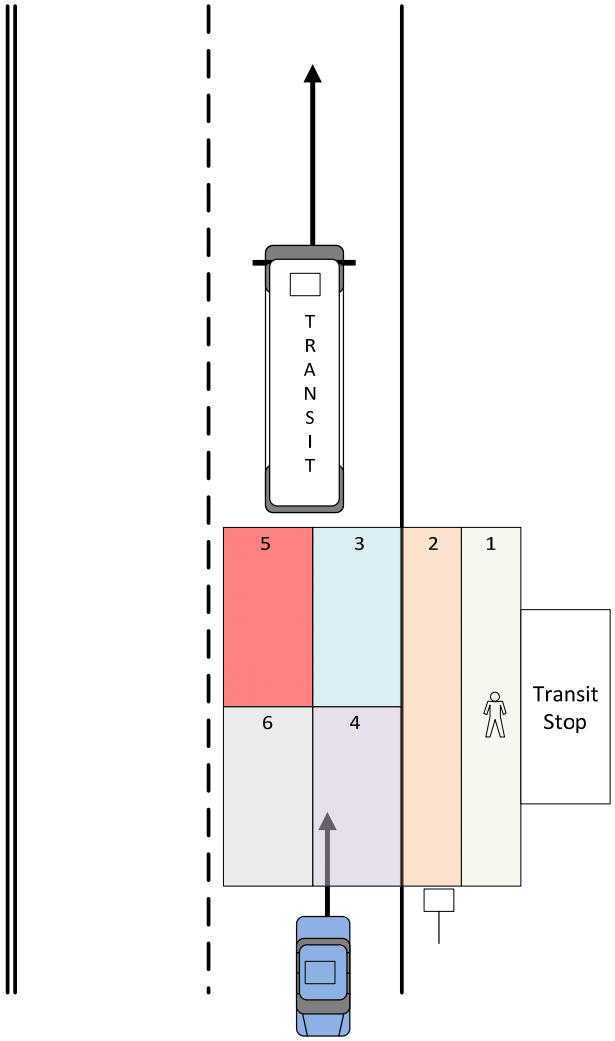


Source: Battelle

Figure 6-62. Scenario 62 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the safe zone inside of the transit shelter and there is an oncoming vehicle behind the transit vehicle

Scenario 63 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the safe zone and there is an oncoming vehicle behind the transit vehicle

- The transit vehicle is departing the transit stop and has cleared both roadway zones.
- The waiting rider does not receive an alert.
- The on-coming vehicle behind the transit vehicle does not receive an alert.

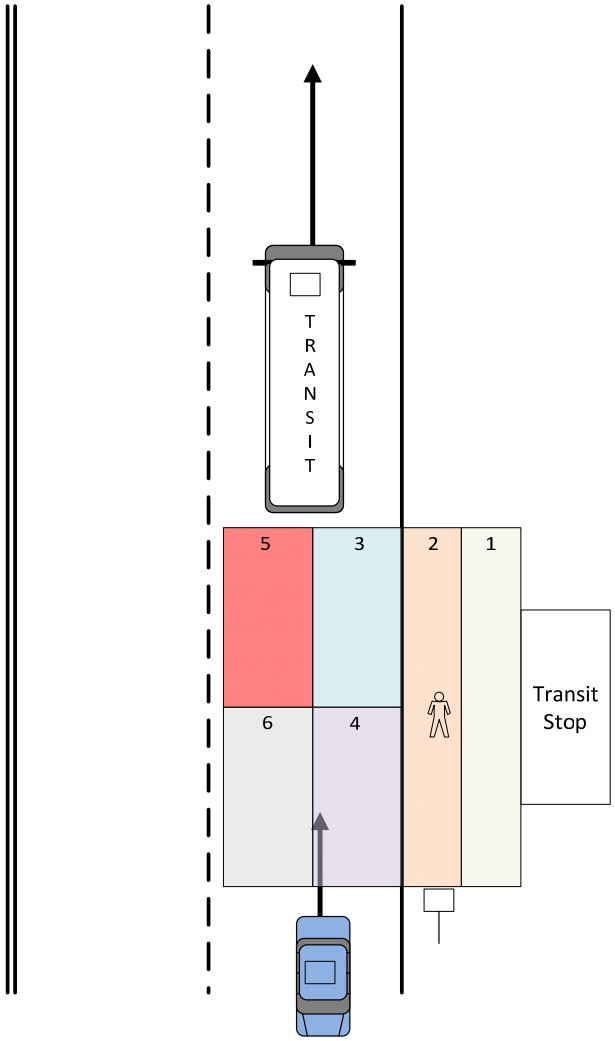


Source: Battelle

Figure 6-63. Scenario 63 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the safe zone and there is an oncoming vehicle behind the transit vehicle

Scenario 64 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the danger zone and there is an oncoming vehicle behind the transit vehicle

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The waiting rider does not receive an alert.
- The on-coming vehicle behind the transit vehicle does not receive an alert.

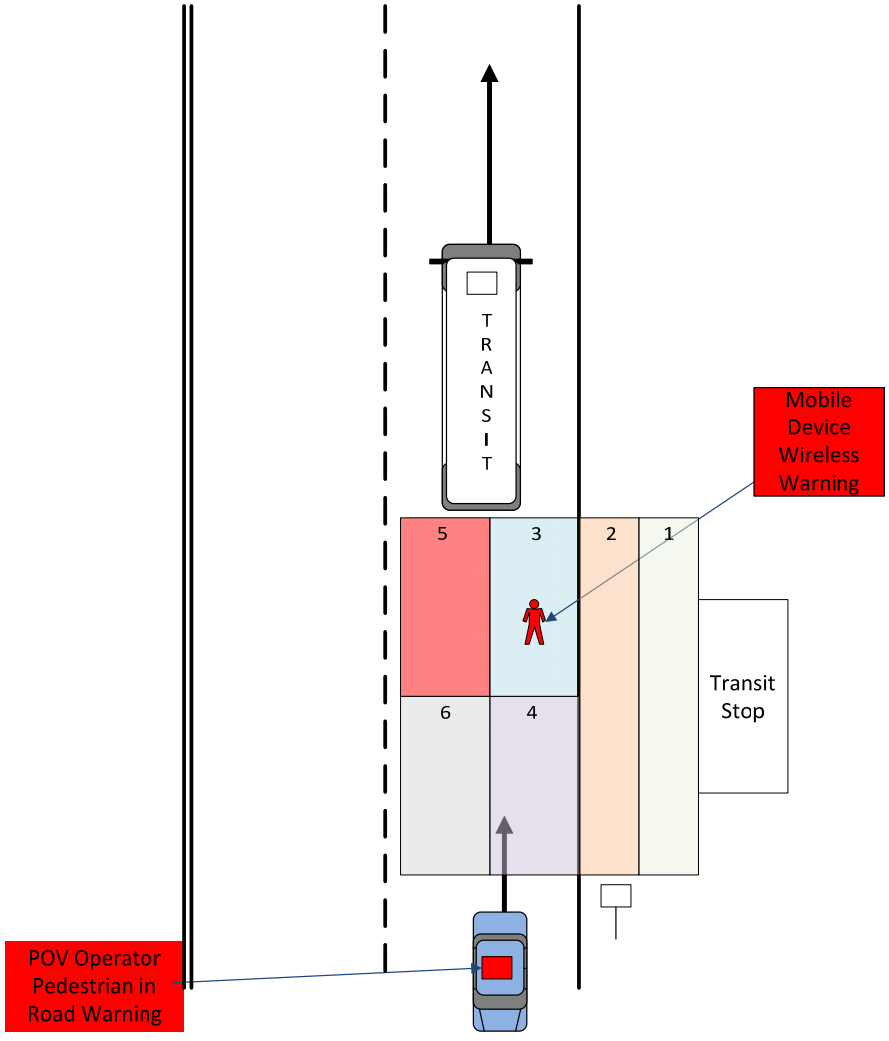


Source: Battelle

Figure 6-64. Scenario 64 – Transit vehicle is departing and has cleared all roadway zones with a waiting rider in the danger zone and there is an oncoming vehicle behind the transit vehicle

Scenario 65 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward curbside roadway zone and there is an oncoming vehicle behind the transit vehicle

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The pedestrian in the forward roadway curbside zone receives a Red warning alert via a mobile device.
- The oncoming vehicle behind the transit vehicle receives a Red warning alert indicating that there is a pedestrian in the roadway.

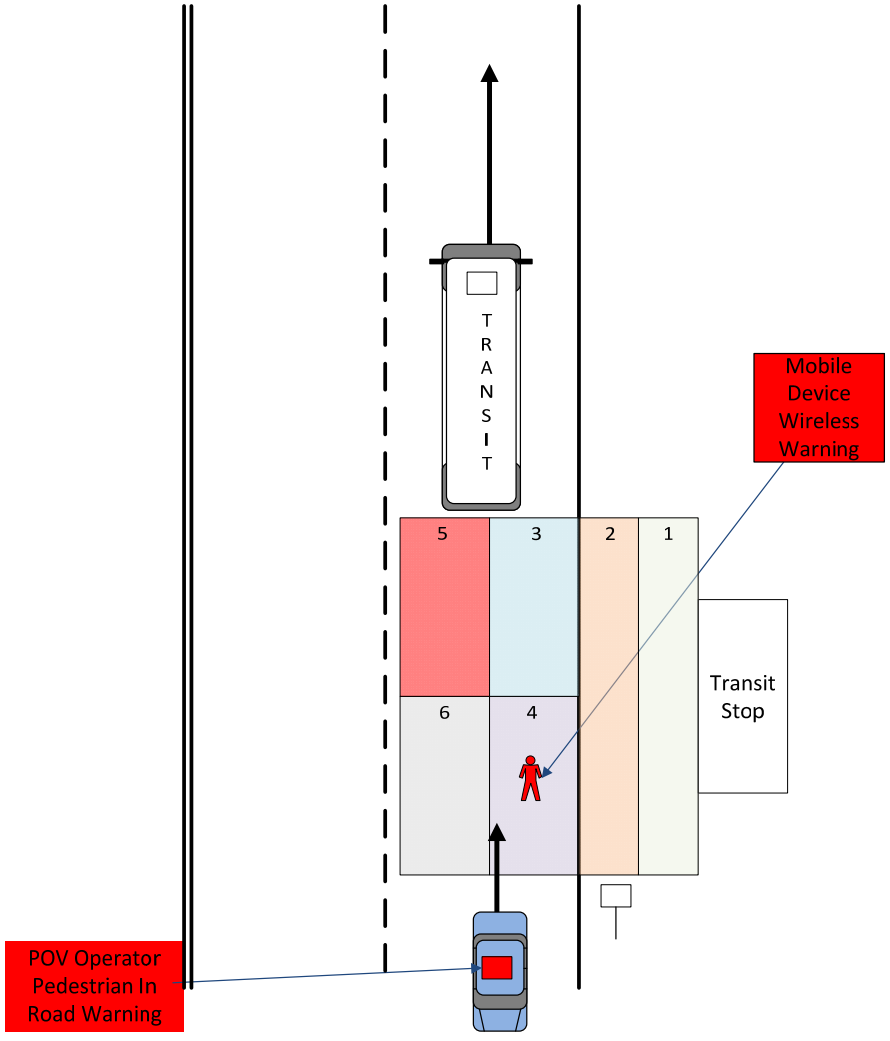


Source: Battelle

Figure 6-65. Scenario 65 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward curbside roadway zone and a connected vehicle approaching the transit stop

Scenario 66 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear curbside roadway zone and there is an oncoming vehicle behind the transit vehicle

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The pedestrian in the rear curbside roadway zone receives a Red warning alert via a mobile device.
- The oncoming vehicle behind the transit vehicle receives a Red warning alert indicating that there is a pedestrian in the roadway.

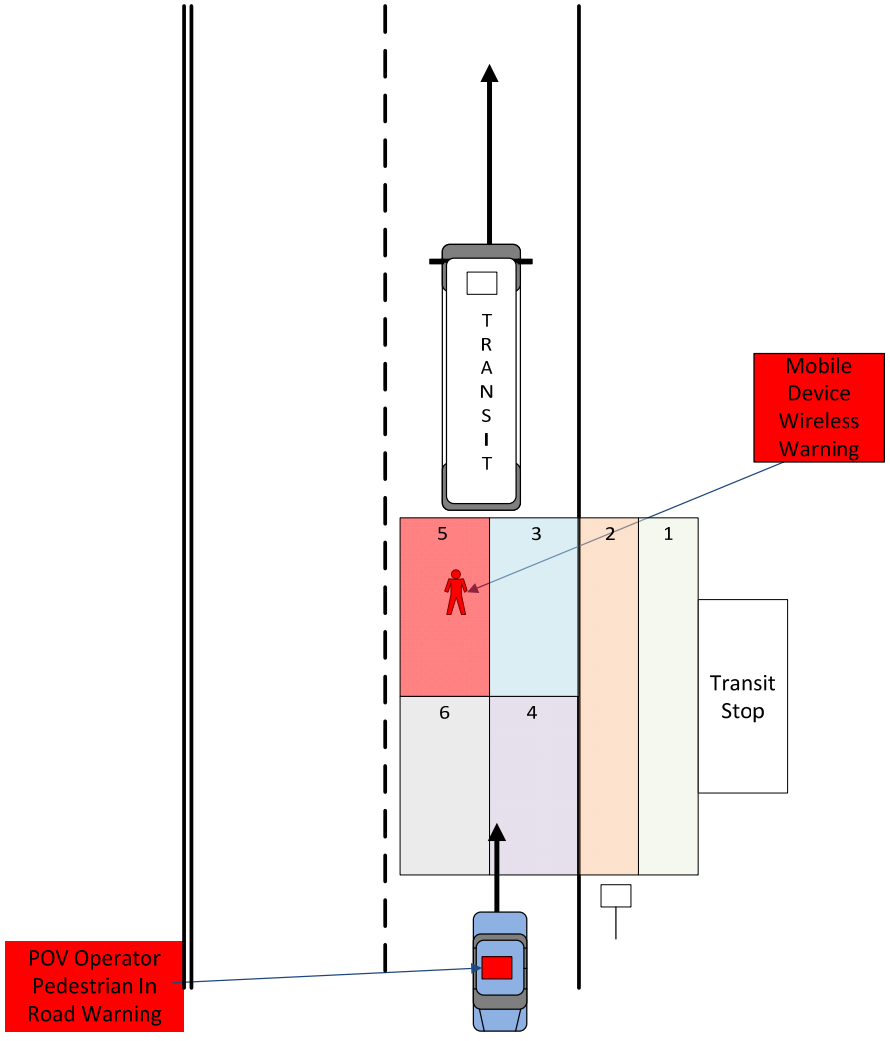


Source: Battelle

Figure 6-66. Scenario 66 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear curbside roadway zone and there is an oncoming vehicle behind the transit vehicle

Scenario 67 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward center roadway zone and there is an oncoming vehicle behind the transit vehicle

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The pedestrian in the forward roadway center zone receives a Red warning alert via a mobile device.
- The oncoming vehicle behind the transit vehicle receives a Red warning alert indicating that there is a pedestrian in the roadway.

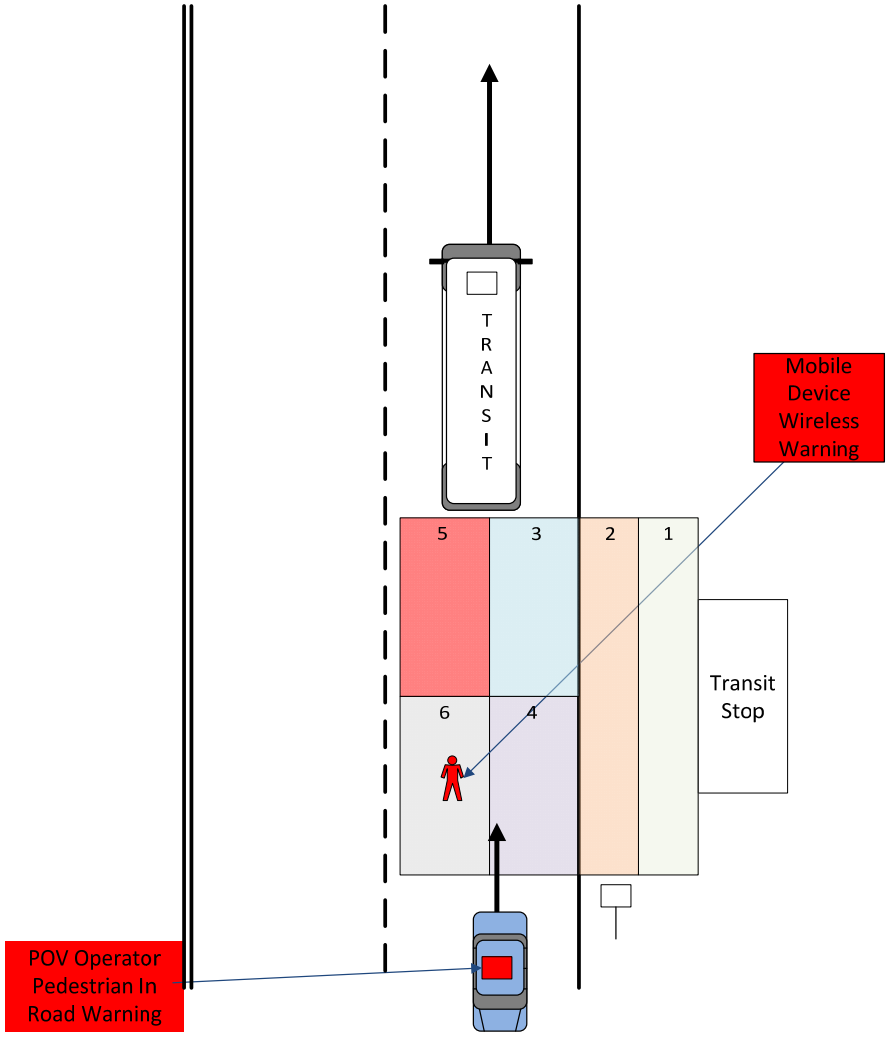


Source: Battelle

Figure 6-67. Scenario 67 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward center roadway zone and a connected vehicle approaching the transit stop

Scenario 68 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear center roadway zone and there is an oncoming vehicle behind the transit vehicle

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The pedestrian in the rear center roadway zone receives a Red warning alert via a mobile device.
- The oncoming vehicle behind the transit vehicle receives a Red warning alert indicating that there is a pedestrian in the roadway.

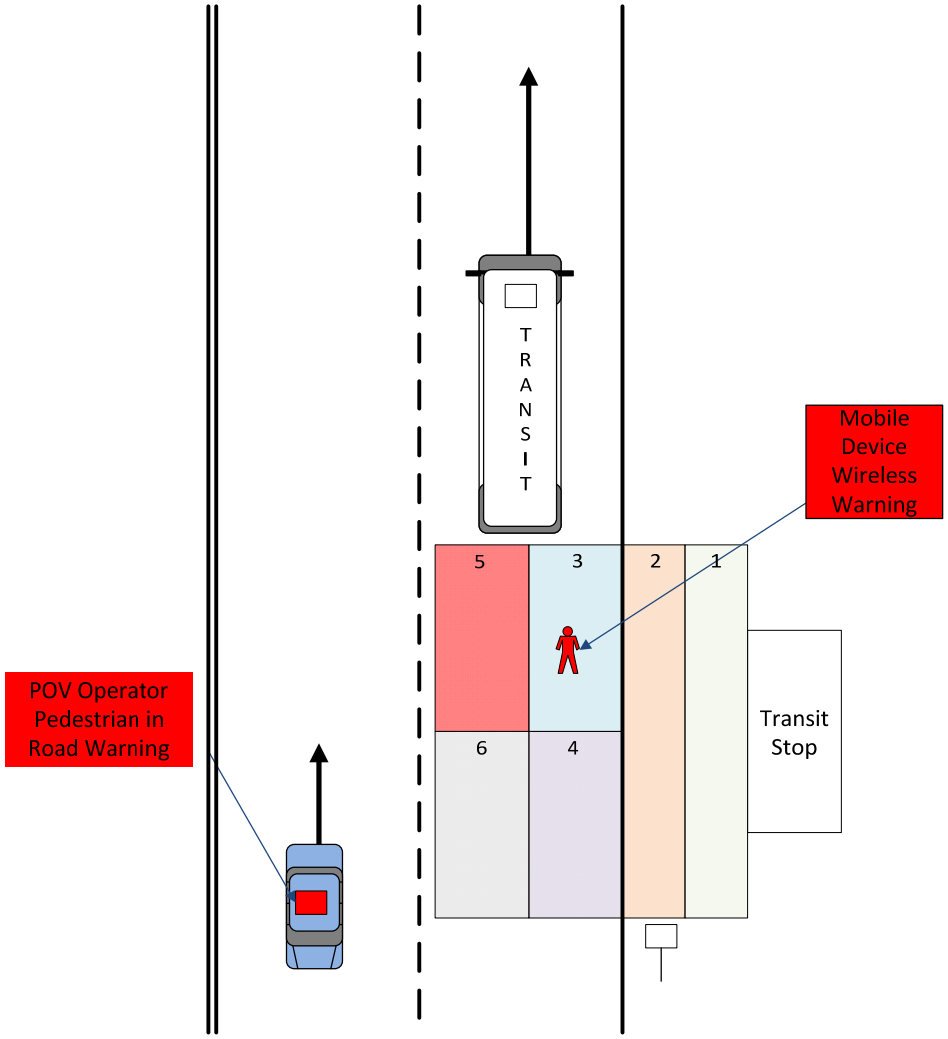


Source: Battelle

Figure 6-68. Scenario 68 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear center roadway zone and there is an oncoming vehicle behind the transit vehicle

Scenario 69 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward curbside roadway zone and there is an oncoming vehicle passing the transit vehicle

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The pedestrian in the forward curbside roadway zone receives a Red warning alert via a mobile device.
- The oncoming vehicle passing the transit vehicle receives a Red warning alert indicating that there is a pedestrian in the roadway.

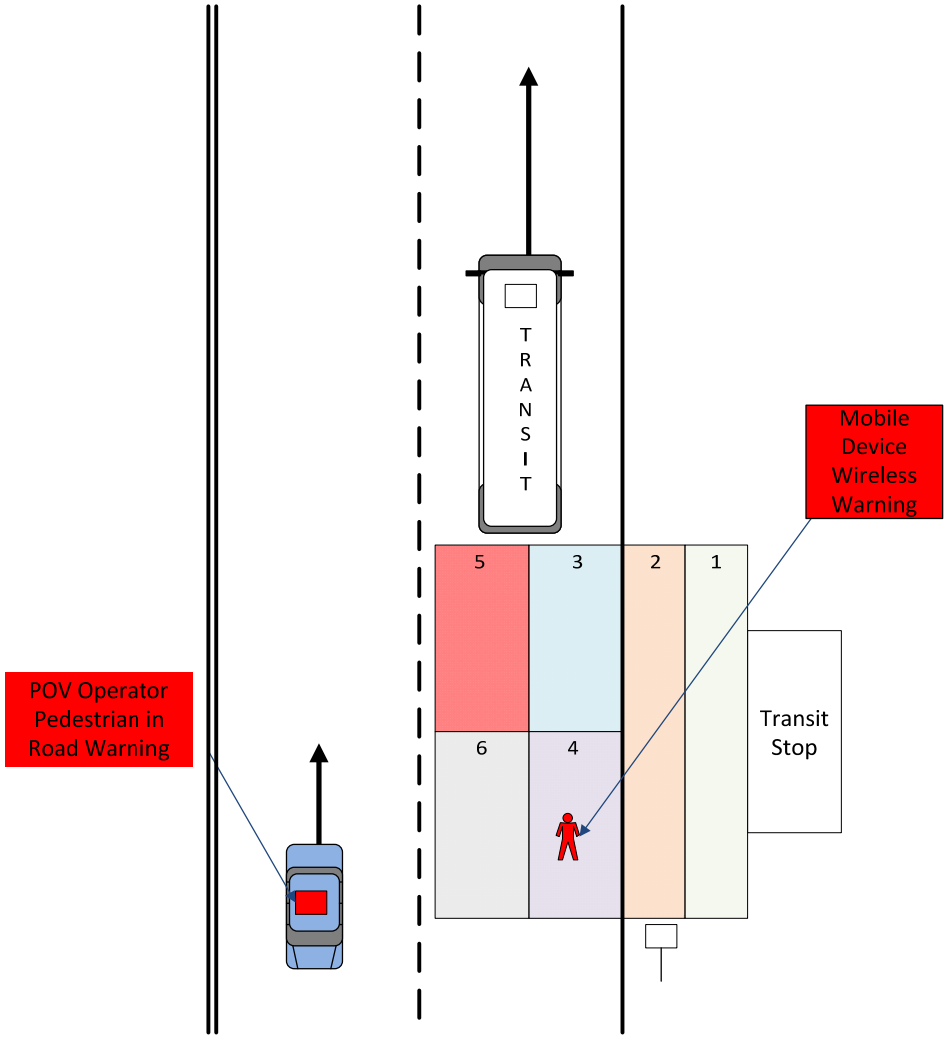


Source: Battelle

Figure 6-69. Scenario 69 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the foreward curbside roadway zone and there is an oncoming vehicle passing the transit vehicle

Scenario 70 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear curbside roadway zone and there is an oncoming vehicle passing the transit vehicle

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The pedestrian in the rear curbside roadway zone receives a Red warning alert via a mobile device.
- The oncoming vehicle passing the transit vehicle receives a Red warning alert indicating that there is a pedestrian in the roadway.

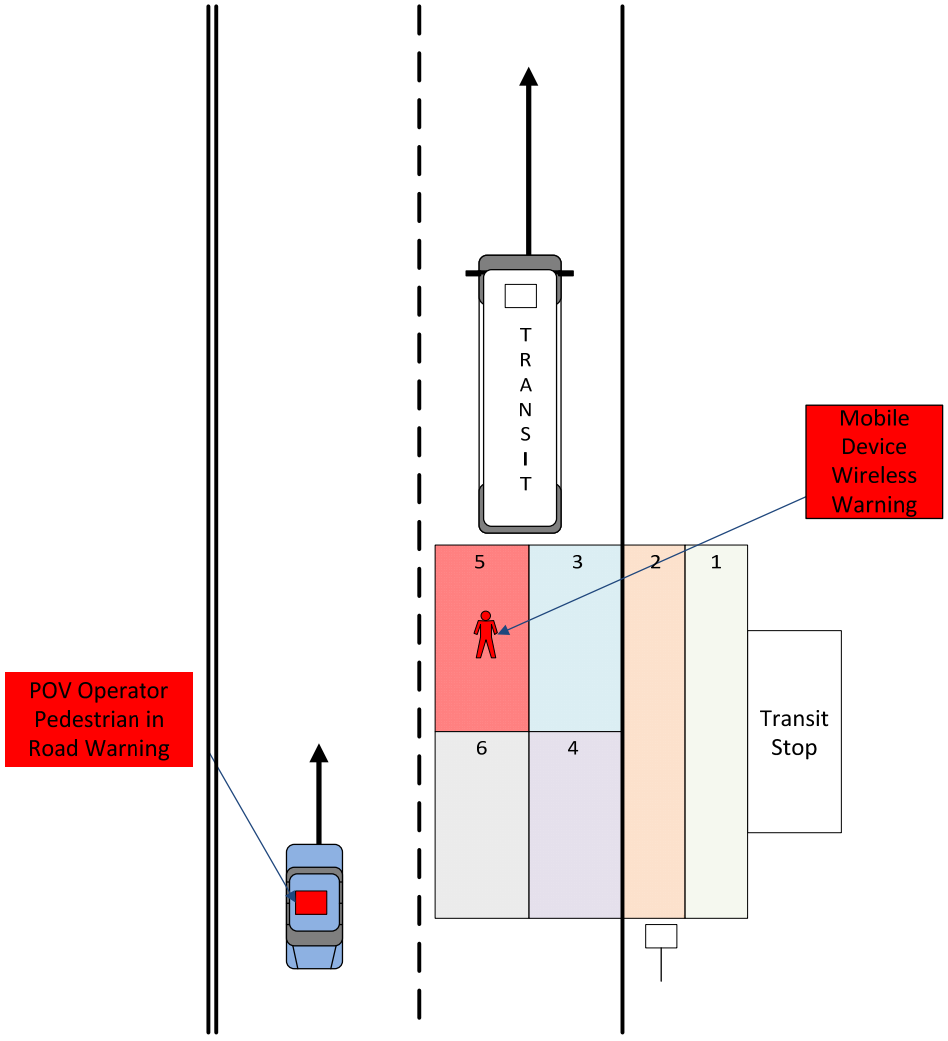


Source: Battelle

Figure 6-70. Scenario 70 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear curbside roadway zone and there is an oncoming vehicle passing the transit vehicle

Scenario 71 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward center roadway zone and there is an oncoming vehicle passing the transit vehicle

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The pedestrian in the forward center roadway zone receives a Red warning alert via a mobile device.
- The oncoming vehicle passing the transit vehicle receives a Red warning alert indicating that there is a pedestrian in the roadway.

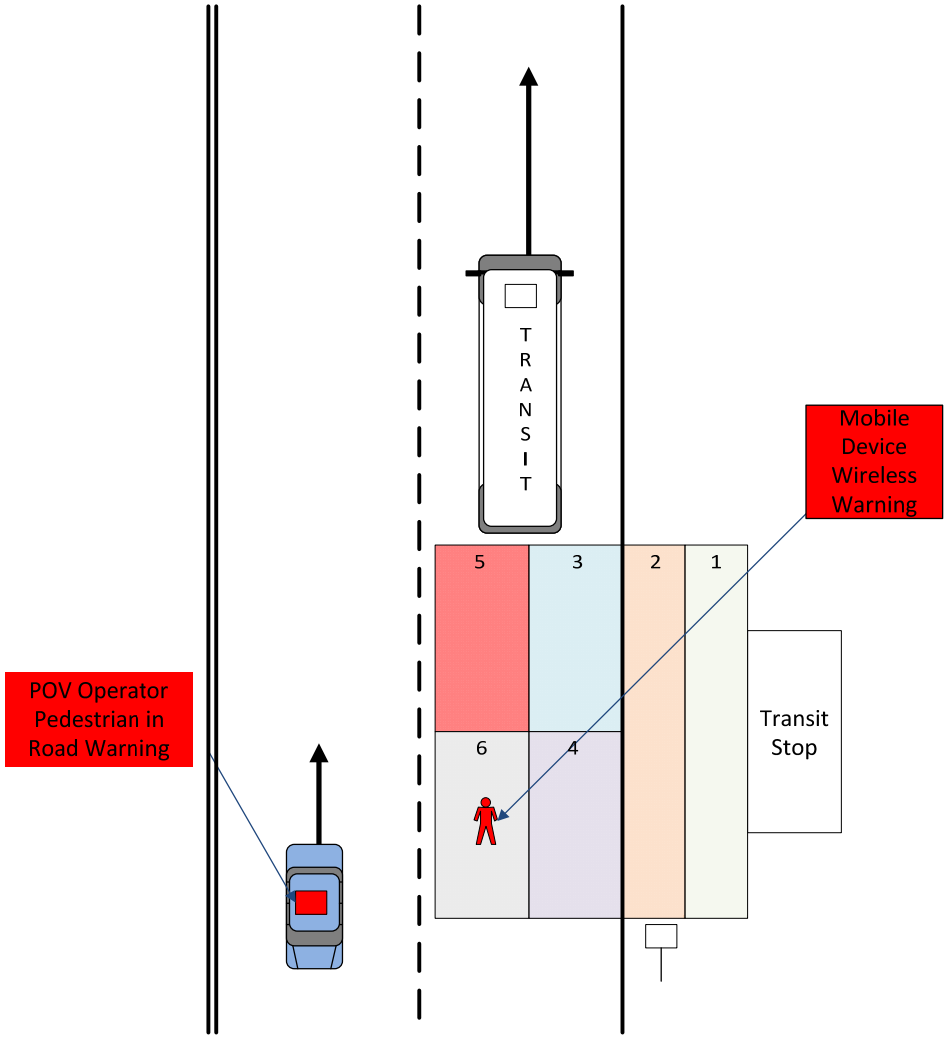


Source: Battelle

Figure 6-71. Scenario 71 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the forward center roadway zone and there is an oncoming vehicle passing the transit vehicle

Scenario 72 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear center roadway zone and there is an oncoming vehicle passing the transit vehicle

- The transit vehicle is departing the transit stop and has cleared all roadway zones.
- The pedestrian in the rear center roadway zone receives a Red warning alert via a mobile device.
- The oncoming vehicle passing the transit vehicle receives a Red warning alert indicating that there is a pedestrian in the roadway.

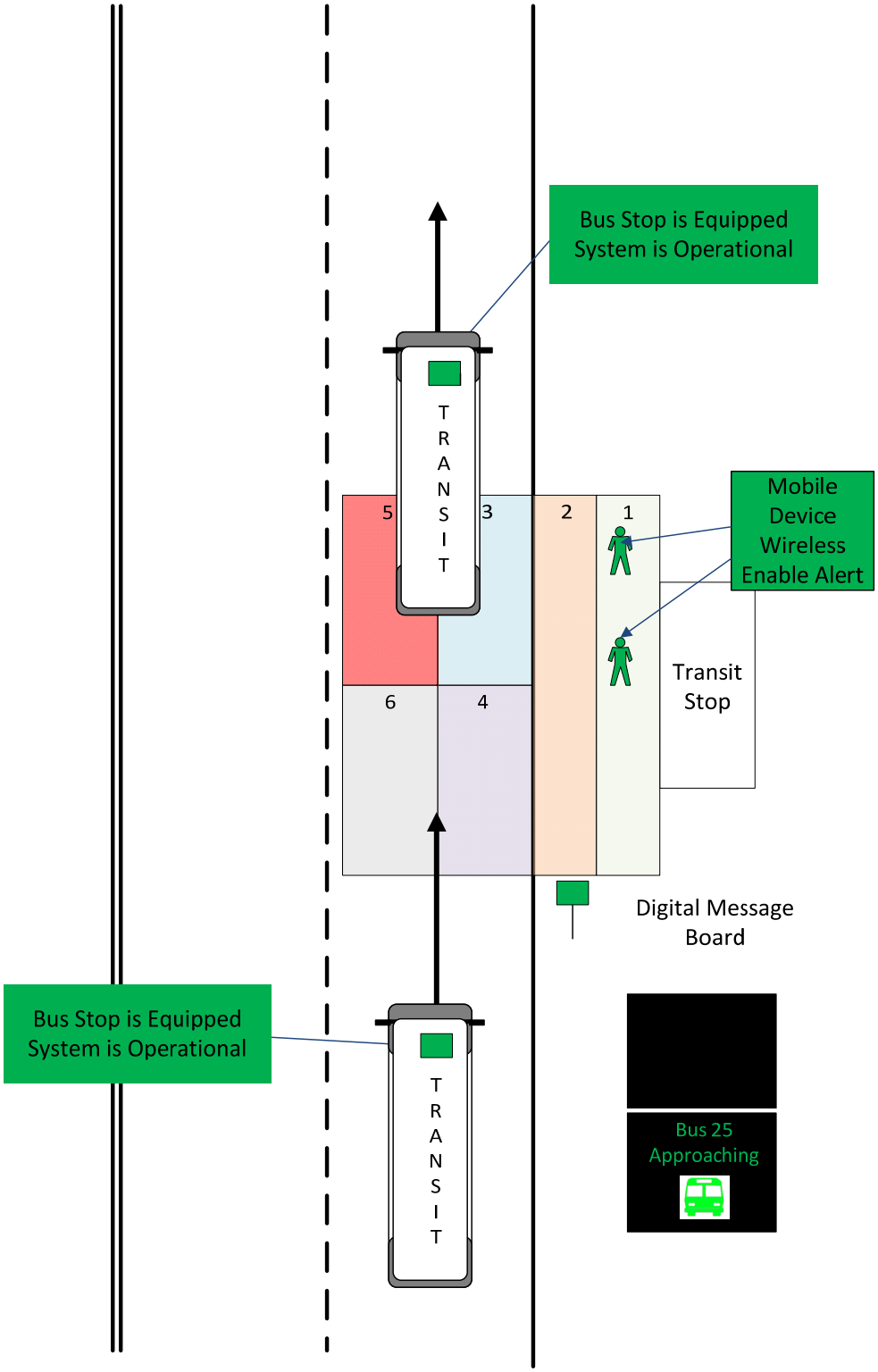


Source: Battelle

Figure 6-72. Scenario 72 – Transit vehicle is departing and has cleared all roadway zones with a pedestrian in the rear center roadway zone and there is an oncoming vehicle passing the transit vehicle

Scenario 73 – First transit vehicle is departing but still in forward roadway zones with the second transit vehicle approaching the transit stop and multiple riders are waiting in the safe zone

- The first transit vehicle is departing the transit stop but is still in the forward roadway zones.
- The TSPW application indicates to the first transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The second transit vehicle is approaching the transit stop but has not entered any of the roadway zones.
- The TSPW application indicates to the second transit vehicle operator that the transit stop is an equipped transit stop and is operational with a Green visual enabled alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Green message.
- The waiting riders inside the safe zone receive a Green enabled alert via a mobile device that indicates that the second transit vehicle is approaching.

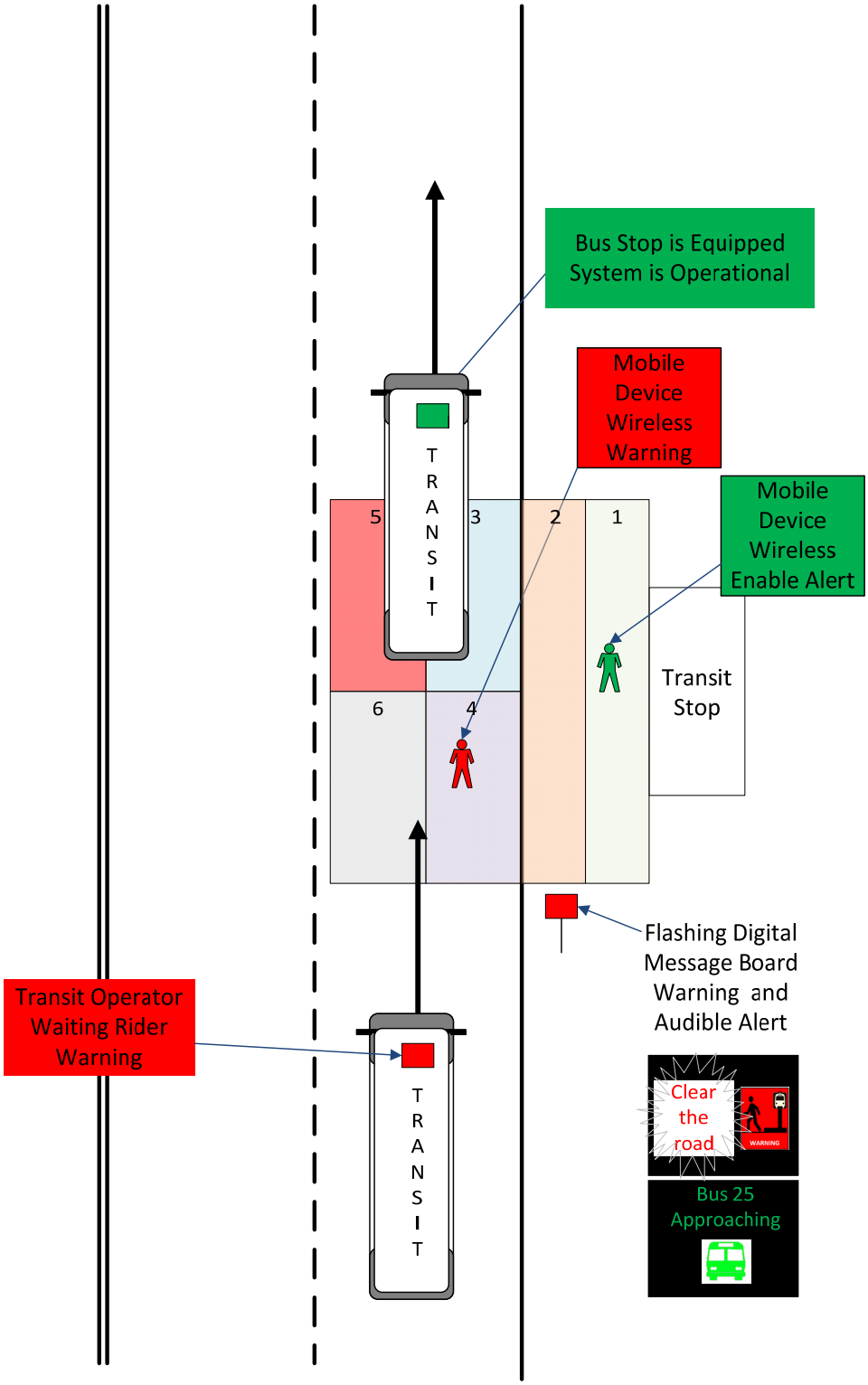


Source: Battelle

Figure 6-73. Scenario 73 – First transit vehicle is departing but still in forward roadway zone with the second transit vehicle approaching the transit stop and multiple riders are waiting in the safe zone

Scenario 74 – First transit vehicle is departing but still in forward roadway zones with the second transit vehicle approaching the transit stop and one rider is waiting in the safe zone while a pedestrian is in the rear curbside roadway zone

- The first transit vehicle is departing the transit stop but is still in the forward roadway zone.
- The TSPW application indicates to the first transit vehicle operator that the transit stop is an equipped transit stop and is operational with a visual enabled alert Green.
- The TSPW application indicates to the second transit vehicle operator that there is a pedestrian in the rear roadway zone with a Red audible and visual warning alert.
- The infrastructure based pedestrian warning device indicates that the transit vehicle is approaching using a Red message that flashes and emits an audible tone.
- The pedestrian in the rear roadway zone receives a Red warning alert via a mobile device that indicates that the second transit vehicle is approaching.
- The waiting rider inside the safe zone receives a Green enabled alert that indicates that the second transit vehicle is approaching.



Source: Battelle

Figure 6-74. Scenario 74 – First transit vehicle is departing but still in forward roadway zone with the second transit vehicle approaching the transit stop and one rider is waiting in the safe zone while a pedestrian is in the rear roadway zone

Chapter 7 Summary of Impacts

Implementation of the TSPW system into GCRTA operations will be the first of a fully operational connected vehicle system of this type in a revenue service environment. The subsections below identify potential operational impacts, organization impacts, and impacts during the development, as well as methods for measuring these impacts.

Operational Impacts

This section describes the impacts that TSPW will have on entities that operate and maintain the system, as well as the end-user impact as these technologies and applications are deployed in operational setting. Operational impacts of the TSPW project will include capabilities that are beneficial to users, developers, operations and maintenance personnel. The most significant operational impact of the TSPW application will be the integration of improved transit safety applications that provide both quantitative and qualitative benefits to the transportation system and transit agency. Expected benefits include:

- Reduction in number of transit vehicle accidents with pedestrians at transit stops.
- Reduction in number of transit vehicle accidents with other vehicles
- Data collection from TSPW-equipped transit vehicles will help in refining and improving the safety application and technologies for use in an operational setting.

The primary impacts to drivers and personnel are in the training and maintenance of the hardware components and applications as well as interactions with the equipment during operations. The hardware will include the pedestrian detectors and other RSE, in-vehicle displays, DSRC radios, GPS receivers, on board storage, etc. that will need to be maintained. Expected operational impacts include:

- 80-100 Transit Vehicles updated with connected vehicle technology (i.e., the E-TRP and TSPW hardware and software components).
- four transit stops retrofitted for pedestrian detection and alerting
- Training of operators and maintenance staff to operate the TSPW application
- Training of operators and maintenance staff to maintain the TSPW application.

Organizational Impacts

This section addressed the impacts the enhanced system will have on operators of the TSPW application. The organizational impacts will affect primarily the transit vehicle operators and the maintenance staff. Training will include both classroom and hands-on training on each subsystem as well as operations and maintenance training. Classroom training will provide the drivers and maintenance staff with the concept of operations, relationships, features, and an introduction to the hardware and software interfaces. The hands-on training will prepare this group to work with hardware components and software applications to practice basic operator and maintainer tasks.

Because TSPW will be installed on large number transit vehicles, staff will likely be tasked with additional duties to maintain the system. While their workload is likely to increase during the early stages of learning, this is expected to level off and decrease as staff become more familiar with the system and process.
If work load on operators and maintenance staff increases to a point where the cost to adopt the system outweighs the benefit, other approaches will need to be explored, including modifications to the operator interface, additional hands-on training, and/or hiring additional staff.

Impacts During Development

This section addresses the impacts that TSPW will experience while the system is being developed. During the development phases, there will likely be a need for continuous coordination and planning with the agency, operators, and maintenance staff. The activities may include site visits to inspect bus stop locations, scheduling of equipment installation, coordination of testing activities, and collection of evaluation data. Additional impacts may include the following:

- Involvement in studies, meetings, and discussions prior to design and implementation
- Involvement in reviews and demonstrations, evaluation of revised operating capabilities, development or modification of safety applications, and required training
- Involvement in TSPW bench and field interoperability testing
- Impact of new interfaces for the transit vehicle driver
- Project schedule delays due to one or more of the following:
    - Delay in identifying the specific message protocols and/or content to be used at TSPW transit stops
    - Delay in installation of roadside infrastructure or vehicle-based equipment necessary to support the components of the TSPW application.
    - Delay in identifying Independent Evaluator's specific data needs
    - Delays associated with coordinating operational trainings and maintenance support.

If successful, the TSPW application will provide benefits for improving safety in reducing transit and pedestrian incidents at transit stops. However, one potential impact of the system is that transit vehicle operators will be exposed to additional information while operating their transit vehicle, which does increase their cognitive workload. This additional information has the potential to negatively impact performance if they are perceived as "nuisance," "false," or distracting alerts by the operators.

Chapter 8 Analysis of the Proposed System

Summary of Improvements

Most directly, the TSPW application will provide transit vehicle operators with better situational awareness related to pedestrians at transit stops and in the roadways near transit stops. This improved situational awareness will enable the transit vehicle operator to have better decision making and will ultimately reduce the number of such incidents encountered by transit vehicle operators. Additionally, by implementing both infrastructure-based and mobile alerts, pedestrians can become much more aware of their situation as it pertains to potential conflict with incoming and departing transit vehicles at bus stops.

Disadvantages and Limitations

The TSPW application is being deployed on a target number of 80-100 transit vehicles and four transit bus stops. The DSRC-equipped approaching remote vehicles, in the scenarios related to an approaching DSRC-equipped connected vehicle, will only be operated on a small number of vehicles (1-3) and in a controlled environment for the purposes of this project. The main disadvantage is that the amount of transit stops outfitted is somewhat limited. This limited set of data may not provide adequate substantiation for the benefits of the new safety applications. Additionally, as this is a first-of-its-kind demonstration project, the applications and various systems may not operate exactly as designed/planned and therefore may not be able to fully illustrated all of the expected benefits.

The technologies included in the study also have limitations inherent to them. While processing speed has greatly increased in recent years, there will still be inherent latencies from when a pedestrian or vehicle of interest is identified to when the alert is presented to the transit vehicle operator, remote vehicle operator, and pedestrian's mobile device. It remains to be seen whether these latencies are such that they prevent a meaningful real-time notification to the transit vehicle operator, remote vehicle operator, and pedestrian. Additionally, the TSPW application is highly dependent upon the ability of the pedestrian detector to successfully identify when a pedestrian is present in one of the four designated zones near a transit stop, while at the same time reducing false positives and false negatives. Studies evaluating pedestrian detection are ongoing as this technology is still relatively innovative and not as mature as other technologies being employed.

Alternatives and Trade-offs Considered

Throughout the development of the ConOps, a number of alternatives and trade-offs have been considered that will affect the definition of the TSPW application. In particular, the increase in the popularity and the introduction of on-board vehicle detection systems for pedestrians is appealing and may have merit. At the same time, the benefits of infrastructure-based systems are also significant in that they can reduce processing power because they can be specifically and individually calibrated and established for a fixed location. Regardless, on-board camera detection systems may ultimately present a viable alternative for the transit

vehicle operator. Included in this project will be the capture of video from the transit vehicle that may provide the ability for a comparison of the connected vehicle technologies versus on-board sensor systems.

Other trade-offs and alternatives include the use of different communication protocols, particularly cellular and/or Bluetooth instead of connected vehicle technologies to communicate the status of pedestrians in one of the four transit stop zones. Certainly, detecting and communicating pedestrian status at a transit stop may be viable using one or more of these alternative communication protocols. However, DSRC remains the key selection because it offers the additional benefit of providing the forward capability to the transit agenc(ies) that do require low latent communications (e.g., Forward Collision Warning, Curve Speed Warning, etc.) and because of a potential National Highway Traffic Safety Administration heavy vehicle rulemaking. Although these applications are not included in this project, the equipment and particularly the DSRC radios can easily be adapted to enable these applications when the penetration rate of CV vehicles makes it beneficial to do so.

APPENDIX A. List of Acronyms and Abbreviations

CAN	Controller-Area Network
ConOps	Concept of Operations
CPU	Central Processing Unit
CCP	Common Computing Platform
CMS	Cloud-based Management System
COTS	Commercial-Off-The-Shelf
DAS	Data Acquisition System
DSRC	Dedicated Short-Range Communication
E-TRP	Enhanced Transit Safety Retrofit Package
FHWA	Federal Highway Administration
FT	Field Test
FTA	Federal Transit Administration
GCRTA	Greater Cleveland Regional Transit Authority
GID	Geometric Intersection Description
GPS	Global Positioning System
GUI	Graphical User Interface
HIS	Human Interface System
IEEE	Institute of Electrical and Electronics Engineers
IPS	Integration of Proximity Sensors
ISTEA	Intermodal Surface Transportation Efficiency Act
ITS	Intelligent Transportation System
IVBSS	Integrated Vehicle Based Safety Systems Initiative
IVI	Intelligent Vehicle Initiative
LED	Light-emitting Diode
MAC	Medium Access Control
mPCIe	mini PCI express
NHTSA	National Highway Traffic Safety Administration
OBE	On-Board Equipment
OEM	Original Equipment Manufacturer
OS	Operating System
PDS	Pedestrian Detection System
PHY	Physical Layer
RCI	Rear Camera Integration to Driver Display
RSU	Roadside Unit
SAE	Society of Automotive Engineers
SODS	Side Object Detection Systems
TEA-21	Transportation Equity Act for the 21st Century
TRP	Transit Safety Retrofit Package
U.S. DOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
WAVE	Wireless Access in Vehicular Environments

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