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

Transit Bus Stop Pedestrian Safety Application: Operational Concept

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16. Abstract

This document serves as an Operational Concept for the Transit Bus Stop Pedestrian Safety application. The purpose of this document is to communicate user needs and desired capabilities for and expectations of the Transit Bus Stop Pedestrian Safety application. This document also serves to build consensus among transit user groups and stakeholders concerning these needs and expectations.

The Transit Bus Stop Pedestrian Safety application will alert nearby pedestrians indicating the transit vehicle's intention of pulling into or out of a bus stop. The application allows messages to be sent from transit vehicles to instrumented transit stops that in turn provide audible or visual alerts to pedestrians in the vicinity of a bus stop. This Operational Concept describes how the application applies to motor buses; however the application is also applicable to other transit types such as light rail. Four scenarios are described, including:

- Scenario 1. Motor Bus Approaching the Transit Bus Stop
- Scenario 2. Motor Bus Departing from the Transit Bus Stop
- Scenario 3. Warning to Pedestrians of Oncoming Vehicles when Alighting the Motor Bus at the Transit Bus Stop

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

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1 Introduction

This document serves as an Operational Concept for the Transit Bus Stop Pedestrian Safety application. The purpose of this document is to provide an operational description of "how" the Transit Bus Stop Pedestrian Safety application will operate.

The Transit Bus Stop Pedestrian Safety application will alert nearby pedestrians, indicating the transit vehicle's intention of pulling into or out of a transit bus stop. The application allows messages to be sent from transit vehicles to instrumented transit stops/stations that in turn provide audible or visual alerts to pedestrians in the vicinity of a transit bus stop. The Operational Concept discusses the following scenarios:

- **Scenario 1.** This scenario describes warning pedestrians when a motor bus approaches a transit bus stop. Infrastructure is used to notify pedestrians at the bus stop that a motor bus is arriving so they do not put themselves in a dangerous situation (e.g., step into the street in front of the motor bus). As an option, the application may be supplemented with a pedestrian detector(s) located at the bus stop that detects the presence of a pedestrian in the roadway or too close to the curb who is in danger of being hit by a motor bus approaching the bus stop, and may warn the driver via the Driver-Vehicle Interface (DVI) of a potential collision between the pedestrian and motor bus. The application may be integrated with a bus stop traveler information system using the same wayside infrastructure (e.g., dynamic message sign) where pedestrians are informed of basic information about the bus, such as the route number and final destination, estimated arrival time, and accessibility information, such as whether it is a high or low-floor vehicle and if wheelchair seating is available.
- **Scenario 2.** This scenario describes warning pedestrians when a motor bus departs from the transit bus stop. Infrastructure warns pedestrians located at the bus stop that the motor bus is departing. As an option, the application may be supplemented with a pedestrian detector(s) located at the transit bus stop that detects the presence of a pedestrian in the roadway (e.g., a pedestrian attempting to gain the attention of a bus driver of a bus that is about to or has just departed the bus stop) or too close to the curb who is in danger of being hit by a motor bus leaving the bus stop, and may warn the driver via the Driver-Vehicle Interface (DVI) of a potential collision between the pedestrian and motor bus.
- **Scenario 3.** This scenario describes warning alighting bus passengers of a potential collision with oncoming motor vehicles in the vicinity of the bus stop. Infrastructure located at the transit bus stop alerts passengers of approaching vehicles after receiving wireless messages sent from motor vehicles to the roadside infrastructure. In this scenario, passengers getting off the bus that walk in front of the bus may not see motorists traveling in lanes to the left of the bus due to limited line of sight. As an option, this scenario may be supplemented with a pedestrian detector(s) located at the bus stop that detects the presence of a pedestrian in the roadway, and may warn the bus driver and drivers of other motor vehicles in close proximity to the bus stop and/or crosswalk, via their respective DVIs, of a potential collision between the pedestrian and their vehicle.

This Operational Concept describes how the application applies to motor buses; however the application may be adapted to consider other transit modes, such as light rail.

1.1 Goals

The Transit Bus Stop Pedestrian Safety application is expected to meet the following goals:

- **Goal #1: Reduce Frequency and Severity of Transit Crashes near Transit Bus Stops.** This application is expected to reduce frequency and severity of transit crashes at bus stops through improved situational awareness of pedestrians that leverage connected vehicle technologies.
- **Goal #2: Promote Pedestrian Safety at or near Transit Bus Stops.** This application is expected to promote pedestrian safety by leveraging connected vehicle technologies to provide proper alert or warning pedestrians, transit motor bus drivers, and other motor vehicle drivers regarding heightened collision risk to at or near bus stops.

1.2 Connected Vehicle Research

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

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

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

1.3 The Transit V2I Safety Research Program

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

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

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

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

Objectives: Use V2I technology:

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

A successful Transit V2I Program will lead to the more rapid and cost-effective deployment of interoperable technologies and applications that improve transit safety and enhance mobility for transit vehicles. The Transit V2I Program will act to promote the highest levels of collaboration and cooperation in the research and development of V2I applications for connected vehicles. The Transit

V2I Program positions the federal government to take on an appropriate and influential role as a technology steward for a continually evolving integrated transportation system.

1.4 Document Overview

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

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

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

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

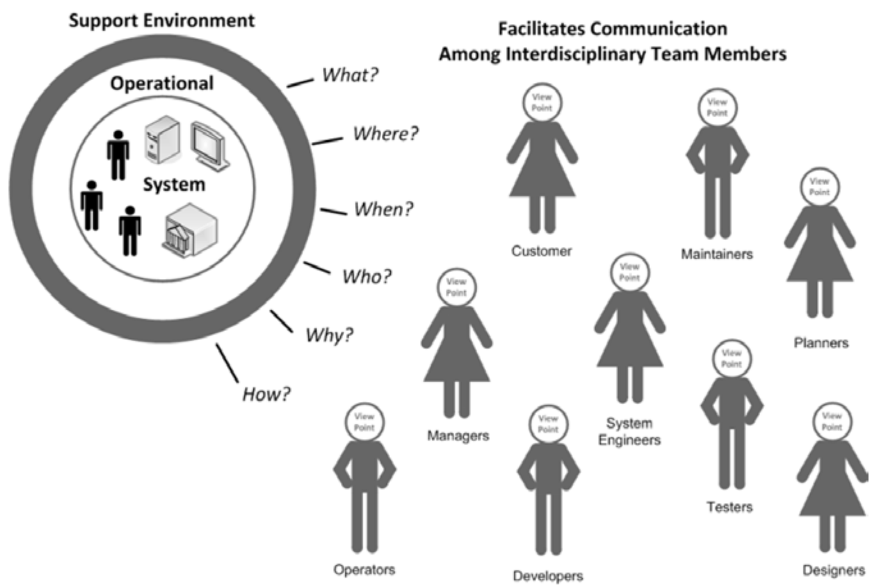

Figure 1-1: Conceptual Representation of the Operational Concept Document (*Source: Noblis, adapted from ANSI/AIAA's "Guide for the Preparation of Operational Concept Documents" ANSI/AIAA G-043-1992)*

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

This document includes the following chapters:

- **Chapter 1** provides the scope, introduction to the Transit V2I Program, and an overview of the document.
- **Chapter 2** includes an overview of transit collisions and the role of the Transit V2I Program to mitigate these collisions. Includes statistics of motor bus collisions, injuries, and fatalities from the 2010 National Transit Database (NTD). This chapter also includes an overview of near term Transit V2I applications being investigated by the USDOT.
- **Chapter 3** provides a description of the current situation and is intended to help stakeholders better understand the reasons the application is desired. Section 3.1 provides statics about motor bus collisions with pedestrians at transit bus stops and also described three situations where the Transit Bus Stop Pedestrian Safety application may help avoid collisions. Section 3.2 describes existing systems that have been implemented to improve safety at transit bus stops.
- **Chapter 4** describes the shortcomings of current systems, situations, or applications that motivate research and development of the prototype application. This chapter provides a transition from Chapter 3 of the Operational Concept, which describes the current situation, to Chapter 5, which describes the proposed prototype concept.

- **Chapter 5** describes the Transit Bus Stop Pedestrian Safety application from a systems engineering perspective. This chapter begins with a description of the system and is followed by an architecture diagram of the application and user needs or desired capabilities of the system.
- **Chapter 6** provides scenarios which help the readers of the document understand how the application may be implemented to provide safety benefits in the vicinity of transit bus stops. Scenarios are described in a manner that allows readers to walk through them and gain an understanding of how all the various parts of the application will function and interact.
- **Chapter 7** provides references used in the Operational Concept document.
- **Appendix A** provides a list of acronyms used in the report.

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

One of the main focuses of the USDOT's Connected Vehicle Research program is to use connected vehicle technology to improve safety. Connected vehicle safety applications are designed to increase situational awareness and reduce crashes through V2V and V2I data transmissions that support driver advisories and warnings. Transit vehicles are expected to leverage these applications to improve transit safety through reduction of the occurrence of crashes that result in injuries and fatalities to passengers, motorists, pedestrians and bicyclists, as well as damage to vehicles and property. Transit crashes are responsible for hundreds of deaths, thousands of injuries and millions of dollars in property damage each year.

2.1 Transit Collisions Summary

In January 2013, the Transit V2I Program completed a report entitled *Analysis of Collisions Involving Transit Vehicles and Applicability of Connected Vehicle Solutions*. The report included a thorough analysis of transit collision characteristics. The report assisted the Transit V2I Program in determining whether and the extent to which connected vehicles can effectively reduce the number and severity of collisions that involve transit vehicles. The study analyzed transit collision datasets from the National Transit Database (NTD) which is the Federal Transit Administration's (FTA's) primary national database for statistics related to the transit industry. NTD data is used extensively by the transit community to derive values for transit performance measures and have become the sole source of standardized and comprehensive data for use by all constituencies of the transit industry.

Table 2-1, Table 2-2, and Table 2-3 depict transit collisions, injuries, and fatalities reported to the NTD by mode from 2005 to 2010. It should be noted that the total number of collisions reported per year to the NTD between 2005 and 2007 were significantly higher than the total number of collisions reported per year between 2008 and 2010. These differences were the result of new criteria or rules for reporting data to the NTD that were made in 2008. As shown in the tables, motor buses account for the highest number of collisions and injuries in the United States. The large number of motor bus collisions can be attributed to the fact that motor buses travel more miles per year than any other mode and thus have more opportunities to be in a collision than other modes. Additionally, there are more motor buses in the United States than vehicles from other modes. As shown in Table 2-3, motor buses have the highest numbers of fatalities per mode between 2005 and 2007. Between 2008 and 2010, motor buses were the second highest transit mode for fatalities behind heavy rail. However it should be noted that there is a significant increase in heavy rail fatalities after 2007. A reason for the difference may be the results of changes in 2008 and forward where suicides are included in the data. Prior to 2008, suicides were not included. Between 2008 and 2010, motor buses were involved in an annual average of 3,172 collisions resulting in an average of 14,743 injuries and 80 fatalities.

Table 2-1: NTD Transit Collisions Reported from 2005 to 2010

Mode	2005	2006	2007	2008	2009	2010
Demand Responsive	1,618	1,934	1,382	672	571	549
Heavy Rail	65	102	112	62	81	116
Light Rail	73	586	577	162	169	177
Motor Bus	6,327	8,341	7,932	3,161	3,132	3,224
Other	34	88	192	35	58	42
Total	**8,117**	**11,051**	**10,094**	**4,092**	**4,011**	**4,108**

Table 2-2: NTD Transit-Related Injuries Reported from 2005 to 2010

Mode	2005	2006	2007	2008	2009	2010
Demand Responsive	1,180	1,607	1,768	1,979	1,896	1,651
Heavy Rail	3,766	4,728	4,980	7,248	7,536	7,518
Light Rail	614	656	843	1,006	1,054	914
Motor Bus	12,266	12,704	13,981	14,179	15,249	14,803
Other	173	274	303	205	525	337
Total	**17,999**	**19,969**	**21,875**	**24,617**	**26,260**	**25,223**

Table 2-3: NTD Transit-Related Fatalities Reported from 2005 to 2010

Mode	2005	2006	2007	2008	2009	2010
Demand Responsive	12	12	11	7	7	10
Heavy Rail	35	23	32	67	100	96
Light Rail	19	17	33	16	34	24
Motor Bus	75	107	104	80	78	84
Other	3	3	5	2	7	7
Total	**144**	**162**	**185**	**172**	**226**	**221**

Table 2-4 breaks down 2010 NTD collisions by the object hit. Objects defined by the NTD include: motor vehicles, persons, fixed objects, rail vehicles, and other. As shown in this table, in 2010 motor buses had 2,684 (83.2%) of collisions with motor vehicles, 451 (13.9%) with a person, 80 (2.4%) with a fixed object, and 10 (2.4%) with 'other'.

Table 2-5 depicts a further breakdown of motor bus injuries and fatalities in 2010. As shown in the table, 70.6% of motor bus injuries were with passengers, 4.0% with revenue facility occupants, 7.3% with employees of the transit agency, 0.7% with bicyclists, 1.9% with pedestrians, and 11.3% with the other vehicle occupant. The highest number of fatalities occurred when the motor bus collided with pedestrians and the other vehicle occupant (both with 27 fatalities in 2010). Ten bicyclists and ten revenue facility occupants were killed in 2010 as the result of motor vehicle collisions.

Table 2-4: 2010 NTD Collision Data by Object Hit

Mode	With Motor Vehicle	With Person	With Fixed Object	With Rail Vehicle	With Other	Total
Demand Responsive	475	44	29	0	2	**549**
Heavy Rail	1	108	3	2	2	**116**
Light Rail	104	65	3	4	1	**177**
Motor Bus	2,684	451	80	0	10	**3,224**
Other	29	8	2	1	1	**41**
Total	**3,293**	**676**	**117**	**7**	**16**	**4,108**

Table 2-5: 2010 NTD Motor Bus Injuries and Fatalities

Type	Passenger	Rev Facility Occupant	Employee	Bicyclist	Pedestrian	Other Vehicle Occupant	Other	Total
Injuries	10,456	594	1,088	97	283	1,674	609	**14,803**
Fatalities	3	10	1	10	27	27	6	**84**

2.2 Transit V2I Program Near Term Applications

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

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

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

- **Left-Turn Assist (Left-turn Head-on Crashes at Intersections with Permissive Left-turn Phase.** The Left Turn Assist (LTA) application provides information to drivers performing unprotected left turns to judge the gaps in oncoming traffic and to warn them when it is unsafe to perform a left turn on a permissive green light. While this application may be supported using V2V communications where vehicles exchange information about their location, speed, trajectories, and other vehicles at the intersection, it may also leverage V2I communications such as SPaT, intersection map data, and infrastructure based vehicle and pedestrian detectors. The purpose of the application is to provide information to support the driver's decision making process regarding when it is unsafe to make a left turn at an intersection (i.e., gap rejection), but not make the decision for the driver. In other words, the LTA application does not tell the driver when it is safe to proceed, but assists with rejecting gaps that are unsafe.
- **Stop Sign Gap Assist.** The Stop Sign Gap Assist (SSGA) application provides the vehicle operator with timely, relevant information regarding unsafe conditions at a stop-controlled intersection. The SSGA safety application is intended to improve safety at two-way stop controlled intersections where only the minor road has posted stop signs. This application includes both onboard (for equipped vehicles) and roadside signage warning systems (for non-equipped vehicles). The purpose of the application is to provide information to support the driver's decision making process regarding when it is unsafe to proceed through the intersection (i.e., gap rejection), but not make the decision for the driver. In other words, the

SSGA application does not tell the driver when it is safe to proceed, but assists with rejecting gaps that are unsafe.

- **Spot Weather Information Warning.** The Spot Weather Information Warning (SWIW) application is intended to improve safety in areas subject to repeated and localized adverse or inclement weather events, which may include relatively high-elevation or low-elevation areas that are more prone to reduced visibility, adverse surface conditions due to rain, snow, ice, and/or flooding, and high winds. This will be achieved through the integration of both vehicle-based and infrastructure-based technologies as well as backhaul networks to weather and TMCs, including onboard and roadside signage warning systems, to make drivers approaching an area with adverse weather conditions aware of the need to reduce speed or divert to safely navigate through or avoid the adverse weather impact area. This is not an application that is intended to provide the driver with weather information at every geographic location, but rather provide real time weather information at areas that are prone to adverse weather events, such as low-lying flood zones and bridges with high winds which may impose restrictions on high-profile vehicles. In this way, the SWIW application will help to increase driver awareness of the severity of hazardous weather conditions, reducing the risk potential for conflicts and crashes.
- **Transit Bus-Pedestrian/Cyclist Crossing Warning.** This application provides alerts to transit bus drivers of a pedestrian's or cyclist's presence while they are crossing the roadway at intersections and midblock crossings, using V2I wireless communications. When a pedestrian or cyclist is detected via the infrastructure, a RSU would send a message to nearby buses that a pedestrian or cyclist is in or may be entering the roadway. The application would provide alerts to bus drivers for all bus movements (left, right, and straight) at infrastructure-equipped signalized and non-signalized intersections and at midblock crossings when imminent conflicts with pedestrians and bicyclists are possible.
- **3D Intersection Mapping for Collision Avoidance and Situational Awareness.** This 3D Mapping application enables RSE to rapidly recognize/update intersection configurations in 3D (latitude, longitude and elevation), including fixed objects such as signal cabinets and light poles. This 3D intersection configuration information embedded in the RSE will support V2I safety applications to mitigate single vehicle crashes.
- **Transit Bus Stop Pedestrian Safety.** The application, using V2I wireless communications, would provide alerts to pedestrians, via infrastructure (e.g., electronic signage with audible warnings), at major bus stops (e.g., those equipped with bus shelters serving multiple bus routes) indicating a transit bus' intention of pulling into or out of a bus stop. In certain situations and locations, the application may also alert pedestrians of motor vehicles in the vicinity of the bus stop, specifically alerting passengers alighting buses at the stop to address potential collisions of pedestrians with motor vehicles, whose sight are blocked by the bus.
- **Reduced Speed Zone Warning.** The Reduced Speed Zone Warning (RSZW) safety application features the concept of reduced speed zone where a reduction in transit approaching speed is required and/or advised, such as entrance to work zones, school zones, and roadway configuration alteration (e.g., lane closures, lane shifts). This will be achieved through the integration of both vehicle-based and infrastructure-based technologies, including onboard and roadside signage warning systems.
- **Transit Vehicle and Center Data Exchange.** Modern transit buses are equipped to collect/process data on transit vehicles (such as engine health monitoring) as well as the surrounding environment such as external facing digital cameras. This Transit Vehicle and Center Data Exchange application allows the authorized entities (such as traffic management

centers, fire and emergency medical series (EMS), and transit dispatch centers) see what is happening at a location such as non-recurring congestion due to a crash or disabled vehicle by pinging an infrastructure point to request the next transit vehicle or vehicles passing the point to provide a snapshot of requested information, such as a short video. The bus could then capture a geo-referenced visual and upload at the next access point.

- **Traveler-Oriented Integrated Infrastructure Information.** The Traveler-Oriented Integrated Infrastructure Information application allows transit vehicles and travelers to be connected to nearby infrastructure, such as a smart intersection, smart bus stop, and smart parking. For example, transit vehicles would communicate with transit stops to provide travelers information on approaching vehicles, such as passenger loads, available disability seating, bicycle rack availability, fare information, etc. The application would support dynamic trip planning at transit stops.
- **Portable Infrastructure.** This transit V2I application features the concept of portable infrastructures such as portable RSEs and signage which may be used to handle special events (i.e., surging demand) at strategic locations, such as bus depots and light rail platforms to perform dynamic information collection/dissemination such as added buses or routes or assist transit vehicle maneuvers and detours.

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

3 Description of the Current Situation

This chapter provides a description of the current situation and is intended to help stakeholders better understand the reasons the application is desired. Included are statics about motor bus collisions with pedestrians at bus stops and situations where the Transit Bus Stop Pedestrian Safety application may help avoid collisions. This chapter also describes existing technologies and systems that have been (or could be) implemented to improve pedestrian safety at bus stops.

3.1 Motor Bus/Pedestrian Collisions at Transit Stops/Stations

According to the NTD, in 2010 there were 449 motor bus collisions with pedestrians accounting for 14% of all motor bus collisions. While this percentage is relatively low, these collisions often result in a large percentage of injuries or fatalities. Data show that there were 283 pedestrian injuries and 27 fatalities in 2010. Table 3-1 provides a summary of motor bus collisions with pedestrians. Of the 449 collisions, 51.6% of these collisions occurred at intersections, 25.9% at mid-block, and 22.1% when the motor bus was at a transit stop/station. As many transit stops/stations are located close to intersections, it is presumed that “intersection” collisions include only those within the boundaries of the intersection. There were slightly more collisions when the motor bus was leaving a bus stop, 58 collisions, versus when the motor bus was making a stop, 42 collisions.

Table 3-1: Motor Bus Collision with Pedestrians *(Source 2010 NTD)*

Description	Number of Collisions	% Pedestrian Collisions
Intersection: Motor Bus Going Straight	130	28.9%
Intersection: Motor Bus Turning Left	73	16.2%
Intersection: Motor Bus Turning Right	29	6.5%
Mid-Block: Motor Bus Going Straight	117	25.9%
Transit Stop/Station: Leaving the Stop/Station	58	12.8%
Transit Stop/Station: Stopping at the Stop/Station	42	9.3%
Total	**449**	**100%**

While each collision at a transit stop/station is unique, there are three situations that the Transit V2I Program wants to investigate further. These situations are described in the following sections and figures below.

3.1.1 Situation #1: Motor Bus/Pedestrian Collisions as the Motor Bus Approaches the Transit Bus Stop

As a motor bus approaches a transit bus stop, a pedestrian is standing too close to the roadway, is standing in the roadway, or steps in front of the motor bus. This situation is depicted in Figure 3-1 where the driver of the motor bus may not see the pedestrian or if the driver sees the pedestrians the driver may not have enough time to stop the vehicle before colliding. Alternatively, the pedestrian may not see the bus as they are inadvertently standing in the roadway. Pedestrians, even when crossing directly in front of the bus, may be obscured from the view of the driver who must also be attuned to approaching traffic as well as to boarding passengers. Tragically, a pedestrian who has strayed too near the bus, his or her attention directed elsewhere, may be unaware of the danger engendered by the approach of the bus until it is too late for either the driver or the pedestrian to avoid a serious accident. According to the NTD, in 2010 this type of collision represented 9.3% of all motor bus collisions with pedestrians. These collisions may be avoided by alerting the pedestrian that a motor bus is approaching the bus stop.

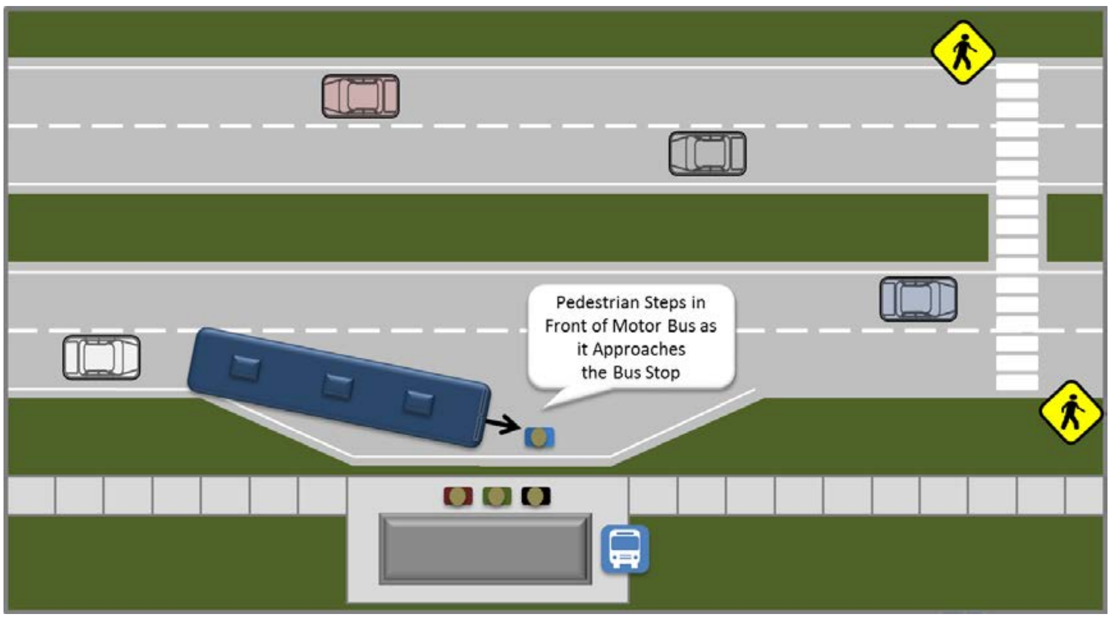

Figure 3-1: Situation #1 – Motor Bus/Pedestrian Collisions as the Motor Bus Approaches the Transit Bus Stop (Source: USDOT, 2014)

Each motor bus crash with a pedestrian that occurs when the bus is making a stop is unique. Table 3-2 includes descriptions of motor bus crashes with pedestrians when the motor bus was making a stop at a bus stop. These real-world descriptions help readers of this document better understand the situation described above. Specific examples of interest are highlighted in blue.

Table 3-2: Descriptions of Motor Bus Crashes with Pedestrians when the Bus is Making a Stop (*Source: 2010 NTD)*

No.	Description
1	"TRANSIT BUS MADE CONTACT WITH A WHEELCHAIR PEDESTRIAN..."
2	"TRANSIT BUS WAS PULLING INTO A COACH STOP WHEN THE DRIVER HEARD A LOUD THUMP ON THE LEFT HAND SIDE OF THE COACH; WHICH WAS A BICYCLIST."
3	"A MAN WAS SITTING BEHIND A BUSH, CONSUMING ALCOHOL AND WAITNG FOR THE BUS. AS THE BUS PASSED, THE MAN GOT UP AND WAS ATTEMPTING TO RUN TO THE BUS STOP BUT HE STUMBLED AND FELL INTO THE ROAD WHERE THE RIGHT REAR TIRES OF THE BUS ROLLED OVER BOTH OF HIS LEGS."
4	"ON MARCH 23, 2010, BUS #2009 TRAVELING NB AT THE INTERSECTION OF PULASKI RD. /LAKE ST., WHILE ENTERING THE BUS STOP, WITH ITS RIGHT FRONT MIRROR STRUCK A PERSON WHO WAS HEADING WB TO BOARD THE BUS. THE PERSON WAS TAKEN TO THE HOSPITAL."
5	"ON APRIL 5, 2010, BUS #6407 TRAVELING NB AT 3465 S. INDIANA AV., WHILE ENTERING THE BUS STOP, WITH ITS RIGHT HORIZONTAL MIDSECTION, COLLIDED WITH A PEDESTRIAN WHO STEPPED OFF OF THE CURB HEADING WB. THE PEDESTRIAN WAS TRANSPORTED TO THE HOSPITAL."
6	"ON MAY 20, 2010, BUS #1050 MOVING WB AT THE MADISON ST./SPRINGFIELD AV. INTERSECTION, WHILE PULLING INTO THE BUS STOP, WITH ITS RIGHT SIDE, KNOCKED AN EB RIDING BICYCLIST WHO WAS TRAVELING IN THE WB LANE ONTO THE HOOD OF A PARKED AUTO. THE BICYCLIST WAS TAKEN TO THE HOSPITAL."
7	"ON JUNE 14, 2010, BUS #1841 TRAVELING SB AT THE INTERSECTION OF MICHIGAN AV. /103RD ST., WHILE ENTERING THE BUS STOP, STRUCK, WITH ITS RIGHT MIRROR, AN INTENDING BUS PASSENGER WHO WAS STANDING IN THE BUS STOP. THE PERSON WAS TRANSPORTED TO THE HOSPITAL."
8	"ON AUGUST 18, 2010, BUS #1742 MOVING SB AT THE WESTERN AV. /69TH ST. INTERSECTION, WHILE ENTERING THE BUS STOP, WITH ITS RIGHT FRONT MIRROR, STRUCK A SB WALKING PEDESTRIAN. THE PEDESTRIAN WAS CARRIED TO THE HOSPITAL."
9	"ON DECEMBER 1, 2010, BUS #6769 MOVING NB AT THE MILWAUKEE AV./DEVON AV. INTERSECTION, WHILE ENTERING THE ON-STREET BUS TERMINAL, WAS STRUCK ON ITS FRONT LEFT SIDE BY AN EB RIDING BICYCLIST. THE BICYCLIST WAS TAKEN TO THE HOSPITAL."
10	"ON DECEMBER 6, 2010, BUS #505 TRAVELING EB NEAR THE INTERSECTION OF 60TH ST./UNIVERSITY AV., AFTER GOING OUT-OF-CONTROL DUE TO ICY ROAD CONDITIONS WHILE ENTERING THE BUS STOP AND BRAKING TO AVOID A COLLISION, WITH ITS FRONT END, STRUCK A PEDESTRIAN WHO WAS SPREADING SALT. THE BUS CONTINUED AND STRUCK THE PEDESTRIAN'S SALT TRUCK WHILE PINNING THE PEDESTRIAN BETWEEN THE REAR END OF THE TRUCK AND THE FRONT BUMPER OF THE BUS. THE BUS OPERATOR AND THE PEDESTRIAN WENT TO THE HOSPITAL."
11	"DRIVER WAS AT STOP DROPPING PAX OFF BUS, CLOSE DOORS TOOK FOOT OFF BRAKE AND BUS STARTED NOTICE PERSON TAKING OFF RACK STOP FAST NUDGE PERSON SCRAPE ON ARM."
12	"A MAINTENANCE WORKER WAS MOWING A LAWN ENDED UP FALLING INTO THE SIDE OF THE BUS."
13	"PEDESTRIAN CLAIMED THE BUS HIT HIM AS IT WAS STOPPING."
14	"OPERATOR WAS CHANGING LANES TO MOVE OVER AND PICK UP PEDESTRIAN - PEDESTRIAN WAS A FOOT FROM THE CURB - BUS HIT PEDESTRIAN."
15	"A PEDESTRIAN WAS ON THE SIDEWALK NEAR THE COACH STOP WITH HIS BACK TO THE STREET. AS THE COACH APPROACHED THE STOP HE HONKED HIS HORN TO GET THE ATTENTION OF THE PEDESTRIAN. WHEN HE HONKED HIS HORN THE PEDESTRIAN STEPPED BACK INTO THE STREET AND WAS STRUCK BY THE COACH."
16	"THE RIGHT REAR TIRE OF THE COACH, WHILE ENTERING THE ZONE, RAN OVER THE FOOT OF A PEDESTRIAN STANDING NEAR THE CURB. SPD AND SFD RESPONDED TO THE SCENE AND THE PEDESTRIAN WAS TRANSPORTED TO HMC."
17	"PEDESTRIAN STRUCK BY MIRROR."
18	"V-1 (BUS), NORTHBOUND AVALON BLVD, APPROACHING A BUS STOP, STRUCK A BLIND PEDESTRIAN, STANDING AT THE CURB, WITH THE CONVEX MIRROR OF THE BUS."

No.	Description
19	“V-1 (BUS), WAS WEST ON VANOWEN ST., APPROACHING BUS STOP WEST OF LAUREL CYN. BLVD. P-2, A PEDESTRIAN, WAS STANDING AT THE BUS STOP MOVING FORWARD AND BACKWARD(STAGGERING BACK AND FORTH) ON THE EDGE OF THE CURB AT THE BUS ZONE. AS THE BUS ENTERED THE BUS ZONE, THE PATRON LOST HIS BALANCE AND HIT HIS FACE APPROX. 4FT. BEHIND THE ENTRANCE DOOR OF THE BUS ON THE LEFT SIDE, RECEIVING FACIAL INJURIES.”
20	“V1(BUS)WAS APPROACHING THE FARSIDE BUS ZONE ON RODEO DR., WEST OF LA BREA STREET. AS V1 BEGAN PULLING INTO THE ZONE, A PEDESTRIAN, P1(EANY OSORIO), LEANED FORWARD FROM THE NORTH CURB OF RODEO DR. AND MADE CONTACT WITH THE RIGHT OUTSIDE MIRROR OF V1 AND THE LEFT SIDE OF HIS HEAD.”
21	“V-1 (BUS) WAS STANDING W/B FIRESTONE BLVD AT THE RAYO BUS ZONE WHEN P-2 (BICYCLIST), ALSO W/B ON FIRESTONE BLVD COLLIDED WITH THE REAR OF THE STANDING BUS.”
22	“THE BUS WAS APPROACHING THE BUS STOP AND THE MIRROR ON THE BUS HIT A LITTLE GIRL IN THE HEAD. THE OPERATOR WAS UNAWARE THAT THE MIRROR HAD STRUCK THE GIRL UNTIL HER SISTER SPOKE TO THE OPERATOR.”
23	“OPERATOR STATED PASSENGER INFORMED HER THAT HER FOOT WAS RUN OVER BY THE BUS.”
24	“BUS AT BUS STOP; OPERATOR ACTIVATED KNEELER IN ORDER TO BOARD A CUSTOMER; A SECOND INTENDING CUSTOMER STANDING BEHIND THE FIRST INTENDING CUSTOMER WAS STRUCK ON RIGHT LEG AS BUS LOWERED, CLAIMED INJURY TO FOOT AND WAS REMOVED BY EMS TO AREA HOSPITAL.”
25	“BUS MOVING INTO BUS STOP. INTENDING CUSTOMER STANDING AT CURB IN BUS STOP AREA IS STRUCK ON HEAD WITH R/F TRAFFIC MIRROR. CUSTOMER CLAIMED INJURY; MOVED TO HOSPITAL.”
26	“BUS MOVING INTO BUS STOP. MALE PED STEPPED OFF CURB MOVING RIGHT TO LEFT RIGHT OF BUS. PED STRUCK R/F OF BUS, CLAIMING INJURY TO ARM.”
27	“BUS MOVING INTO BUS STOP. PEDESTRIAN AGE, 31 CLAIMED R/F MIRROR OF BUS STRUCK HER ON THE HEAD AND CLAIMED INJURY TO THE SAME.”
28	“BUS MOVING INTO BUS STOP. PEDESTRIAN WALKED FROM RIGHT TO LEFT RIGHT OF BUS. PED IS STRUCK BY R/F CORNER OF BUS. PED FELL CLEAR OF BUS, AND CLAIMED UNJURY; MOVED TO HOSPITAL BY EMS.”
29	“AS BUS WAS PULLING INTO SERVICE STOP, PROSPECTIVE PASSENGER (STANDING ON STREET) HIT HIS HEAD ON RIGHT SIDE MIRROR OF THE BUS.”
30	“HIT THE BACK OF THE HEAD OF A PEDESTRIAN WITH MIRROR.”
31	“BUS WAS AT BUS STOP BOARDING PASSENGERS WHEN A BICYCLIST STRUCK THE BUS IN THE REAR.”
32	“AS BUS DRIVER WAS ATTEMPTING TO PULL CLOSER TO THE CURB A PASSENGER WENT TO TRY TO REMOVE THEIR BICYCLE FROM THE FRONT BICYCLE RACK. THE BUS MADE CONTACT WITH THE LEFT LEG OF THE PASSENGER. PASSENGER (BY REQUEST) WAS TRANSPORTED FROM THE SCENE.”
33	“COACH 8428 WAS TRAVELING INBOUND HEADING SOUTH ON PLYMOUTH AVE. AS THE COACH HAD ALMOST COMPLETED PULLING INTO THE BUS ZONE LOCATED ON PLYMOUTH IMMEDIATELY SOUTH OF OCEAN AVE, THE FRONT OF THE COACH ALLEGEDLY MADE CONTACT WITH A WOMAN WHO HAD BEEN STANDING AT THE BUS STOP. ACCORDING TO A WITNESS, THE WOMAN THEN RAN TOWARDS THE BUS, NO COACH/PEESTRIAN CONTACT OCCURRED, YET THE WOMAN HELD HER HEAD AND SAT HERSELF DOWN SLOWLY. SHE WAS TRANSPORTED TO KAISER HOSPITAL.”
34	“ACCORDING TO THE INFORMATION, THE BUS WAS PULLING INTO THE ZONE WHEN THE PEDESTRIAN STEPPED OFF THE CURB AND INTO THE BUS. PEDESTRIAN HAS SIGNS OF ALCOHOL USE/INTOXICATION.”
35	“THE BUS MADE CONTACT WITH BICYLIST IN BIKE LANE AS THE BUS WAS MAKING A STOP TO PICK UP A CUSTOMER.”
36	“BUS WAS STOPPED SOUTHBOUND ON 700 EAST 3300 SOUTH ALIGHTING PASSENGERS. A BICYCLIST HEADING SOUTHBOUND TRIED TO MANUEVER AROUND THE BUS ON THE RIGHT SIDE. THE BIKE MADE CONTACT WITH THE SIDE OF THE BUS AND THE RIDER WAS THROWN OFF ONTO THE CURB COMING TO REST AGAINST S SIGN POST.”
37	“AS A BUS PULLED UP TO A BUS STOP A FEMALE PEDESTRIAN WAS STRUCK BY ANOTHER PERSON DURING AN ALTERCATION. THE FEMALE FELL BACKWARDS AND UNDERNEATH THE REAR WHEELS OF THE BUS WHICH THEN RAN OVER HER TORSO.”

No.	Description
38	"METROBUS WAS TRAVELING SOUTHBOUND ON SOUTH BUCHANAN ST. IN THE CURB LANE AND WAS PULLING INTO THE BUS STOP. AS THE OPERATOR DID SO, A FEMALE CUSTOMER WAS STANDING AT THE STOP AND SUDDENLY BENT DOWN TO PICK UP SOME DROPPED CHANGE. AS SHE BENT DOWN, THE BUS' RIGHT FRONT CORNER BUMPER HIT THE CUSTOMER IN THE LEFT SIDE OF HER HEAD AND SHE FELL TO THE GROUND."

3.1.2 Situation #2: Motor Bus/Pedestrian Collisions as the Motor Bus Departs from the Bus Stop

Figure 3-2 depicts where a motor bus/pedestrian collision occurs when the motor bus departs from the transit bus stop. According to the NTD, in 2010, this type of collision represented 12.8% of all motor bus collisions with pedestrians. In this situation, the motor bus driver may not see a pedestrian as the vehicle starts to move away from the bus stop and merges back into the roadway. Alternatively, the pedestrian may be unaware the motor bus is about to move and is too close to the departing bus or inadvertently steps into the road in front of the bus. Similar to Situation #1 described in the previous section, pedestrians, even when crossing directly in front of the bus, may be obscured from the view of the driver who must also be attuned to approaching traffic as well as to boarding passengers. Tragically, a disembarked passenger who has strayed too near the bus, his or her attention directed elsewhere, may be unaware of the danger engendered by the departure of the bus until it is too late for either the driver or the passenger to avoid a serious accident. These collisions may be avoided by alerting the pedestrian that the motor bus is about to move. Descriptions from the 2010 NTD describing actions where motor buses collided with pedestrians when the bus was leaving the bus stop are included in Table 3-3. Selected collisions of interest have been highlighted in blue (those highlighted in orange apply to Situation #3, discussed in Section 3.1.3).

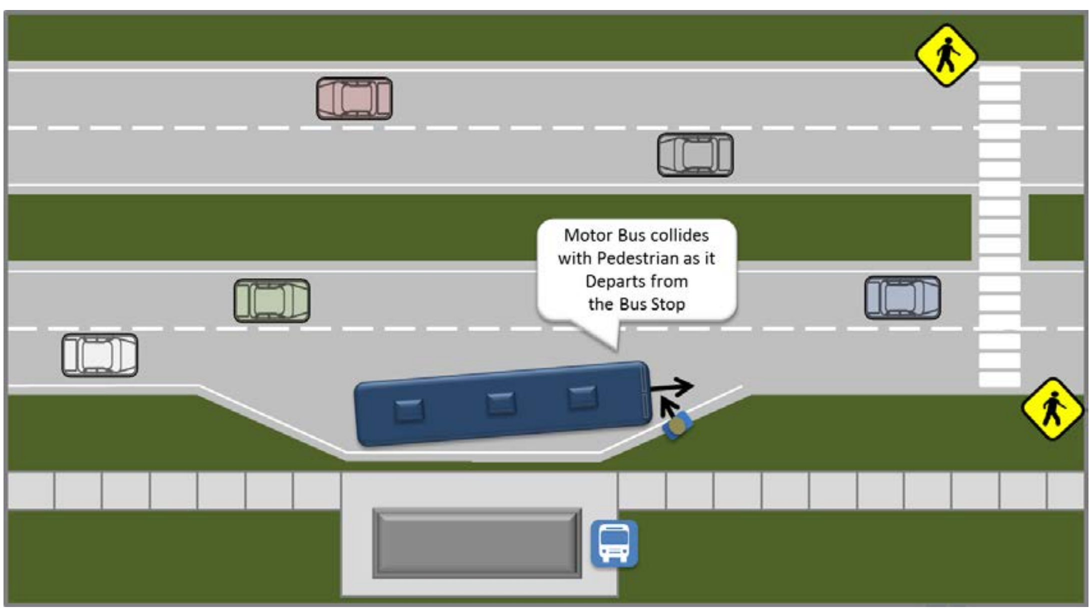

Figure 3-2: Situation #2 – Motor Bus/Pedestrian Collisions as the Motor Bus Departs from the Bus Stop *(Source: USDOT, 2014)*

Table 3-3: Descriptions of Motor Bus Crashes with Pedestrians when the Bus is Leaving a Bus Stop *(Source: 2010 NTD)*

No.	Description
1	"MALE RUNS INTO PATH OF BUS."
2	"BUS LEAVING BUS STOP PLATFORM TRAVELING NORTHBOUND. PEDESTRIAN WALKING STRAIGHT NORTHBOUND ON PLATFORM, STUMBLED AND ROLLED OFF THE PLATFORM AND WAS CRUSHED BETWEEN THE CURB AND THE BUS RIGHT REAR WHEEL."
3	"OPERATOR WAS PULLING AWAY FROM A DESIGNATED BUS STOP IN WHICH HE HAD JUST FINISHED BOARDING PASSENGERS. APPROXIMATELY 25 FEET PAST THE DESIGNATED STOP, ANOTHER PERSON AT THE BUS STOP WANTED TO GET ON THE BUS AND STARTED RUNNING ALONG SIDE OF THE BUS. WITNESSES SAY HE TRIPED AND FELL WHILE RUNNING ALONG SIDE THE BUS AND UNFORTUNATELY FELL UNDER THE REAR WHEELS OF THE TRANSIT BUS. HE WAS REPORTED DECEASED UPON ARRIVAL AT BROWARD GENERAL HOSPITAL."
4	"A MAN WAS RUNNING ALONG SIDE OF THE BUS IN AN ATTEMPT TO GET IT TO STOP AND FELL. THE REAR WHEELS RAN OVER THE MANS ARM."
5	"A CUSTOMER WAS TALKING ON A CELL PHONE AS HE ALIGHTED THE BUS. HE STARTED WALKING ON THE SIDEWALK IN THE SAME DIRECTION AS THE BUS WAS FACING. WHEN THE BUS STARTED MOVING, THE CUSTOMER TURNED AND WALKED INTO THE STREET INTO THE RIGHT FRONT CORNER OF THE BUS. HE WAS KNOCKED TO THE GROUND, BUT RECEIVED ONLY MINOR INJURIES."
6	"PED STATES UNIT RAN OVER FOOT AS UNIT WAS PULLING FROM STOP."
7	"PASS ALIGHTED AFTER VERBAL CONFORTATION, ALLEGES REAR OF UNIT HIT HIM."
8	"CUSTOMER WAS INTOXICATED AND ALIGHTED THE BUS. AS OPERATOR WAS PULLING AWAY FROM SERVICE STOP, CUSTOMER STUMBLED INTO MB/DO."
9	"A CUSTOMER APPROACHED THE MB/DO AS IT WAS LEAVING A SERVICE STOP, SLIPPED AND FELL ONTO THE ROADWAY AND MB/DO REAR WHEELS RAN OVER THE CUSTOMER."
10	"BUS WB ON DANIEL AT THIRD AT A PASSENGER STOP. OPERATOR WAS CLOSING REAR DOORS WHEN PEDESTRIAN/PASSENGER ATTEMPTED TO BOARD REAR TRAILER SECTION DOOR GETTING ARM/HAND STUCK IN REAR DOOR. BUS WAS MOVING FROM THE STOP WITH THE PEDESTRIAN/PASSENGER RUNNING ALONG SIDE THE BUS. A PASSENGER AT THE REAR DOOR (ON BOARD THE BUS) NOTICED THE SITUATION AND FREED THE ARM/HAND OF THE PEDESTRIAN/PASSENGER CAUSING HER TO FALL FACE FIRST ON STREET AND BUS REAR TIRE ROLLED OVER HER HAND. FM PEDESTRIAN/PASSENGER WAS TRANSPORTED FOR MEDICAL FROM THE ACCIDENT SCENE."
11	"ON JANUARY 29, 2010, BUS #1022 MOVING SB AT THE INTERSECTION OF HALSTED ST./127TH ST., WHILE LEAVING THE BUS STOP, WITH ITS FRONT END, STRUCK A PEDESTRIAN WALKING EB WHO HAD JUST ALIGHTED THE BUS. THE PEDESTRIAN WAS CARRIED TO THE HOSPITAL."
12	"ON APRIL 29, 2010, BUS #1478 TRAVELING EB AT THE INTERSECTION OF NORTH AV./BESLY CT., WHILE LEAVING THE BUS STOP, WITH ITS RIGHT SIDE REAR WHEEL WELL COLLIDED WITH A NB MOVING BICYCLIST. THE BICYCLIST WAS CARRIED TO THE HOSPITAL."
13	"ON JULY 24, 2010, A WB BUS AT THE INTERSECTION OF 55TH ST./COTTAGE GROVE AV., WHILE LEAVING THE SERVICE STOP, WITH ITS RIGHT REAR TIRES, STRUCK A BUS PASSENGER WHO HAD JUST ALIGHTED. THE BUS PASSENGER WAS TRANSPORTED TO THE HOSPITAL."
14	"ON AUGUST 7, 2010, BUS #1908 TRAVELING EB AT THE NORTH AV./ASHLAND AV. INTERSECTION, WHILE LEAVING THE BUS STOP, WITH ITS RIGHT SIDE STRUCK A PEDESTRIAN WHO HAD JUST ALIGHTED AND FELL BACKWARDS INTO THE BUS. THE PEDESTRIAN WAS CARRIED TO THE HOSPITAL. HOWEVER, THERE IS A CONFLICTING REPORT INDICATING THE PEDESTRIAN FELL ON THE SIDEWALK AND DID NOT MAKE CONTACT WITH THE BUS."
15	"ON SEPTEMBER 11, 2010, BUS #1611 MOVING EB AT THE INTERSECTION OF 93RD ST./COLFAX AV., WHILE EXITING THE BUS STOP, WITH THE FRONT LEFT CORNER OF ITS FRONT BIKE RACK, STRUCK A SB RUNNING PEDESTRIAN. THE PEDESTRIAN WAS CARRIED TO THE HOSPITAL."
16	"ON OCTOBER 15, 2010, BUS #1437 TRAVELING NB AT THE INTERSECTION OF PULASKI RD./DIVISION ST., WHILE EXITING THE BUS STOP, STRUCK A NB RUNNING PEDESTRIAN WHO TRIPPED WHILE RUNNING ALONGSIDE THE BUS AND SLID WB UNDER THE BUS WHERE THE REAR RIGHT TIRES CRUSHED HIS RIGHT LEG. THE PEDESTRIAN WAS TAKEN TO THE HOSPITAL."

No.	Description
17	“ON NOVEMBER 23, 2010, BUS #1055 TRAVELING EB AT THE INTERSECTION OF ARMITAGE AV./LECLAIRE AV., WHILE LEAVING THE BUS STOP, WAS STRUCK JUST BEHIND THE FRONT DOORS ON ITS RIGHT SIDE BY A NB RUNNING PEDESTRIAN WHO TRIPPED ON THE SIDEWALK WHILE TRYING TO CATCH THE BUS. THE PEDESTRIAN WAS TRANSPORTED TO THE HOSPITAL.”
18	“ON NOVEMBER 29, 2010, BUS #1054 TRAVELING EB AT THE NORTH AV./KEELER AV. INTERSECTION, WHILE EXITING THE BUS STOP, HAD A NB RUNNING PEDESTRIAN COLLIDE WITH THE RIGHT HORIZONTAL MIDSECTION OF THE BUS.”
19	“ON NOVEMBER 29, 2010, BUS #2006 MOVING NB AT THE INTERSECTION OF LARAMIE AV./LEMOYNE ST., WHILE JUST BEGINNING TO EXIT THE BUS STOP AND WHILE BRAKING TO AVOID CONTACT, WITH ITS FRONT END, STRUCK A PEDESTRIAN WHO HAD JUST ALIGHTED THE BUS AND WAS ATTEMPTING TO RETRIEVE HIS BICYCLE FROM THE FRONT END BIKE RACK. THE PEDESTRIAN WAS TAKEN TO THE HOSPITAL.”
20	“MAN WAS TAKING BIKE OFF BIKE RACK WHEN DRIVER BEGAN TO PULL AWAY FROM CURB. APPEARS MAN WAS STRUCK BY RACK, CAUSING HIM TO FALL.”
21	“A PASSENGER ALIGHTED THE COACH AND WALKED AROUND SOME CONSTRUCTION BARRELS THAT WERE IN FRONT OF THE COACH. THE COACH PULLED OFF AND STRUCK THE PASSENGER AND KNOCKED HER TO THE GROUND BUT DID NOT RUN OVER HER.”
22	“A PERSON GOT OFF THE COACH THAT WAS INTOXICATED. AS THE COACH STARTED TO PULL OFF THE PERSON RAN FOR THE FRONT DOOR AND STARTED TO STIKE IT. HE THEN FELL ON THE SNOW THAT WAS AT THE CURB AND FELL UNDER THE COACH. THE COACH STOPPED BEFORE HE WAS STRUCK BY THE REAR WHEELS.”
23	“AN INEBRIATED PEDESTRIAN FELL AGAINST THE RIGHT SIDE OF THE COACH AND TO THE GROUND AS THE COACH WAS LEAVING THE ZONE. SPD AND AID RESPONDED TO THE SCENE AND THE PEDESTRIAN WAS TRANSPORTED VIA SFD TO HMC.”
24	“V-1 WAS STOPPED N/B BUS ZONE OF VERMONT AT 4TH ST. ALIGHTING PATRONS. WHEN THE LIGHT TURNED GREEN, V-1 BEGAN MOVING FORWARD AND A FEMALE PEDESTRIAN ENTERED THE SOUTH CROSSWALK, WALKING WEST ON A RED LIGHT, COLLIDING WITH V-1.”
25	“BUS 1116 WAS AT A BUS FAR SIDE BUS STOP. AS THE BUS WAS PULLING AWAY A WITNESS ALLEDGED THAT THE BUS HIT A PEDESTRIAN WHO WAS RUNNING TO TRY TO GET ON THE BUS. CONTACT WAS MADE BEHIND THE REAR DUALS OF THE 40' BUS. MALE WAS TRANSPORTED WITH SHOULDER INJURY.”
26	“CUSTOMER AT BUS STOP FELL INTO THE SIDE OF THE BUS AS BUS WAS PULLING AWAY FROM STOP. PRIOR TO PULLING AWAY THE BUS OPERATOR HAD SECURED THE BUS AND ASSISTED THE CUSTOMER IN GETTING THEIR BIKE OFF OF THE BIKE RACK. AS THE CUSTOMER WAS THANKING THE BUS OP FOR ASSISTING HIM, THE CUSTOMER TRIPPED OVER HIS PANTS THAT HAD FALLEN DOWN. ACCORDING TO THE BUS OPERATOR AND TWO CUSTOMER REPORTS THIS INDIVIDUAL WAS DRUNK. THERE WERE NO APPARENT INJURIES ON THE CUSTOMER, WHO WAS BREATHING BUT APPEARED TO BE UNCONSIOUS. CUSTOMER WAS TRANSPORTED.”
27	“THE BUS PULLED AWAY FROM THE BUS STOP AND A PEDESTRIAN APPROCHED THE BUS, APPEARED TO LOSE HIS BALANCE, FELL AGAINST THE BUS, INTO THE STREET AND WAS HIT BY THE REAR DUALS.”
28	“OPERATOR MADE BUS STOP, CLOSED DOORS, CHECKED FOR TRAFFIC, CHECKED MIRRORS AND PROCEEDED ON GREEN LIGHT, BUS MOVED ONE LENGTH WHEN PASSENGERS IN MIDDLE OF BUS BEGAN SHOUTING, BUS STOPPED. OP ASKED WHAT HAPPENED, EXITED BUS AND SAW PERSON LAYING ON GROUND.”
29	“OPERATOR STATED WHILE EXITING SERVICE STOP AND MOVED THE BUS FORWARD CONTACT WAS MADE WITH PATRON BENT OVER IN FRONT OF BUS THAT OPERATOR DID NOT SEE.”
30	“AS THE CONDUCTOR WAS EXITING THE TERMINAL (TRAIN STATION IN CENTRO MEDICO) HE SAW A SHADOW, STOPED THE BUS A MAN HIT A BUS IN THE FRONT RIGHT SIDE OF THE BUMPER, FELT TO THE FLOOR. THE MAN WAS TRASPORTED TO THE HOSPITAL IN AN AMBULANCE.”
31	“BUS LEAVING BUS STOP AREA. INTENDING MALE CUSTOMER FORCED RIGHT FOOT INTO CLOSING DOORS OF BUS, AND FELL ONTO ROADWAY. INTENDING CUSTOMER CLAIMED INJURIES; MOVED TO HOSPITAL.”
32	“BUS #2937 WAS TRAVELING NORTH ON SAN JACINTO LEAVING A BUS STOP WHEN A PEDESTRIAN FELL INTO THE REAR PANEL OF THE BUS. HE WAS VERY INCOHERENT AND NOT COOPERATING WITH HPD OR PARAMEDICS THAT WERE TREATING HIM.”

No.	Description
33	“BUS #2901 WAS STOPPED UNLOADING AND LOADING PASSENGERS AT THE BUS STOP. A PEDESTRIAN WHO APPEARED TO BE INTOXICATED APPROACHED THE BUS BUT DID NOT BOARD. THE OPERATOR ASKED HIM TO MOVE AWAY FROM THE DOOR AND HE STEPPED BACK. AS THE OPERATOR WAS PULLING AWAY FROM THE STOP THE PEDESTRIAN FELL FORWARD CAUSING HIS FOOT TO GET CAUGHT BETWEEN THE CURB AND THE TIRE.”
34	“A MAN REPORTED A BUS HIT HIM WHEN LEAVING A BUS STOP.”
35	“CHILD FELL UNDER BUS. WHILE BUS WAS PULLING AWAY.”
36	“BUS PULLING AWAY FROM STOP. PASSENGERS ON BUS CALLING OUR TO DRIVER TO HOLD ON. DRIVER HEARD A BANG AS IF SOMEONE HIT THE BUS. A GLANCE IN THE CURBSIDE MIRROR REVEALED SOMEONE LYING ON THE SIDEWALK. PASSENGER ONBOARD INDICATE THAT THE INDIVIDUAL WAS TRYING TO CATCH THE BUS.”
37	“PASSENGER CLAIMED BACKPACK WAS CAUGHT IN CLOSED DOOR OF BUS AND PASSENGER WAS DRAGGED BY THE BUS.”
38	“V1 PULLING AWAY FROM BUS SHELTER WHEN A FEMALE RAN INTO THE SIDE OF THE BUS.”
39	“CUSTOMER EXITED BUS AND DOUBLED BACK AFTER BUS BEGAN TO LEAVE STOP AND BUS MADE CONTACT WITH CUSTOMER.”
40	“V1 STRUCK PEDESTRAIN WHILE PULLING AWAY FROM STOP. V1 WAS PULLING OUT FROM STOP WHEN A PEDESTRAIN RAN UP TO BUS AND HIT THE SIDE OF THE COACH TO GET DRIVERS ATTENTION IN DOING SO THE MOTION OF THE COACH KNOCKED THE PEDESTRAIN TO THE GROUND. THE OPERATOR WAS MOVING FORWARD WHILE HELPING A PAX WITH THE FARE BOX. OPERATOR FAILED TO SCAN MIRROR BEFORE PULLING AWAY.”
41	“PEDESTRIAN VS V1. V1PULLING AWAY FROMA ABUS STOP WHEN A PEDESTRIAN ATTEMPTED TO BANG ON THE SIDE OF THE COACH. PEDESTRIAN LOST HIS BALANCE AFTER STRIKING THE RIGHT SIDE WITH HIS FIST AND FELL TO THE GROUND.”
42	“PED HIT V1 AS IT WAS PULLING AWAY FROM THE BUS STOP. PEDESTIAN FELL TO THE GUTTER AND NEXT TO THE BUS HITTING HIS HEAD ON THE SIDE OF V1.”
43	“BICYCLIST STRUCK MOVING V1. V1 PULLING AWAY FROM A BUS STOP WHEN A PASSENGER RETRIEVED HIS BIKE FROM THE BIKE RACK AND BEGAN TO RIDE THE BIKE ON THE SIDEWALK. BICYCLIST LOST HIS BALANCE AND STRUCK THE RIGHT SIDE OF THE COACH. BICYCLIST SUSTAINED A BROKEN RIGHT LEG.”
44	“BICYCLE RIDER ROAD AROUND BEHIND BUS AND STOPPED LEANING AGAINST THE BUS. THE DRIVER NEVER SAW THE BICYCLE AND PULLED AWAY FROM THE BUS STOP, DRIVER OVER AND KILLING THE BICYCLIST.”
45	“PATRON RAN AFTER DEPARTING BUS, MADE IT TO THE FRONT PASSENGER CORNER, AND FELL IN FRONT OF BUS. PATRONS FOOT WAS RUN OVER BY THE FRONT WHEEL OF THE BUS.”
46	“BUS RAN OVER PASSENGERS FOOT WHILE PULLING OUT OF BUS STOP. DRIVER WAS UNAWARE OF THE CONTACT WITH PASSENGER. INCIDENT REPORTED TO DRIVER OF THE NEXT BUS THAT PULLED IN. PASSENGER WAS TRANSPORTED FROM THE SCENE.”
47	“PASSENGER WENT TO TAKE BIKE OFF THE FRONT OF THE BUS. DRIVER WAS UNAWARE, AND BUS MOVED FORWARD A FEW INCHES AND CONTACTED PASSENGER IN THE LEG. PASSENGER CLAIMED INJURY AND WAS TRANSPORTED FROM THE SCENE.”
48	“THE AVAILABLE INFORMATION INDICATES A PEDESTRIAN WAS CHASING AFTER THE COACH AS IT PULLED AWAY FROM THE STOP. THIS PEDESTRIAN SLIPPED ON THE WET SIDEWALK AND FELL INTO THE ROADWAY UNDER THE PASSENGER SIDE REAR WHEEL OF THE COACH.”
49	“INDIVIDUAL WAS ATTEMPTING TO CATCH BUS WHEN HE TRIPPED AND COACH RAN OVER HIS TOES AND LEGS.”
50	“WHEN COACH WAS LEAVING STOP PEDESTRIAN RAN UP TO COACH AND STARTED TAPPING ON SIDE OF COACH AND FELL.”
51	“A WOMAN RAN AFTER THE BUS AS IT WAS TURNING, TRIPPED OFF THE CURB AND FELL UNDER THE RIGHT REAR TIRE.”

No.	Description
52	"METROBUS WAS TRAVELING WESTBOUND IN THE CURB LANE LEAVING A BUS STOP. AS THE BUS WAS PULLING AWAY FROM THE SERVICE STOP, A PEDESTRIAN WAS RUNNING ON THE SIDEWALK ALONGSIDE OF THE BUS AND TAPPING ON THE SIDE PANEL. THE PEDESTRIAN TRIPPED AND FELL MAKING CONTACT ON THE RIGHT SIDE PANEL OF THE BUS. PG POLICE DETERMINED THAT THE PEDESTRIAN WAS INTOXICATED AT THE TIME."
53	"BUS WAS LEAVING STOP AND WOMAN WALKED INTO FRONT BUMPER AS BUS WAS DEPARTING STOP."
54	"WOMAN DEPARTED BUS AND WAS ON CELL PHONE WHEN SHE WALKED INTO SIDE OF BUS AS BUS WAS LEAVING STOP. PASSENGER WENT BACK ONTO BUS AND WAITED FOR MEDICAL ASSISTANCE."

3.1.3 Situation #3: Motor Vehicle/Pedestrian Collisions as Pedestrians Cross the Street after Exiting the Motor Bus

Figure 3-3 depicts collisions with pedestrians that are attempting to cross the street in front of the bus after alighting the bus at a bus stop. In this situation, passengers getting off the bus that walk in front of the bus may not be seen by the bus driver or motorists traveling in lanes to the left of the bus due to limited line of sight. Pedestrians may be crossing legally or illegally across the street. An example of this situation occurs often with school buses that are dropping off children at the bus stop; however the situation is not limited to school buses. In this example, the school bus typically has a stop sign, flashing beacons, and a stop arm that alert motorists behind the bus to stop while children cross the street. Motor buses operating by public transit agencies typically do not have stop signs and flashing beacons, thus making the occurrence of these collisions as likely as or even more likely for public transit vehicles than school buses. In general, these collisions may be avoided by alerting motor vehicles that pedestrians are crossing the street in front of the motor bus. Descriptions from the 2010 NTD describing actions where motor buses collided with pedestrians that had just alighted are included in Table 3-3 and highlighted in orange.

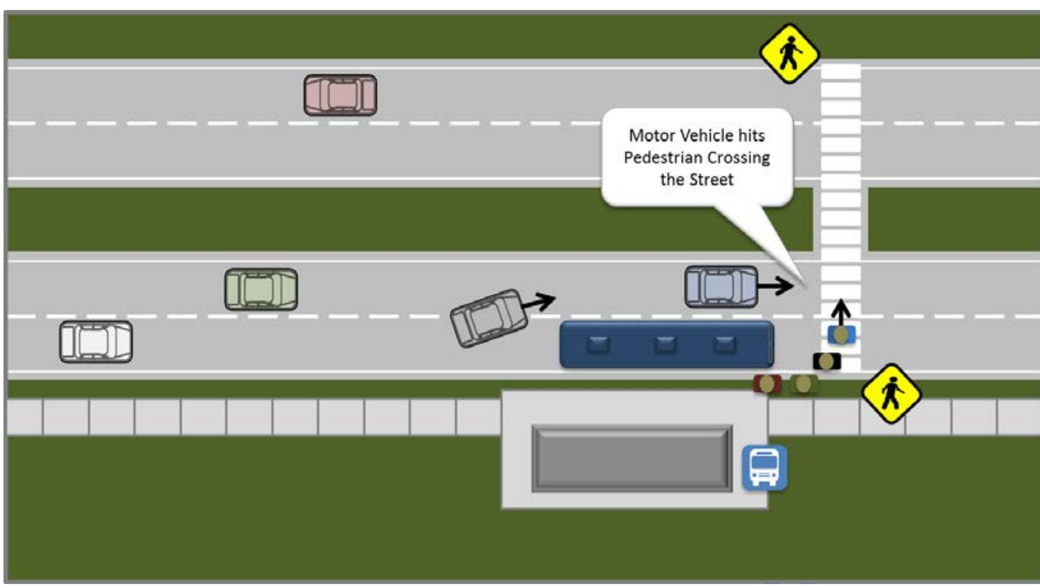

Figure 3-3: Situation #3 – Motor Vehicle/Pedestrian Collisions as Pedestrians Cross the Street after Exiting the Motor Bus *(Source: USDOT, 2014)*

3.2 Existing ITS Solutions to Mitigate Motor Bus Collisions with Pedestrians

The following are five examples of vehicle-based systems where technology has been implemented to mitigate vehicle-pedestrian collisions.

3.2.1 WMATA's Pedestrian Warning Systems

In January 2007, the Washington Metropolitan Area Transit Authority (WMATA) in Washington, D.C. began a pilot program of pedestrian warning on its transit bus fleet. WMATA installed a special warning strobe atop its test fleet of Metrobuses. A yellow warning strobe light warned pedestrians and motorists of an approaching Metrobus. The strobe lights resemble the warning lights on school buses to increase vehicle visibility. As stated in WMATA's press release:

> *"Metro is the first transit agency in the United States to test warning strobe lights atop buses. We believe this is another helpful safety tool designed to improve pedestrian safety throughout the region."* [1]
>
> In November 2010, WMATA began testing the use of exterior audible pedestrian warnings that say "Pedestrians, bus is turning." on some of their Metrobuses. Interior alerts driver to use caution and "look both ways." The volume of the warning adjusts to environmental noise, playing louder in high volume neighborhoods, and playing more quietly in neighborhoods with less noise. [2]

3.2.2 TriMet's Audible Pedestrian Warning System

TriMet, a public transit organization that provides light rail and commuter rail transit services in the Portland, Oregon, metro area tested a system that makes automatic announcements when a bus is turning, similar to the system tested by WMATA and described in 3.2.1. The agency equipped buses with an external audible warning system. When the operator turns the steering wheel to enter a turn, an external announcement is triggered, announcing "Pedestrians, bus is turning." The announcements are made in both English and Spanish. The announcement is activated if the steering wheel is turned one revolution to the right or left. Buses changing lanes should not activate the system. The audio level is set at 100 decibels (dB), which is the same level as TriMet's external automatic stop announcement system. While the TriMet system is designed to alert pedestrians when a bus is turning – most likely at an intersection – the system could be adapted to provide audible warnings when a motor bus is arriving or departing at a stop/station.

According to TriMet's website, it was recommended that TriMet explore the technology as part of the comprehensive safety review initiated following a fatal bus crash in April 2010 where five pedestrians were struck. TriMet states that other transit agencies, including agencies in Baltimore, Cleveland, and Washington D.C., have experimented with similar systems.[3]

The Portland-area agency tried the pedestrian warning system in 2011, but the initial system had some problems. According to The Oregonian, a local newspaper:

> *"…the audible alert didn't go off until a bus was in the middle of the crosswalk. The external speakers were also located in a poorly insulated section of the bus frame, meaning the woman's voice often drowned out stop announcements inside the buses. Often, the warning misfired when drivers simply pulled into and out of a stop."* [4]

In 2013, TriMet received $400,000 from the Federal Transit Administration to test three different warning systems: (1) Dinex Star LED headlight with Pedestrian Crossing Alert, (2) Protran Technology Safe Turn Alert, and (3) Clever Devices Turn Warning System. The agency started the test in September 2013, installing each system on 15 buses.

3.2.3 Mobileye's Pedestrian Detection System

Both static and moving pedestrians can be detected to a range of around 30 meters using Video Graphics Array (VGA) resolution imagers. As higher resolution imagers become available range will scale with imager resolution, making detection ranges of up to 60 meters feasible. Mobileye's first production for Pedestrian detection systems was in 2009 on a range of industrial powered vehicles where 8 EyeQ2 based monocular cameras provide a 360 degree all-round pedestrian detection system to a range of 15 meters and will warn the vehicle operator via Audio/Visual warnings of pedestrian in the vehicles path. The Mobileye system has been installed on 150 transit buses in Israel. [5]

Figure 3-4: Mobileye's Pedestrian Detection System *(Source: Mobileye [5])*

3.2.4 School Bus Arm Camera by RedFlex

The RedFlex Student Guardian® is another system developed to improve the safety of children at bus stops. The system a fully automated school bus stop arm camera photo enforcement solution for monitoring and deterring drivers who illegally pass school buses, risking the safety and security of some 26 million children nationwide who rely on school bus transportation. When the school bus stop arm is activated, the system uses cameras to automatically detect vehicles passing the stopped school bus requiring no bus driver involvement. The system records a close-up of the vehicle license plate and a broader image of the violation incident. An on-board computer captures images, data, time, GPS location, and the bus route of each incident. Data is provided back to a central server using 3G/4G wireless communications.[6]

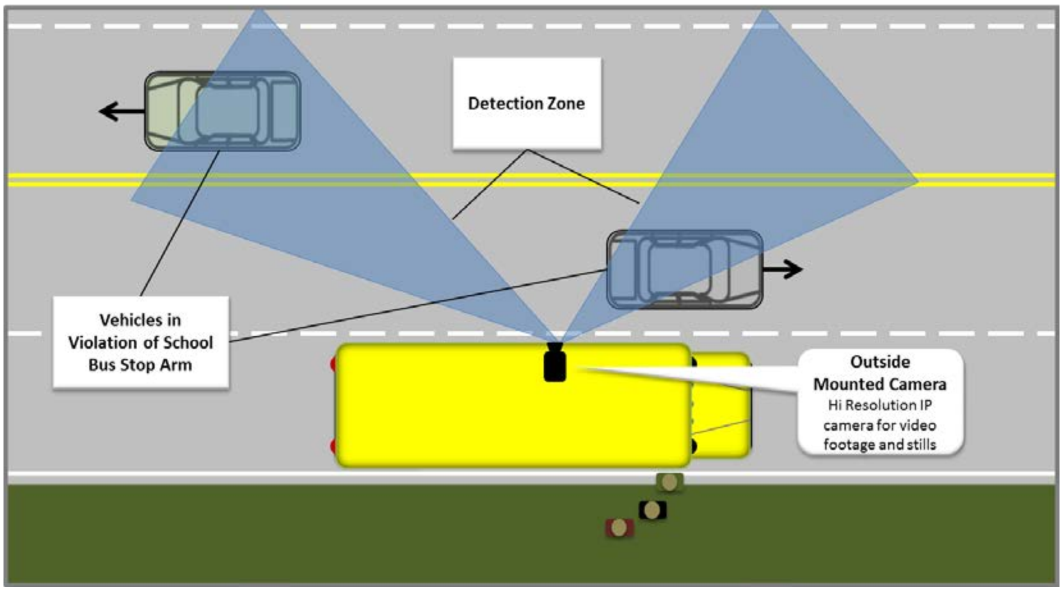

Figure 3-5: RedFlex Student Guardian System *(USDOT, 2014 – Adapted from RedFlex graphic)*

This system is not directly applicable to transit vehicles, as it is not illegal to pass a transit bus. However, a camera detection system like the RedFlex Student Guardian® could be adapted to provide warnings to drivers of surrounding vehicles (via their DVIs) or pedestrians (through infrastructure) that there could be a collision between a pedestrian and a motor vehicle, as described in Scenario #3.

3.2.5 Student Detection System by Rostra

Several systems have been deployed on school buses to improve safety. Sadly, each year children are injured, or worse, in accidents while boarding and leaving buses. Rostra Precision Controls (and others) developed a system utilizing the latest technology to help ensure children's safe arrival at school and home. The Rostra Student Detection System is a motion-activated detection system that uses reflected radar waves to detect a moving target. When a target, a child, is detected within specified danger zones in the front, rear, and sides of the bus, an alarm sounds to alert the driver, and corresponding LEDs on a display panel indicate the target's location by zone. The system can also include a RearSentry Rear Obstacle Sensing System, installed for rear coverage when the bus moves in reverse. [7] Figure 3-6 depicts Rostra's Student Detection System.

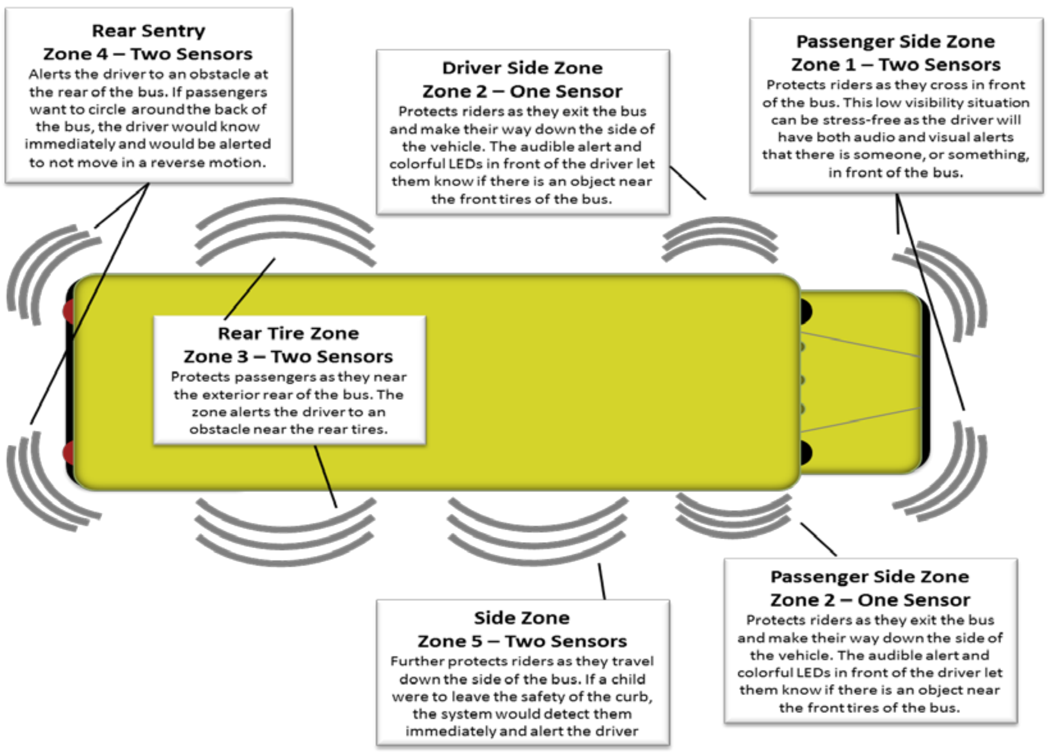

Figure 3-6: Sentry Pro-Grade Student Detection System by Rostra *(USDOT, 2014 – Adapted from Rostra graphic)*

3.3 Automated Pedestrian Detection Systems

Pedestrian detection systems (PDS) are another type of system implemented on vehicles that notify the vehicle operator of an impending collision with a pedestrian. Due to constraints with radar and LIDAR sensors, video-based recognition accounts for the majority of technologies used to implement pedestrian detection. The systems use pattern recognition and optical flow techniques to differentiate between a pedestrian and an inanimate object. PDS detect pedestrians through a search of objects containing specific characteristics. The systems then separate a potential pedestrian from the background images. The software compares body ratios, specific size constraints, etc. to differentiate a non-human object from a pedestrian. A PDS has a typical range of 10 to 40 meters.

PDS have also been designed for infrastructure. These systems 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. [8] These Pedestrian Detection systems use infrared, microwave or video detection systems, as well as pressure-sensitive mats, to activate a call. The need for these additional technologies emerged as approaches to better accommodate pedestrians with reduced physical mobility were identified. These same technologies also help improve the intersection safety for pedestrians who choose not to use the existing call buttons. A microwave Doppler pedestrian detector was recently used as part of the Transit Retrofit Package (TRP) for the USDOT's Connected Vehicle Safety Pilot. The SmartWalk™ XP sensor was used to detect the presence of a pedestrian in the crosswalk, as depicted in Figure 3-7.

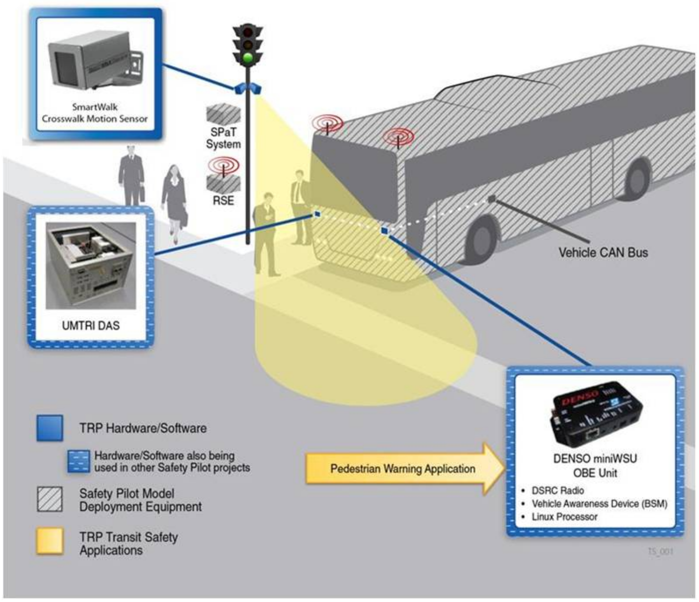

Figure 3-7: Illustration of the Pedestrian Warning Application from the TRP with All Hardware Components *(Source: Transit Retrofit Package ConOps, USDOT, 2012)*

Recently, research into the use of smart phones as yet another potential approach to support pedestrian calls has been made. The report, *Development of Mobile Accessible Pedestrian Signals (MAPS) for Blind Pedestrians at Signalized Intersections* [9] describes how smart phones might be used to improve intersection safety by allowing both the call to be made to the controller, as well as to provide the pedestrian with additional information related to the intersection.

An optional component in the Transit Bus Stop Pedestrian Safety Application relies on consistent and accurate pedestrian detection in the vicinity of bus stops and crosswalks near those bus stops. At bus stops, pedestrian detection through push button is highly unlikely to be deployed. The use of automated pedestrian detection technologies could improve awareness of hazardous situations for both pedestrians and transit vehicle drivers.

3.3.1 Usage of Automated Pedestrian Detection (APD)

Technological advances and increased knowledge about pedestrian behaviors have made innovative solutions to the pedestrian detection issue possible. One example of such is the emergence of automated pedestrian detection (APD) technologies. However, APD is currently used largely at intersection and mid-block crosswalks. A 2008 FHWA (Federal Highway Administration) Pedestrian Safety Report to Congress [10] found that despite of their potentials, these APD technologies "require additional research and extensive field testing to demonstrate and evaluate the benefits of deploying the systems." The FHWA report further pointed out the gap between limited U.S. experience and broader European and Australian acceptance of these devices.

APD provides continuous and real-time recognition (e.g., location, direction of travel, speed) of pedestrians' movements in the proximity of bus stops. This information enhances situational awareness for optional functionality of the safety application, which in turns computes and determines appropriate alerts to transit bus drivers, pedestrians, as well as nearby motorists, if warranted.

Regardless of type of APD technologies used, the targeted zones for pedestrian detection near crosswalks generally fall into two categories: detection zones on/near sidewalks/curbs, and detection zones within crosswalks, as shown in Figure 3-8. This application would utilize the detection zones on/near sidewalks/curbs to detect the presence of pedestrians waiting at the bus stop.

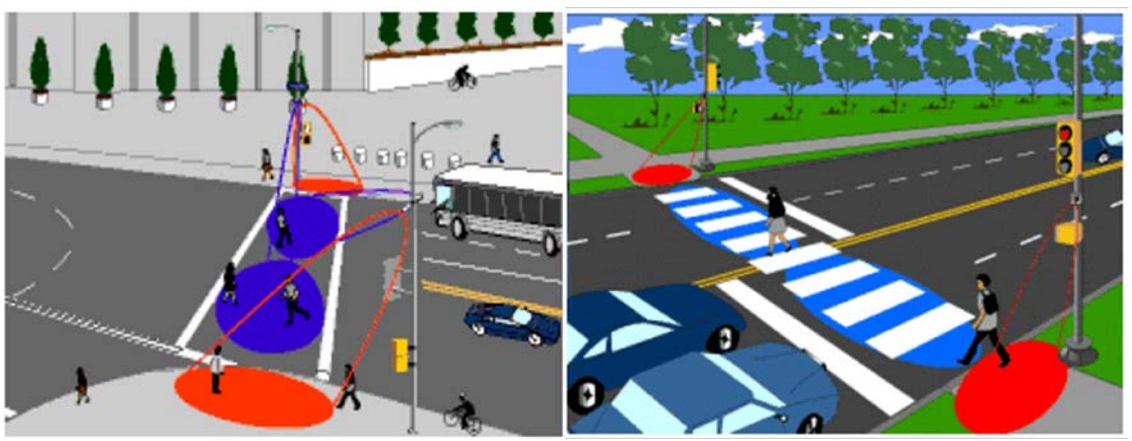

Figure 3-8: Placement of Automated Pedestrian Detection Devices and Detection Zones at Intersection and Mid-block Crosswalk Locations *(Source: FHWA, 2006 [11])*

3.3.2 Effectiveness of APD

Hughes et al. (2001)*[8]* conducted a study for the U.S. FHWA to test automated pedestrian detectors (infrared and microwave) in Los Angeles, California; Rochester, New York; and Phoenix, Arizona to determine how effective the detectors were at crosswalks. The following was found:

- When automated pedestrian detectors were used in conjunction with the pushbutton, this resulted in a significant reduction in the percentage of pedestrians beginning to cross during the DON'T WALK signal.

- With extended crossing time for pedestrians, more pedestrians were able to complete the crossing during the protected phase.
- The use of automatic pedestrian detectors in conjunction with the conventional pushbutton significantly reduced vehicle-pedestrian conflicts where either the pedestrian or the motorist had to stop or slow down so that the other can proceed.
- One problematic cause of false calls (i.e., false positive) was heavy rain.

A study by Steindel and Montufar (2008) cited 12 intersections in the City of Portland, OR with microwave detectors to monitor both curbside and crosswalk and to extend or cancel crossing phases. [12] Sites that received detectors were selected because of poor pedestrian compliance and high volumes of pedestrians with disabilities. The City has found that the curbside detectors are less effective than the crosswalk detection. As a result, push buttons are still used for pedestrian actuation.

Pecheux, et.al. (2009) evaluated video pedestrian detection systems in San Francisco and Miami. [13] In San Francisco, video detection technology was used to provide additional time for late-crossing pedestrians. In Miami, video detection was used to detect pedestrians approaching a mid-block crossing and change the signal accordingly. The only significant finding measured by the researchers was a 9 percent decrease in the percentage of cycles where a pedestrian was trapped in the roadway. There were no significant effects on pedestrian-vehicle conflicts or pedestrian clearance at the sites.

3.3.3 APD Technology Options

Among the most commonly deployed APD options are microwave, infrared, video imaging, and pressure mat/inductive loop. Depending on the deployment location characteristics (e.g., geometry, topology, weather condition, etc.), and other functional and performance requirements, it is advised that the subject safety application should consider these various APD options individually or in combination to effectively detect pedestrians at bus stops.

There have been many studies and testing on these APD technologies with respect to their usage, performance (e.g., reliability and accuracy) and overall deployment experience by local jurisdictions. Results from these studies are mixed without a clear indication of one technology consistently outperformed the others. These mixed study findings support the assentation that accurately detecting and monitoring pedestrian movements for traffic safety purposes is a very difficult task, especially in more complex urban locations where pedestrian movements and interactions are more dynamic and unconstrained. For instance, pedestrians may not walk into the detection zone when waiting for a transit vehicle to arrive, or pedestrians may walk into the detection zone, but are not waiting for the arrival of a transit vehicle.

Despite some limitations on sidewalk/curbside detection expressed by the studies discussed in 3.3.2, major advances in sensor technologies over the past several years should improve the detection rates experienced by the sites evaluated for these studies in the mid-2000s. The proliferation of handheld devices may also allow for other detection methods not previously studied in the pedestrian environment, such as Bluetooth.

Table 3-4 summarizes the four most commonly used APD options, their applicability at various locations, and sample manufacturers. It is not the intent of this Table to provide an exhaustive list of technology and supplier choices, and the USDOT holds no particular preference for these identified manufacturers/products.

Table 3-4: Comparison of Major APD Technology Options [12, 14]

	Microwave	Infrared	Video Imaging	Pressure Mats/Inductive Loops/Tubes
	Transmits radio wave and analyze bounced back signals for frequency change	Passive: detects a change in thermal contrast| Active: emits and detects obstruction in the infrared beam	Performs pattern recognition and classifiers through image processing and analysis	Senses pressure on a material either tube or underground sensor
Crosswalk Setting (within crosswalk)	YES	YES	YES	NO
Curbside Setting (entering crosswalk)	YES	YES	YES	YES
Trail or Sidewalk Setting	YES	YES	Questionable/ Inappropriate	YES
Manufacturers (sample list)	MS Sedco (USA) *SmartWalk XM, XP* AGD Systems Ltd. (UK) *AGD220, 625*	Xtrails, Ltd | ASIM Technologies Ltd (Switzerland) *IR308* EcoCounter (France)	Image Sensing Systems Inc. (USA) *Autoscope Solo Terra* Traficon	EcoCounter (France) Traffic 2000 Ltd. (UK)

4 Limitations of Existing Systems and Justification for Change

Chapter 3 provided an overview of existing technologies and systems to enhance pedestrian – and motor bus – safety at bus stops. While these systems have shown promise in reducing collisions, it is envisioned that connected vehicle technologies have the potential to provide additional benefits above current systems. This chapter discusses the limitations of existing systems and provides justification for connected vehicle applications.

4.1 Limitations of Existing Systems

4.1.1 ITS Systems

The transportation industry has long understood the safety issues of pedestrians and has been successful in implementing solutions to reduce the number of collisions occurring at these locations. Conventional traffic engineering solutions have focused on moving bus stops/stations to the far side of an intersection as well as locating the stops/station with good sight distance and alignment (e.g., not on steep grades or on horizontal curves) can reduce pedestrian related collisions. ITS solutions have also been introduced including: (i) adding sensors on vehicles to warn motor bus drivers of pedestrians or objects in the vicinity of the vehicle and (ii) including audible or visual originating from the transit vehicle to warn pedestrians of the bus' presence. While conventional traffic engineering and ITS solutions have helped reduce the occurrences of motor bus collisions with pedestrians at stops/stations, as documented in Section 3.1, these collisions still occur and often result in injuries and sometimes fatalities.

In general, current systems are fundamentally limited to either providing solutions solely targeted at either the pedestrian or the motor bus driver. Given current advances in technologies, a more robust solution is possible to improve the safety of pedestrians at transit stops/stations. Limitations of existing systems are listed below:

1. **Most motor buses are not equipped with sensors to alert the driver when a pedestrian or object is in the vicinity of the motor bus.** Sensor technologies are realizing widespread adoption by the automobile industry, but have not been widely adopted by the transit industry. There is an opportunity to integrate object detection systems (ODS) and pedestrian detection systems (PDS) on transit vehicles to help identify situations where a motor bus may collide with a pedestrian.
2. **Transit vehicles do not communicate with infrastructure located at the bus stop, and vice versa.** More robust solutions to improve safety at transit stops/stations should consider data exchanged between the vehicle and the infrastructure. Many existing vehicle systems are limited in that they do not share data with nearby infrastructure. These data could be used to alert pedestrians of imminent collisions earlier. Likewise, data originating from infrastructure could be shared with the driver of the motor bus and other vehicles to provide advanced warnings.

3. **Transit stops/stations do not have technologies in place to detect if a pedestrian is in imminent danger of being hit by a motor bus.** The vast majority of transit stops/stations do not include technologies to determine the presence of a pedestrian in danger of being hit by a motor bus. Infrastructure-based pedestrian detection systems could be deployed to detect the presence of a pedestrian at a bus stop in a danger zone.
4. **If deployed at transit stops/stations, current infrastructure-based pedestrian detection systems are likely to produce false alarms unless the presence of the transit vehicle is known.** While pedestrian detection systems can be deployed at bus stops, these systems should warn pedestrians only if the pedestrian is in imminent danger of being hit by the motor bus. To do this, infrastructure systems would need to know the location of the motor bus in relation to the bus stop.
5. **Visual and audible warnings originating from vehicles may be difficult for pedestrians to see, hear, or understand how the warnings relate to them.** As discussed in Section 3.2.2, the original test for the TriMet audible system had some issues. The external speakers were also located in a poorly insulated section of the bus frame, meaning the woman's voice often drowned out stop announcements inside the buses. Additionally, in a noisy environment (i.e., urban area), pedestrians may not see or hear these warnings and be confused by where the warning is coming from. As a result, pedestrians may actually put themselves in a more dangerous situation while trying to determine where the warning is coming from.
6. **Pedestrians located at bus stops do not receive alerts when a motor bus is arriving at or departing from the bus stop.** While visual (strobe lights) and audible warning systems have been instrumented on transit vehicles, a literature review revealed that there are few systems located at bus stops to warn pedestrians.
7. **Alighting passengers and pedestrians have limited line of sight to oncoming vehicles when crossing in front of a stopped motor bus.** If a pedestrian walks in front of the bus to cross the street, they may not be able to see other approaching motor vehicles due to the bus blocking their line of sight. Current systems do not provide warnings to pedestrians that motor vehicles are approaching and they will endanger themselves by crossing at that time.

4.1.2 Transit Retrofit Package (Connected Vehicle Safety Pilot)

As part of the connected vehicle Safety Pilot in Ann Arbor, Michigan, the USDOT deployed the Transit Retrofit Package (TRP) that included a Pedestrian Crossing Warning (PCW) application. This field test utilized two rounds of operational use, with the second round coming after revisions to the application were made based on data analysis and feedback from the bus drivers using the system. The contractor's revisions report provided the following lessons learned from the preliminary round of testing and potential modifications:

- **Crosswalk detector accuracy is insufficient for PCW application.** Decrease crosswalk detector target speed and increase crosswalk detector verification time in order to reduce the number of false positives from the system in the near-term. Using improved pedestrian detection sensing technologies as they continue to evolve is a long-term revision.
- **TRP application logic should be independent of actual bus route.** The original set up assumed specific bus routes and provided alerts accordingly, even if the vehicle was not operating on that route at the time of the alert. In the short-term, the application was altered to

not provide alerts when the bus was in a "straight only" lane at the intersection where the system was tested.

- **PCW alerts should be suppressed after bus enters the crosswalk.** The application originally maintained alerts when the GPS determined the bus was within 28 meters of the center of the intersection. In the short term, the application was modified so that the alerts are dismissed/suppressed after the center of the bus has entered the crosswalk.
- **GPS accuracy is insufficient for PCW applications.** The minimum specified accuracy of a Wide Area Augmentation System enabled GPS receiver is not accurate enough to support lane tracking. In practice, the system is more accurate than the specification, but improved locational accuracy technologies should be utilized as they continue to be developed.

4.2 Connected Vehicle Technologies

Connected vehicle technologies offer tremendous promise for safety improvements. Connected vehicle technologies function using a V2V and V2I data communications platform that, like the Internet, supports numerous applications, both public and private. This wireless communications platform provides the foundation to integrate data from the infrastructure (e.g., systems located at transit stops/stations) with data from the vehicle (e.g., position, speed, brake status). V2I communications offer an environment rich in vehicle and infrastructure data that can be used by applications residing on the roadside unit to provide pedestrians with alerts to avoid collisions with motor vehicles or transit vehicles.

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

Connected vehicle V2I data communications will enable vehicles to communicate with infrastructure located on the roadway. V2I safety applications utilize Dedicated Short Range Communications (DSRC) and other low latency communications, which are needed for crash imminent situations. V2I safety applications heavily rely on the basic safety message (BSM), Signal Phasing and Timing (SPaT) and Traveler Information Message (TIM) which are key message sets defined in the Society of Automotive Engineers (SAE) Standard J2735, DSRC Message Set Dictionary (November 2009). The development of the J2735 is ongoing and evolving. For instance, at the time of writing, the BSM consists of two parts, with the following characteristics:

- BSM Part 1 contains core data elements, including vehicle position, heading, speed, acceleration, steering wheel angle, and vehicle size. It is transmitted at a rate of about 10 times per second.
- BSM Part 2 contains a variable set of data elements drawn from an extensive list of optional elements. They are selected based on event triggers (such as when the antilock braking system [ABS] is activated). BSM Part 2 data elements are added to Part 1 and sent as part of the BSM message but are transmitted less frequently to conserve data communications bandwidth.

It is important to note that even if a data element is defined in BSM Part 2 of the SAE J2735 standard, it does not necessarily mean that vehicle manufacturers will provide it. Most of the Part 2 data elements are defined as optional information in the standard. Some of the Part 2 data elements are currently available on the internal data bus of some vehicles; others are not.

V2I data communications will enable vehicles to communicate with infrastructure located on the roadway. In context of the Transit Bus Stop Pedestrian Safety application, V2I communication would enable transit vehicles to communicate with infrastructure located at a bus stop. For example, transit vehicles may send BSMs to infrastructure about the vehicle's location, speed, braking status, and intent to stop at the bus stop.

Connected vehicle technologies, as they relate to the Transit Bus Stop Pedestrian Safety application, are discussed in more detail in Sections 5 and 6.

4.3 Description of Desired Changes

The objective of the Transit V2I Program is focused on how connected vehicles can provide safety benefits for road users of all modes. The focus of the changes to existing systems involves the mechanism and nature of information being provided to infrastructure by the motor bus. In short, the desire is to test the feasibility of using connected vehicle technologies to provide safety enhancements pertaining to pedestrian safety at bus stops. A key priority will be to integrate the connected vehicle technologies onto existing transit vehicles and at bus stops.

This Operational Concept builds upon the lessons learned from the TRP, particularly in regards to pedestrian detection capabilities.

4.4 Changes Considered But Not Included

There are a number of different possible combinations of technologies that could be explored and researched related to pedestrian safety at transit stops/stations. In particular, solutions to improve the physical design of the transit vehicle were not considered. A review of the NTD collision descriptions noted that several collisions between motor buses and pedestrians occurred when the side mirror struck the pedestrian waiting to board the motor bus. While new designs for mirrors that do not protrude as far to the side or solutions where the side mirrors are replaced with cameras could be considered, these strategies were deemed outside the scope of this effort. Another change that was considered, but not included, is the implementation of automation into the transit vehicle. Systems could be designed that once a pedestrian or object is detected by vehicle sensors, and it is determined that a collision is imminent, the vehicle automatically engages the brakes. Finally, systems that involve the pedestrian carrying a nomadic device and communicating with the vehicle were not considered. Vehicle-to-pedestrian (V2P) applications are expected to be researched in the future by USDOT.

5 Transit Bus Stop Pedestrian Safety Application

5.1 Application Overview

The Transit Bus Stop Pedestrian Safety application leverages V2I communications between the motor bus and the bus stop that provide audible or other alerts to pedestrians in the vicinity of a bus stop. Alternatively, infrastructure located at transit stops/stations instrumented with sensors/detectors to warn motor bus drivers of pedestrians in the vicinity of the bus stop that may be hit by the motor bus.

The Operational Concept discusses the following scenarios:

- **Scenario 1.** This scenario describes warning pedestrians when a motor bus approaches a transit bus stop. Infrastructure is used to notify pedestrians at the bus stop that a motor bus is arriving so they do not put themselves in a dangerous situation (e.g., step into the street in front of the motor bus). As an option, the application may be supplemented with a pedestrian detector(s) located at the bus stop that detects the presence of a pedestrian in the roadway or too close to the curb who is in danger of being hit by a motor bus approaching the bus stop, and may warn the driver via the Driver-Vehicle Interface (DVI) of a potential collision between the pedestrian and motor bus. The application may be integrated with a bus stop traveler information system using the same wayside infrastructure (e.g., dynamic message sign) where pedestrians are informed of basic information about the bus, such as the route number and final destination, estimated arrival time, and accessibility information, such as whether it is a high or low-floor vehicle and if wheelchair seating is available.
- **Scenario 2.** This scenario describes warning pedestrians when a motor bus departs from the transit bus stop. Infrastructure warns pedestrians located at the bus stop that the motor bus is departing. As an option, the application may be supplemented with a pedestrian detector(s) located at the transit bus stop that detects the presence of a pedestrian in the roadway (e.g., a pedestrian attempting to gain the attention of a bus driver of a bus that is about to or has just departed the bus stop) or too close to the curb who is in danger of being hit by a motor bus leaving the bus stop, and may warn the driver via the Driver-Vehicle Interface (DVI) of a potential collision between the pedestrian and motor bus.
- **Scenario 3.** This scenario describes warning alighting bus passengers of a potential collision with oncoming motor vehicles in the vicinity of the bus stop. Infrastructure located at the transit bus stop alerts passengers of approaching vehicles after receiving wireless messages sent from motor vehicles to the roadside infrastructure. In this scenario, passengers getting off the bus that walk in front of the bus may not see motorists traveling in lanes to the left of the bus due to limited line of sight. As an option, this scenario may be supplemented with a pedestrian detector(s) located at the bus stop that detects the presence of a pedestrian in the roadway, and may warn the bus driver and drivers of other motor vehicles in close proximity to the bus stop and/or crosswalk, via their respective DVIs, of a potential collision between the pedestrian and their vehicle.

Figure 5-1 depicts a high-level system architecture for the Transit Bus Stop Pedestrian Safety application. Included are six actors:

- **Transit Vehicle Driver.** The Transit Vehicle Driver actor represents the human entity that operates a licensed transit vehicle on the roadway. For the purposes of this document, the driver operates a motor bus. This actor originates driver requests and receives driver information that reflects the interactions which might be useful to the transit vehicle.
- **Transit Vehicle.** The Transit Vehicle actor is a motor bus that provides the sensory, processing, storage, and communications functions necessary to support efficient, safe, and environmentally efficient travel. Both one-way and two-way communications options, including 5.9 GHz band approved for DSRC use by the FCC and other wireless communications such as cellular, support a spectrum of information services. These capabilities allow the Transit Vehicle actor to disseminate information about its status (i.e., current speed, acceleration, braking, and average emissions) to other vehicles or to the Roadside Unit actor. Advanced sensors, processors, enhanced driver interfaces, and actuators complement the driver information services so that the driver travels these routes in a safer and more consistent manner.
- **Roadside Unit (RSU).** The Roadside Unit actor includes devices that are capable of both transmitting and receiving data using DSRC radios, using the 5.9 GHz band approved for DSRC use by the FCC. For this application, RSUs will be deployed at selected bus stops. These RSUs will transmit necessary infrastructure information (e.g., pedestrian detection, etc.) from the ITS Roadway Equipment for processing and triggering alerts to the Transit Vehicle Driver actor and Other Vehicle actor as appropriate.
- **ITS Roadway Equipment.** For the purposes of this document, the ITS Roadway Equipment actor includes other equipment (in addition to RSUs) located at a bus stop. These devices include pedestrian detectors, as well as other devices, located at the transit bus stop that may provide warnings or information to pedestrians, in visual and/or audio formats, of transit vehicles arriving or departing from the bus stop and potential conflicts with Other Vehicles after alighting the Transit Vehicle.
- **Other Vehicle.** The Other Vehicle actor provides the sensory, processing, storage, and communications functions necessary to support efficient, safe, and environmentally efficient travel. Both one-way and two-way communications options, including 5.9 GHz band approved for DSRC use by the FCC and other wireless communications such as cellular, support a spectrum of information services. This capability allows the Other Vehicle actor to disseminate information about its status (i.e., current speed, acceleration, braking, and average emissions) to other vehicles or to the RSU actor.
- **Pedestrian.** The Pedestrian actor consists of any and all types of pedestrians who would be at or near transit bus stops.

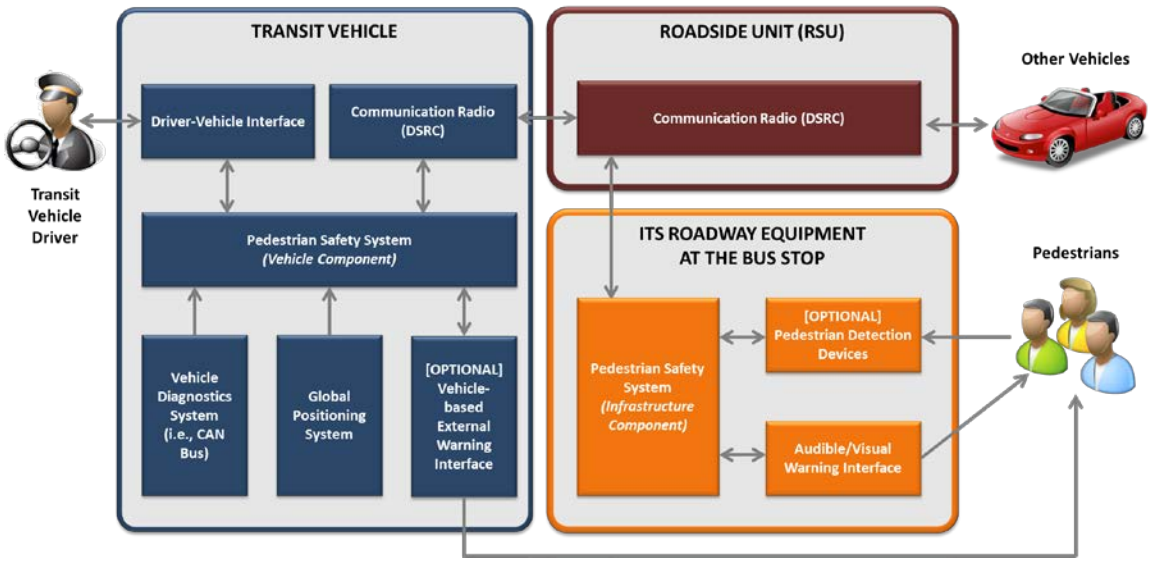

Figure 5-1: Transit Bus Stop Pedestrian Safety Application *(Source: USDOT, 2014)*

5.2 Transit Bus Stop Pedestrian Safety Application Subsystems

5.2.1 Transit Vehicle Subsystems

The Transit Vehicle actor includes seven subsystems:

- **Driver-Vehicle Interface.** The Driver-Vehicle Interface (DVI) Subsystem provides the means by which the user (e.g., transit vehicle driver) and a computer system interact. The types of interface may incorporate any combinations of audible, visual, and haptic feedback for drivers.

- **Communication Radio (DSRC).** The Communications Radio (DSRC) Subsystem within the Transit Vehicle actor provides the capability for the transit vehicle to disseminate and receive messages using DSRC communications. This capability allows the transit vehicle to communicate wirelessly with infrastructure, and vice versa.

- **Vehicle Diagnostics System.** The Vehicle Diagnostics Subsystem collects diagnostics data from on-board systems located on the transit vehicle. Data includes the vehicle's location, speed, acceleration, trajectory, braking status, and other data elements included in SAE J2735 BSM – Part 1.

- **Global Positioning System (GPS).** The Global Positioning System (GPS) Subsystem includes a GPS antenna and receiver that allows the transit vehicle to provide lane level accuracy of the transit vehicle's position.

- **Pedestrian Safety System *(Vehicle Component)*.** The Pedestrian Safety System (Vehicle Component) processes the data for the Basic Safety Message (BSM) and other necessary messages which contain information about the bus (e.g. route number, destination, ETA) for transmission to the RSU via the Transit Vehicle DSRC. Optional functionality includes the processing of data received from the RSU that would provide alerts to the Transit Vehicle Driver through the DVI of potential collisions with pedestrians in the vicinity of a bus stop.

- **[OPTIONAL] Vehicle-based External Warning Interface.** The optional subsystem receives input from the transit vehicle Pedestrian Safety System and, if needed, broadcasts appropriate alerts (audible and/or visual) to external pedestrians (e.g. alighting passengers, passengers crossing roadway in front of the bus) about heightened collision risk, using horns, special lighting, an annunciator, etc.

5.2.2 Roadside Unit Subsystems

The Roadside Equipment Unit actor consists of a single subsystem:

- **Communication Radio (DSRC).** The Communications Radio (DSRC) Subsystem within the Roadside Unit actor provides the capability for the RSU to disseminate and receive messages using DSRC. This capability allows the RSU to collect data, such as pedestrian detection information, from ITS Roadway Equipment for dissemination to the equipped Transit Vehicle or Other Vehicles. The DSRC also receives BSMs from the Transit Vehicle and Other Vehicles, as well as any other messages (e.g. traveler information message) from the Transit Vehicle. An RSU is a device that:
- Contains multiple radio sets for localized communication over 5.9GHz, compliant with FCC regulations for DSRC
- Contains an integrated GPS receiver for positioning and UTC time,
- Contains a PoE capable Ethernet interface that supports IPv4 and IPv6 connectivity, compliant with 802.3at, and is housed in a dedicated, NEMA 4X-rated enclosure.

5.2.3 ITS Roadway Equipment at the Transit Bus Stop Subsystems

The ITS Roadway Equipment includes three subsystems:

- **Pedestrian Safety System *(Infrastructure Component).*** The Pedestrian Safety System (Infrastructure Component) provides waiting passengers with information and alerts about arriving or departing vehicles, as well as about Other Vehicles when the Transit Vehicle is stopped at the bus stop, based on information received from the RSU. Additional optional functionality includes processing data from Pedestrian Detection Devices at the stop and transmission of that data to the RSU to provide alerts to the respective DVIs of the Transit Vehicle Driver and the Other Vehicle. Processing the data from the Pedestrian Detection Devices could optionally be used to provide targeted alerts to pedestrians at the stop only when there is danger of a collision between a pedestrian and a vehicle.
- **Audio/Visual Warning Interface.** The Audio/Visual Warning Interface Subsystem includes components installed at the transit bus stop to provide alerts to pedestrians. These alerts may be visual and/or audio alerts. The subsystem may interface to or be integrated with a bus stop traveler information system (e.g. dynamic message sign) where information such as the bus route and destination, estimated bus arrival time, etc. is provided to transit travelers.
- **[OPTIONAL] Pedestrian Detection Devices.** The Pedestrian Detection Devices Subsystem allows the infrastructure to detect the presence of pedestrians in areas where they may be in danger of being hit by motor buses and other vehicles.

5.3 Assumptions

One significant assumption is that the use of Connected Vehicle technology for the Transit Bus Stop Pedestrian Safety application requires DSRC or other wireless communications (e.g., 3G or 4G) both in the transit vehicle and in infrastructure located the bus stop. During the design of the application careful consideration should be given to the type of communication required for this application. DSRC offer low latency communication whereas other forms of wireless communication may have higher latency that does not meet the safety requirements for the application. This Operational Concept document is technology agnostic, instead assuming that radio communication is available and being used by all vehicles and infrastructure.

A second assumption is that the requisite transit routing and stop information can be appropriately provided to the RSU located at the bus stop through standard message sets. This type of message has not yet been developed.

6 Scenarios

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

Three scenarios are described:

- Scenario 1. Motor Bus Approaching the Transit Bus Stop
- Scenario 2. Motor Bus Departing from the Transit Bus Stop
- Scenario 3. Warning to Pedestrians of Oncoming Vehicles when Alighting the Motor Bus at the Transit Bus Stop

All of the scenarios assume that the optional pedestrian detection is done by infrastructure, not by the Transit Vehicle, and only covers the area near the bus stop and adjacent roadway. Additionally, when describing the scenarios, the generic term "pedestrian" is used to refer to all types of pedestrians and bicyclists. Pedestrians may be violating the "walk/don't walk" signals provided at signalized intersections.

6.1 Scenario #1: Motor Bus Approaching the Transit Bus Stop

Description. This scenario describes warning pedestrians when a motor bus approaches a transit bus stop. Infrastructure is used to notify pedestrians at the bus stop that a motor bus is arriving so they do not put themselves in a dangerous situation (e.g., step into the street in front of the motor bus). As an option, the application may be supplemented with a pedestrian detector(s) located at the bus stop that detects the presence of a pedestrian in the roadway or too close to the curb who is in danger of being hit by a motor bus approaching the bus stop, and may warn the driver via the Driver-Vehicle Interface (DVI) of a potential collision between the pedestrian and motor bus. The application may be integrated with a bus stop traveler information system using the same wayside infrastructure (e.g., dynamic message sign) where pedestrians are informed of basic information about the bus, such as the route number and final destination, estimated arrival time, and accessibility information, such as whether it is a high or low-floor vehicle and if wheelchair seating is available.

Actors. Transit Vehicle (depicted in blue); RSU (depicted in red); and ITS Roadway Equipment (depicted in orange); Pedestrians; and Transit Vehicle Driver

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

- Transit Vehicles are equipped with communication radios to transmit and receive messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- The Transit Vehicle’s onboard system meets minimum performance requirements (e.g., SAE J2945).
- CAN bus information can be obtained from the Transit Vehicle as needed by the safety applications; any missing data needed for the application may be obtained by other means.
- Positioning data is accurate to provide lane level position of the Transit Vehicle using global positioning (GPS) technology.
- A Channel Plan in place to allow the RSU to receive BSMs and other messages.
- A Security Management System in place to allow RSUs to check BSMs and other messages.
- RSUs are equipped with communication radios to transmit and receive messages from infrastructure and vehicles. In this scenario, messages are transmitted and received using DSRC.
- An audible/visual warning interface is located near the transit bus stop to warn pedestrians.
- [Optional] A set of sensors is located at the bus stop to detect the presence of pedestrians in or near the roadway when a bus is approaching. The system can relay this information to the safety application.
- [Optional] The Transit Vehicle is equipped with a DVI to warn the motor bus driver of potential collisions with pedestrians.

Preconditions. The following preconditions apply to this scenario:

- Pedestrians are waiting at the transit bus stop. A pedestrian may be standing in the street in the direct path of the motor bus.
- The motor bus is traveling in the right lane, approaching the transit bus stop, and intends to stop to pick up the pedestrians.

Flow of Events. The flow of events, corresponding to Figure 6-1, is included below:

1. The Transit Vehicle broadcasts a BSM at a rate of 10 hertz. The BSM includes the vehicle's location, speed, acceleration, and other data included in the SAE J2735 BSM – Part 1 message. The Transit Vehicle also disseminates specific information about the transit vehicle including its route number. Messages are broadcast using DSRC.
2. The RSU receives the BSM and information about the transit vehicle's route number. These data are sent to the Pedestrian Safety System located at the transit bus stop.
3. The Pedestrian Safety System located at the transit bus stop processes the data and determines if the Transit Vehicle will be stopping at the transit bus stop. Once it is determined that the Transit Vehicle has a scheduled stop at that bus stop, the Pedestrian Safety System sends a message to the Audible/Visual Warning Interface.
4. The Audible/Visual Warning Interface located at the transit bus stop sends a warning message to pedestrians waiting at the transit bus stop that the Transit Vehicle is approaching.
5. [Optional Pedestrian Detection] Pedestrian Detection Devices detect that there is a pedestrian in the roadway or very close to the curb near the bus stop. The Pedestrian Safety System processes data from the Transit Vehicle and Pedestrian Detection Devices and determines that the pedestrian is in danger of being struck by the approaching motor bus.
    a. ["smart" alert] A warning message is only sent to the Audible/Visual Warning Interface when there is imminent danger of a pedestrian being struck by an approaching motor bus (i.e., when a bus is arriving at a bus stop and a pedestrian is detected very close to the curb or in the roadway).
    b. A warning message is sent via the RSU to the Transit Vehicle. The Transit Vehicle Driver receives a warning through the DVI that there is a pedestrian in the roadway or too close to the curb near the bus stop when the motor bus approaches the bus stop.
6. The alert of an approaching transit vehicle will continue at a designated interval until the Transit Vehicle is stopped at the bus stop. (Repeat 1-4). [Optional] If a pedestrian continues to be detected in the roadway or too close to the curb, the alert(s) to the pedestrians and/or Transit Vehicle Driver will continue.

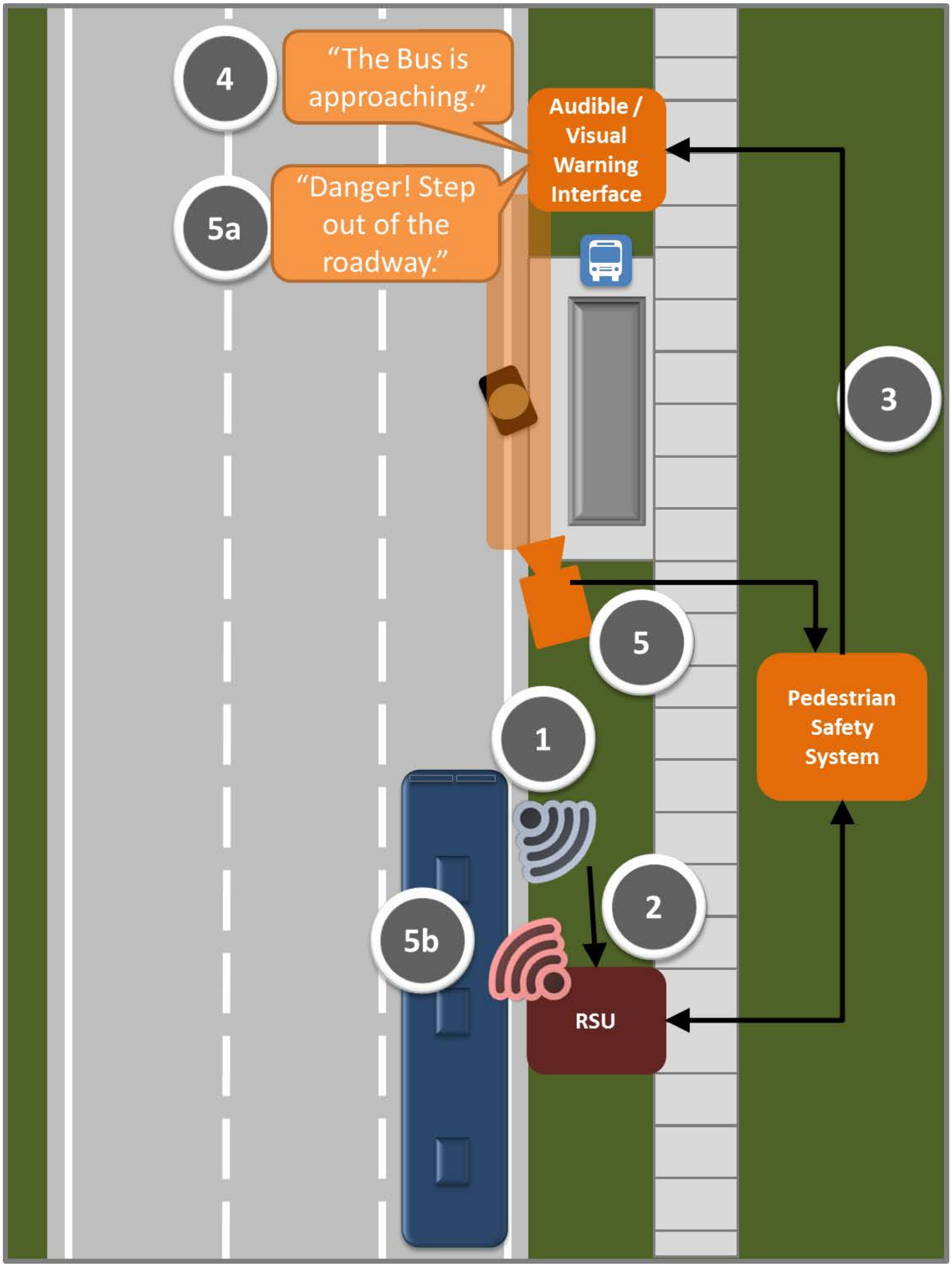

Figure 6-1: Motor Bus Approaching the Transit Bus Stop *(Source: USDOT, 2014)*

6.2 Scenario #2: Motor Bus Departing from the Transit Bus Stop

Description. This scenario describes warning pedestrians when a motor bus departs from the transit bus stop. Infrastructure warns pedestrians located at the bus stop that the motor bus is departing. As an option, the application may be supplemented with a pedestrian detector(s) located at the transit bus stop that detects the presence of a pedestrian in the roadway (e.g., a pedestrian attempting to gain the attention of a bus driver of a bus that is about to or has just departed the bus stop) or too close to the curb who is in danger of being hit by a motor bus leaving the bus stop, and may warn the driver via the Driver-Vehicle Interface (DVI) of a potential collision between the pedestrian and motor bus.

Actors. Transit Vehicle (depicted in blue); RSU (depicted in red); and ITS Roadway Equipment (depicted in orange); Pedestrians; and Transit Vehicle Driver

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

- Transit Vehicles are equipped with communication radios to transmit and receive messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- The Transit Vehicle's onboard system meets minimum performance requirements (e.g., SAE J2945).
- CAN bus information can be obtained from the Transit Vehicle as needed by the safety applications; any missing data needed for the application may be obtained by other means.
- Positioning data is accurate to provide lane level position of the Transit Vehicle using global positioning (GPS) technology.
- A Channel Plan in place to allow the RSU to receive BSMs and other messages.
- A Security Management System in place to allow RSUs to check BSMs and other messages.
- RSUs are equipped with communication radios to transmit and receive messages from infrastructure and vehicles. In this scenario, messages are transmitted and received using DSRC.
- An audible/visual warning interface is located near the transit bus stop to warn pedestrians.
- [Optional] A set of sensors is located at the bus stop to detect the presence of pedestrians in or near the roadway when a bus is departing. The system can relay this information to the safety application.
- [Optional] The Transit Vehicle is equipped with a DVI to warn the motor bus driver of potential collisions with pedestrians.

Preconditions. The following preconditions apply to this scenario:

- The motor bus just picked up passengers at the transit bus stop and is in the process of departing the bus stop.
- A pedestrian may be running towards the bus to catch it before it departs or as it departs.

Flow of Events. The flow of events, corresponding to Figure 6-2, is included below:

1. The Transit Vehicle broadcasts a BSM at a rate of 10 hertz. The BSM includes the vehicle's location, speed, acceleration, and other data included in the SAE J2735 BSM – Part 1 message. Messages are broadcast using DSRC.
2. The RSU receives the BSM from the Transit Vehicle. These data is sent to the Pedestrian Safety System located at the transit bus stop.
3. The Pedestrian Safety System located at the transit bus stop processes the data. It determines that the Transit Vehicle is departing and sends a message to the Audible/Visual Warning Interface at the transit bus stop.
4. The Audible/Visual Warning Interface provides a warning message to pedestrians at the transit bus stop that the Transit Vehicle is departing.
5. [Optional Pedestrian Detection] Pedestrian Detection Devices detect that there is a pedestrian in the roadway or very close to the curb near the bus stop. The Pedestrian Safety System processes data from the Transit Vehicle and Pedestrian Detection Devices and determines that the pedestrian is in danger of being struck by the departing motor bus.
    a. ["smart" alert] A warning message is only sent to the Audible/Visual Warning Interface when there is imminent danger of a pedestrian being struck by a departing motor bus (i.e., when a bus is departing a bus stop and a pedestrian is detected very close to the curb or in the roadway).
    b. A warning message is sent via the RSU to the Transit Vehicle. The Transit Vehicle Driver receives a warning through the DVI that there is a pedestrian in the roadway or too close to the curb near the bus stop when the motor bus departs from the bus stop.
6. The alert of a departing vehicle will continue at a designated interval until the Transit Vehicle has left the bus stop. (Repeat 1-4). [Optional] If a pedestrian continues to be detected in the roadway or too close to the curb, the alert(s) to the pedestrians and/or Transit Vehicle Driver will continue.

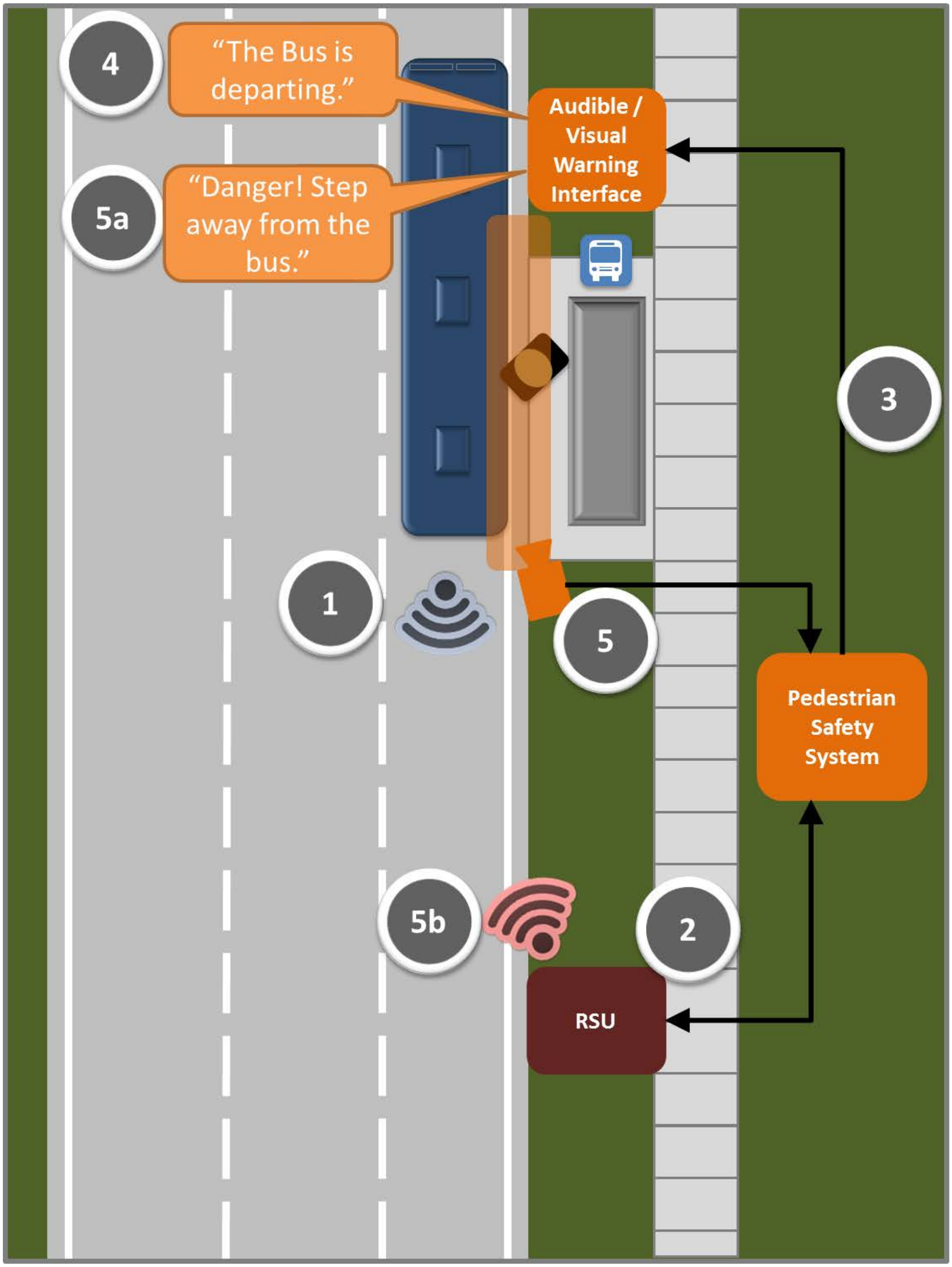

Figure 6-2: Motor Bus Departing from the Transit Bus Stop *(Source: USDOT, 2014)*

6.3 Scenario #3: Warning to Pedestrians of Oncoming Personal Vehicles when Crossing in Front of the Motor Bus

Description. This scenario describes warning alighting bus passengers of a potential collision with oncoming motor vehicles in the vicinity of the bus stop. Infrastructure located at the transit bus stop alerts passengers of approaching vehicles after receiving wireless messages sent from motor vehicles to the roadside infrastructure. In this scenario, passengers getting off the bus that walk in front of the bus may not see motorists traveling in lanes to the left of the bus due to limited line of sight. As an option, this scenario may be supplemented with a pedestrian detector(s) located at the bus stop that detects the presence of a pedestrian in the roadway, and may warn the bus driver and drivers of other motor vehicles in close proximity to the bus stop and/or crosswalk, via their respective DVIs, of a potential collision between the pedestrian and their vehicle.

Actors. Transit Vehicle (depicted in blue); RSU (depicted in red); and ITS Roadway Equipment (depicted in orange); Pedestrians; Other Vehicles; and Transit Vehicle Driver

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

- Transit Vehicles are equipped with communication radios to transmit and receive messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- The Transit Vehicle's onboard system meets minimum performance requirements (e.g., SAE J2945).
- CAN bus information can be obtained from the Transit Vehicle as needed by the safety applications; any missing data needed for the application may be obtained by other means.
- Positioning data is accurate to provide lane level position of the Transit Vehicle using global positioning (GPS) technology.
- Other Vehicles are equipped with DSRC radios and broadcast BSMs.
- A Channel Plan in place to allow the RSU to receive BSMs and other messages.
- A Security Management System in place to allow RSUs to check BSMs and other messages.
- RSUs are equipped with communication radios to transmit and receive messages from infrastructure and vehicles. In this scenario, messages are transmitted and received using DSRC.
- An audible/visual warning interface is located near the transit bus stop to warn pedestrians.
- [Optional] A set of sensors is located at the bus stop to detect the presence of pedestrians in or near the roadway when a bus is stopped at the bus stop. The system can relay this information to the safety application.
- [Optional] Other Vehicles receive messages from infrastructure and have an application on their OBE that will warn the driver, via a DVI, of a pedestrian in the roadway.

Preconditions. The following preconditions apply to this scenario:

- The motor bus just dropped off passengers at the transit bus stop. Pedestrians may attempt to cross the street in front of the motor bus at a marked crosswalk.
- The motor bus is stopped in the right lane at the transit bus stop.
- Pedestrians have a limited line of sight to the Other Vehicles traveling in lanes to the left of the motor bus.

Flow of Events. The flow of events, corresponding to Figure 6-3, is included below:

1. The Transit Vehicle and any Other Vehicles broadcast BSMs at a rate of 10 hertz. The BSM includes the vehicle's location, speed, acceleration, and other data included in the SAE J2735 BSM – Part 1 message. Messages are broadcast using DSRC.
2. The RSU receives the BSMs from the Transit Vehicles and any Other Vehicles in the vicinity of the bus stop. These data are sent to the Pedestrian Safety System located at the transit bus stop.
3. The Pedestrian Safety System located at the transit bus stop processes the data. It determines that the Transit Vehicle is stopped and there is at least one Other Vehicle in the immediate vicinity. Once it is determined that there is potential for a collision, the Pedestrian Safety System sends a signal to the Audible/Visual Warning Interface.
4. The Audible/Visual Warning Interface alerts pedestrians alighting the motor bus that there is an approaching vehicle.
5. [Optional Pedestrian Detection] Pedestrian Detection Devices detect that there is a pedestrian in the roadway in front of the motor bus, which is positioned at the bus stop. The Pedestrian Safety System processes data from the Transit Vehicle, Other Venice(s), and Pedestrian Detection Devices and determines that the pedestrian is in danger of being struck.
    a. ["smart" alert] A warning message is only sent to the Audible/Visual Warning Interface when there is imminent danger of a pedestrian being struck by a departing motor bus (see Scenario #2) or an approaching vehicle in the immediate vicinity of the bus stop.
    b. A warning message is sent via the RSU to the Other Vehicle(s). Other Vehicle Driver(s) receive a warning through their respective DVIs that there is a pedestrian in the roadway in danger of being struck as their vehicle approaches the immediate vicinity of the bus stop.
6. The alert of the approaching vehicle(s) to the Pedestrians will continue at a designated interval until the danger of a potential collision has passed. (Repeat 1-4). [Optional] If a Pedestrian continues to be detected in the roadway after alighting the motor bus, the alert(s) to the Pedestrian and Other Vehicle Driver(s) will continue until the threat of a collision has passed.

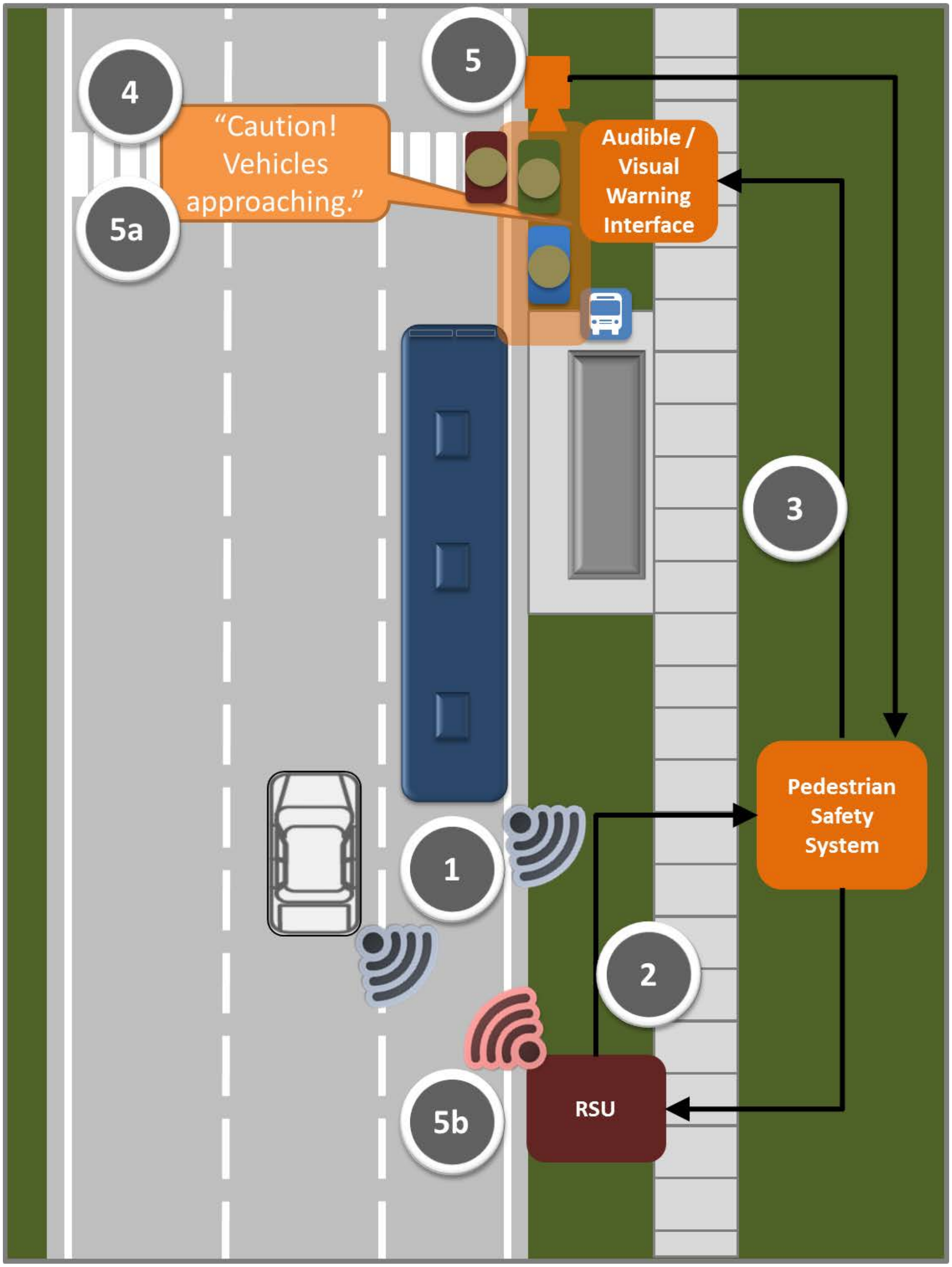

Figure 6-3: Warning to Pedestrians of Oncoming Vehicles when Alighting the Motor Bus at the Transit Bus Stop *(Source: USDOT, 2014)*

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APPENDIX A. List of Acronyms

Acronym	Meaning
AASHTO	American Association of State Highway and Transportatin Officials
ABS	Antilock Braking System
ANSI/AIAA	American National Standards Institute / American Institute of Aeronautics and Astronautics
BSM	Basic Safety Message
CAN	Controller Area Network
CWS	Collision Warning System
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications
DVI	Driver-Vehicle Interface
EMS	Emergency Medical Services
ETA	Estimated Time of Arrival
FCC	Federal Communications Commission
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Adminstration
FTA	Federal Transit Administration
GPS	Global Positioning System
I2V	Infrastructure-to-Vehicle
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
LED	Light-Emitting Diode
LTA	Left-Turn Assist

Acronym	Meaning
MB/DO	Motor Bus, Directly Operated
NHTSA	National Highway Traffic Safety Administration
NTD	National Transit Database
OBE	On-Board Equipment
ODS	Object Detection System
PAX	Passenger
PDS	Pedestrian Detection System
PED	Pedestrian
R/F	Right Front
RCW	Rear Collision Warning
RSE	Roadside Equipment
RSU	Roadside Unit
RSZW	Reduced Speed Zone Warning
SAE	Society of Automotive Engineers
SSGA	Stop Sign Gap Assist
TIM	Traveler Information Message
TRP	Transit Retrofit Package
USDOT	U.S. Department of Transportation
UTC	Coordinated Universal Time
V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
WMATA	Washington Metropolitan Area Transit Authority
X2D	Vehicle or Infrastructure-to-Device

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