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

Transit Bus-Pedestrian/Cyclist Crossing Safety Application: Operational Concept

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16. Abstract

This document serves as an Operational Concept for the Transit Bus-Pedestrian/Cyclist Crossing Safety application. The purpose of this document is to provide an operational description of "how" the Transit Bus-Pedestrian/Cyclist Crossing Safety Warning application may operate.

The Pedestrian/Bicycle Crossing Safety application will alert/warn transit bus drivers as needed based on transit vehicle's intention of traveling across a crosswalk where pedestrians or bicycles may be present and assessed level of collision risk. The application allows messages to be sent to transit vehicle drivers via a driver-vehicle interface, providing an appropriate alert type, based on calculated level of collision risk. The Operational Concept discusses the following scenarios:

- Scenario 1: Motor Bus traveling straight (Signalized intersection)
- Scenario 2: Motor Bus turning (Signalized intersection)
- Scenario 3: Motor Bus traveling straight (unsignalized intersection)
- Scenario 4: Motor Bus turning (Unsignalized intersection)
- Scenario 5: Motor Bus traveling straight (mid-block pedestrian crossing)

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-Pedestrian/Cyclist Crossing Safety application. The purpose of this document is to provide an operational description of "how" the Transit Bus-Pedestrian/Cyclist Crossing Safety application may operate. Within this document, several scenarios that are addressed by this application will be presented. Additionally, when describing the scenarios, the generic term "pedestrian" is used to refer to both pedestrians and bicyclists.

The Pedestrian/Bicycle Crossing Safety application will alert transit bus drivers as needed based on transit vehicle's intention of traveling across a crosswalk where pedestrians or bicyclists may be present and the assessed level of collision risk. The application allows messages to be sent to transit vehicle drivers via a driver-vehicle interface, providing an appropriate alert type, based on calculated level of collision risk. This application is designed to account for multiple transit bus - pedestrian conflict scenarios. The Operational Concept discusses the following scenarios:

- **Scenario 1:** This scenario describes a motor bus approaching a signalized intersection that it will be traveling straight through. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. A roadside unit (RSU) broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.
- **Scenario 2:** This scenario describes a motor bus approaching a signalized intersection where it will be turning. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.
- **Scenario 3:** This scenario describes a motor bus going straight at an unsignalized intersection. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.
- **Scenario 4:** This scenario describes a motor bus turning at an unsignalized intersection. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.
- **Scenario 5:** This scenario describes a motor bus traveling towards an unsignalized, mid-block pedestrian crossing. Pedestrian detection infrastructure detects the presence of a pedestrian in the crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus

OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.

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

1.1 Goals

The Transit Bus-Pedestrian/Cyclist Crossing Safety Warning application is expected to meet the following goals:

- **Goal #1: Utilize Information and Knowledge from Empirical Transit Collision Data.** This application will focus on information derived from empirical data of transit bus and pedestrian/cyclist collisions to improve traffic safety at crossings both at intersection and mid-block locations.
- **Goal #2: Leverage Transit Safety Retrofit Package (TRP) Deployment Experience and Lessons Learned.** This application will leverage accomplishments and lessons learned from TRP, currently being tested and evaluated as part of the Safety Pilot Model Deployment in Ann Arbor, Michigan.
- **Goal #3: Research and Develop Innovative Technologies.** This application is expected to research, develop, and integrate safety technologies and products enabled and/or supported by the connected vehicle environment at pedestrian crossing locations.
- **Goal #4: Promote Pedestrian Safety at intersections and mid-block crossings.** The ultimate goal of this application is to promote pedestrian/cyclist safety by leveraging connected vehicle capabilities to provide proper alerts (inform/caution or warning) regarding heightened collision risk to pedestrians/cyclists and transit drivers at intersections and mid-block crossings.

1.2 Connected Vehicle Research

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

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

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

1.3 The Transit V2I Research Program

The Intelligent Transportation Systems (ITS) Joint Program Office (JPO) is charged with planning and execution the ITS Program as authorized by Congress. The ITS JPO is part of the Research and Innovative Technology Administration (RITA) 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-Pedestrian/Cyclist Crossing 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.

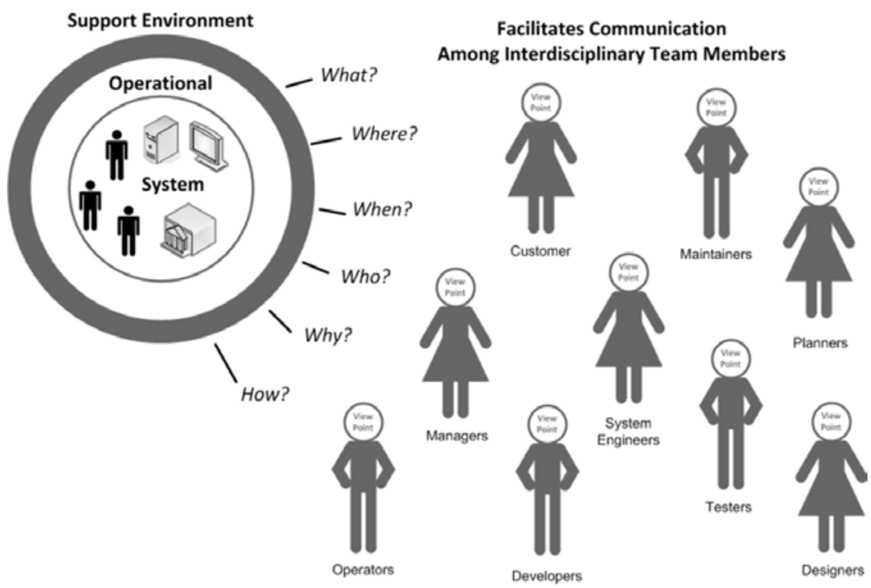

Figure 1-1: Conceptual Representation of the Operational Concept Document (*Source: USDOT, adapted from ANSI/AIAA's "Guide for the Preparation of Operational Concept Documents" ANSI/AIAA G-043-1992)*

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

This document includes the following chapters:

- **Chapter 1** provides the scope, introduction to the Transit V2I Program, and an overview of the document.
- **Chapter 2** includes an overview of transit collisions and the role of the Transit V2I Program to mitigate these collisions. Includes are 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. Included are statistics about motor bus collisions with pedestrians and cyclists at intersections and mid-block crossings and situations where the Transit Bus-Pedestrian/Cyclist Crossing Safety application may help avoid collisions. This chapter also describes existing technologies and systems, including automated pedestrian detection (APD) systems that have been implemented to improve safety at pedestrian crossings.
- **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-Pedestrian/Cyclist Crossing 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 application may be implemented to provide safety benefits at intersections and mid-block pedestrian crossings. 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 transit 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 bus 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 Stop/Station 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 statistics about motor bus collisions with pedestrians and cyclists at intersections and mid-block crossings and situations where the Transit Bus-Pedestrian/Cyclist Crossing Safety application may help avoid collisions. This chapter also describes existing technologies and systems, including automated pedestrian detection (APD) systems that have been implemented to improve safety at pedestrian crossings.

3.1 Motor Bus/Pedestrian Collisions

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. Of these motor bus collisions with pedestrians that resulted in injury, 143 (50.5%) occurred when the pedestrian was in the crosswalk. Twelve fatalities occurred when the pedestrian was in the crosswalk and 15 occurred when the pedestrian was not in the crosswalk. Table 3-1 provides a summary of motor bus collisions with pedestrians. Of the 449 collisions, 51.6% of these collisions occurred at intersections. 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.

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 an intersection is unique, there are three situations that the Transit V2I Program wants to investigate further. These situations are described is the following sections and figures below.

3.1.1 Motor Bus/Pedestrian Collisions at an Intersection where the Motor Bus is Turning

As a motor bus approaches a turn at a signalized intersection, the driver of the bus may not see pedestrians in the crosswalk until the bus is already beginning to turn. The “walk signal” provided to pedestrians gives the pedestrians the right of way and they may not be aware of approaching vehicles. Motor bus drivers may not be able to stop the vehicle before colliding with a pedestrian that they were unable to see when they began the turn. Bicycles, traveling at a significantly faster speed than walkers and joggers, are even more difficult for a driver to spot in advance of a turn. An unsignalized intersection can impose additional operating stress on motorbus drivers, because the must safely navigate the intersection to make the turn without assistance from a traffic signal. Because there are no pedestrian signals, the likelihood of an unexpected pedestrian in the crosswalk increases.

According to the NTD, in 2010, 6.5% of all pedestrian collisions occurred when a motor bus turning right struck a pedestrian in the crosswalk, and 16.2% of all pedestrian collisions when making a left turn. These collisions may be avoided by alerting the motor bus driver to the presence of pedestrians in the crosswalk that the vehicle will be traversing.

Each motor bus crash with a pedestrian that occurs when the bus is making a turn is unique. Table 3-2 includes sample descriptions of motor bus crashes with pedestrians when the motor bus was turning at an intersection. These real-world descriptions help readers of this document better understand the situation described above.

Table 3-2: Sample Descriptions of Motor Bus Crashes with Pedestrians when the Bus is Making a Turn at an Intersection *(Source: 2010 NTD)*

No.	Description
1	LEFT TURNING BUS HIT FEMALE PEDESTRIAN CROSSING STREET.
2	THE DRIVER WAS MAKING A LEFT TURN ON A STEADY GREEN LIGHT. THE INTERSECTION IS CONTROLLED BY AN ELECTRIC SIGNAL THAT HAS STEADY GREEN AND LEFT ARROW GREEN. AS DRIVER WAS MAKING THE LEFT TURN A PEDESTRIAN WAS CROSSING THE CROSSWALK AND WAS STRUCK BY THE BUS. THE PEDESTRIAN HAD A BUMP ON THE HEAD AND SCRAPES AND WAS TAKEN TO THE HOSPITAL FOR TREATMENT AND RELEASED.
3	BUS#2905, TRAVELLING SOUTH ON LOUISIANA INBOUND TO THE RIVER CITY TRAVEL CENTER,STRUCK A PEDESTRIAN IN THE CROSSWALK AS HE WAS MAKING A LEFT TURN ONTO 4TH STREET.
4	BUS SB ON BROADWAY MAKING LEFT TURN TO GO EB ON MAIN STREET COLLIDED WITH A PEDESTRIAN SB IN CROSSWALK ON MAIN STREET. PEDESTRIAN WAS KNOCKED DOWN. PEDESTRIAN WAS TRANSPORTED FOR MEDICAL FROM THE ACCIDENT SCENE.
5	BUS MAKING A LEFT TURN FROM CHESTNUT ST ONTO S.2ND ST. STUCK A PEDESTRIAN THAT CROSSED AGAINST THE POSTED DO NOT WALK LIGHT AND WAS OBSTRUCTED BY ANOTHER VEHICLE. BUS OBSERVED PERSON HIT BRAKES AND BUMPED LADY WHO FELL TO THE ROADWAY.
6	BUS OPERATOR MADE LEFT TURN AND STRUCK PEDESTRIAN WHILE IN THE CROSSWALK.
7	AFTER 2 PASSENGERS EXITED BUS, ONE CROSSED THE STREET IN FRONT OF THE BUS. THE BUS WAS STOPPED AT THE LIGHT AND THEN PROCEEDED TO TURN RIGHT HITTING THE SECOND PASSENGER.
8	GTA BUS WAS MAKE A LEFT TURN FROM BENBOW RD TO BLUFORD AND STRUCK A PEDESTRIAN WHILE CROSSING IN CROSSWALK ON BLUFORD ST
9	INTERCITY TRANSIT BUS WAS TURNING LEFT, HIT PEDESTRIAN IN INTERSECTION CROSSWALK. MEDICS TRANSPORTED WITH MAJOR INJURIES.
10	THE OPERATOR WAS NOTIFIED BY THE COORDINATOR TO HOLD THE COACH AT THE CURRENT LOCATION. THE OPERATOR WAS THEN NOTIFIED THAT THE RIGHT FRONT SIDE OF THE COACH, WHILE TURNING RIGHT AT THE INTERSECTION, MADE CONTACT WITH A PEDESTRIAN WALKING IN THE CROSSWALK. UPON COMPLETING THE TURN, THE RIGHT REAR DUAL TIRE OF THE COACH MADE CONTACT WITH THE PEDESTRIAN LAYING IN THE STREET. THE PEDESTRIAN SUSTAINED LIFE THREATENING INTERNAL INJURIES. SPD AND AID RESPONDED TO THE SCENE AND THE PEDESTRIAN WAS TRANSPORTED VIA MEDIC UNIT #32 TO HMC.
11	THE COACH, WHILE TURNING LEFT AT THE INTERSECTION, MADE CONTACT WITH A PEDESTRIAN WALKING IN THE CROSSWALK. KENT PD AND AID UNIT RESPONDED TO THE SCENE AND THE PEDESTRIAN WAS TRANSPORTED VIA TRI-MED TO VALLEY MEDICAL CENTER. THE TRANSIT OPERATOR WAS CITED.

No.	Description
12	POLICE REPORT SUMMARY: THE DRIVER WAS WESTBOUND ON EMERSON AVENUE AND TURNED SOUTHBOUND ONTO ATLANTIC BLVD. THE PEDESTRIAN WAS ALSO WESTBOUND IN THE SOUTH CROSSWALK AND BEGAN WALKING FASTER TO GET TO THE WEST SIDEWALK. AS THE PEDESTRIAN DID SO, THE VEHICLE COLLIDED INTO HIM AS DRIVER TRIED TO STOP THE VEHICLE. THE PEDESTRIAN WAS SUBSEQUENTLY KNOCKED DOWN ONTO THE ROADWAY WHILE IN THE CROSSWALK AS HE WAS STRUCK ON THE RIGHT SIDE OF HIS BODY.POLICE STATES THAT IF VEHICLE WAS NOT ATTEMPTING TO STOP AND OR TRAVELING AT A HIGHER RATE OF SPEED, HE WOULD HAVE COLLIDED INTO THE PEDESTRIAN AND DRIVEN OVER HIM.THE DRIVER AND PEDESTRIAN CAUSED THIS COLLISION. THE DRIVER SHOULD HAVE STOPPED SOONER AND THEREFORE FAILED TO YIELD TO THE PEDESTRIAN IN THE CROSSWALK. THE PEDESTRIAN ALSO WAS AT FAULT DUE TO THE FACT THAT HE ENTERED INTO THE CROSSWALK DESPITE THE RED HAND AND THEREFORE HE BEGAN TO WALK FASTER WHILE IN THE CROSSWALK TO GET OUT OF THE ROADWAY TO AVOID THE BUS.
13	V-1 BUS NEGOTATING A RIGHT TURN SOUTHBOUND TO WESTBOUND STRUCK PEDESTRIAN-2 SOUTHBOUND IN THE WEST CROSSWALK.
14	BUS WAS N/B ON ARGYLE, MAKING A LEFT TURN TO W/B YUCCA AND STRUCK A PEDESTRIAN WHO WAS CROSSING IN THE WEST CROSSWALK OF THE INTERSECTION.
15	BUS HEADING E/B IN THE RIGHT TURN LANE OF CESAR CHAVEZ AVE, TURNING RIGHT TO S/B VIGNES ST, STRUCK TWO PEDESTRIANS WHO WERE CROSSING N/B IN THE WEST CROSSWALK OF THE INTERSECTION.
16	BUS, TURNING LEFT FROM W/B 1ST ST TO S/B BROADWAY, STRUCK A PEDESTRIAN WHO WAS E/B, CROSSING BROADWAY IN THE SOUTH CROSSWALK.
17	V-1 (BUS), W/B LEFT TURN LANE OF HOLLYWOOD BLVD., TURNING TO S/B ARGYLE AVE, COLLIDED WITH A PEDESTIRAN (P-2), WHO WAS W/B ON THE SOUTH SIDE OF HOLLYWOOD BLVD, AND RAN OUT INTO THE CROSSWALK IN FRONT OF THE BUS.
18	BUS MOVING ON RIGHT TURN. MALE PEDESTRIAN CROSSING LEFT TO RIGHT FRONT OF BUS IS STRUCK. PED CLAIMED INJURY
19	BUS #3448 WAS TRAVELING NORTHBOUND ON LEDWICKE MAKING A LEFT TURN AT THE INTERSECTION OF TILGHAM WHEN CONTACT WAS MADE WITH A PEDESTRIAN IN THE CROSSWALK.
20	BUS #3431 WAS TURNING LEFT FROM BRAZOS TO DALLAS WHEN IT STRUCK A PEDESTRIAN IN THE CROSSWALK.
21	BUS HAD STOPPED FOR A RED LIGHT AND WHEN THE LIGHT TURNED GREEN, THE BUS PROCEEDED IN MAKING A LEFT TURN AND BUS HIT A PEDESTRIAN THAT WAS IN THE CROSSWALK.
22	PEDESTRIAN WAS STRUCK BY AN MST BUS WHILE CROSSING THE STREET AT THE INTERSECTION OF PACIFIC @ DEL MONTE. THE BUS WAS MAKING A LEFT TURN FROM DEL MONTE ONTO PACIFIC AND THE DRIVER DID NOT SEE THE PEDESTRIAN UNTIL THE PERSON STEPPED INTO VIEW FROM THE HEADLIGHTS. THE BUS WAS TRAVELING AT A VERY SLOW SPEED AND ATTEMPTED TO STOP BUT STILL MADE CONTACT WITH THE PEDESTRIAN. IT WAS DARK AND VERY FOGGY AT THE TIME OF THE ACCIDENT. THE 87 YEAR OLD PEDESTRIAN WAS TAKEN TO THE HOSPITAL AND DIED THE FOLLOWING DAY. THE POLICE REPORTED THIS AS MINOR INJURIES AND TREATED AT THE HOSPITAL. IT WAS A FEW DAYS LATER THAT WE LEARNED THE PEDESTRIAN HAD PASSED AWAY.
23	BUS MAKING LEFT TURN; PEDESTRIAN CROSSING LEFT TO RIGHT IN FRONT OF BUS; COLLISION; PEDESTRIAN CLAIMED INJURIES; EMS; HOSPITAL
24	BUS MOVING ON LEFT TURN. MINOR PED CROSSING ROADWAY LEFT TO RIGHT FRONT OF BUS. PED STRUCK R/F SIDE OF BUS, FALLING TO PAVEMENT CLEAR OF BUS. B/O CLAIMS NO KNOWLEDGE OF INCIDENT. PED CLAIMED INJURY TO HAND.
25	BUS MOVING ON LEFT TURN. PEDESTRIAN WALKING IN CROSSWALK FROM LEFT TO RIGHT FRONT OF BUS. L/F OF BUS STRUCK MALE PED CAUSING HIM TO FALL TO PAVEMENT. PED CLAIMED INJURY
26	BUS MOVING ON LEFT TURN. FEMALE PED AGE 81 CROSSING ROADWAY FROM LEFT TO RIGHT FRONT OF BUS. L/F OF BUS STRUCK PED. PED FELL TO ROADWAY. B/O BECAME DISTRAUGHT. PED AND B/O ARE TAKEN TO HOSP. PED EXPIRED ON ARRIVAL AT HOSP.
27	BUS MOVING ON RIGHT TURN. WHEELCHAIR PEDESTRIAN AND ATTENDANT WALKING IN CROSSWALK FROM LEFT TO RIGHT, RIGHT OF BUS. R/R OF BUS STRUCK BOTH PEDESTRIANS. BOTH CLAIMED INJURIES.
28	BUS MOVING ON LEFT TURN. FEMALE PED AGE 26 PUSHING CHILD IN STROLLER IN CROSSWALK FROM RIGHT TO LEFT FRONT OF BUS. L/F OF BUS STRUCK STROLLER. BOTH PEDS FELL TO PAVEMENT. BOTH INJURED
29	BUS MOVING ON LEFT TURN. FEMALE PED AGE 57 CROSSING ROADWAY FROM RIGHT TO LEFT FRONT OF BUS. L/F CORNER OF BUS STRUCK PED. PED FELL TO ROADWAY, CLAIMED INJURY

No.	Description
30	BUS MOVING ON A RIGHT TURN. TWO PEDESTRIANS CROSSING ROADWAY FROM RIGHT TO LEFT RIGHT OF BUS STEP OFF CURB. ONE OF THE PEDS WALK INTO R/R SIDE OF BUS, AND FELL TO PAVEMENT THE OTHER PED APPARENTLY KNOCKED OVER BY THE FIRST, ALSO FALLING TO THE PAVEMENT MAKING NO CONTACT WITH THE BUS. BOTH PEDS CLAIMED INJURY.
31	BUS MOVING ON LEFT TURN. PEDESTRIAN CROSSING STREET FROM RIGHT TO LEFT IN CROSSWALK FRONT OF BUS. R/F BUMPER OF BUS STRUCK PEDESTRIAN, WHO FELL TO ROADWAY. PED CLAIMED LEG INJURY; REMOVED TO HOSPITAL BY EMS.
32	BUS MOVING ON RIGHT TURN. PEDESTRIAN CROSSING ROADWAY RIGHT TO LEFT, LEFT OF BUS. R/F OF BUS STRUCK PEDESTRIAN, WHO FELL TO ROADWAY AND CLAIMED INJURIES; REMOVED TO HOSPITAL BY EMS.
33	BUS MOVING ON RIGHT TURN. FEMALE PEDESTRIAN AGE 71 WALKING IN CROSSWALK FROM RIGHT TO LEFT OF BUS. RIGHT FRONT BUMPER OF BUS STRUCK PEDESTRIAN. PEDESTRIAN FELL AND CLIMED INJURY TO LEFT HIP, REFUSED MEDICAL ATTENTION, AND LEFT SCENE UNASSISTED. FEMALE CUSTOMER AGE 77 CLAIMED INJURY TO IGHT KNEE AND TEETH, WAS REMOVED TO AN AREA HOSPITAL BY EM.
34	BUS TURNING LEFT. FEMALE PEDESTRIAN APPROX AGE 60 CROSSING ROADWAY FROM RIGHT TO LEFT, LEFT OF BUS. RIGHT FRONT SIDE OF BUS STRUCK PEDESTRIAN. PEDESTRIAN FELL TO ROADWAY CLEAR OF BUS, CLAIMED INJURIES AND WAS REMOVED TO AREA HOSPITAL BY EMS.
35	BUS MOVING ON LEFT TURN. PED RUNNING ACROSS ROADWAY FROM RIGHT TO LEFT, RIGHT OF BUS IS STRUCK BY R/F SIDE OF BUS. PED FELL TO ROADWAY, CLEAR OF BUS. PED CLAIMED INJURY; REMOVED TO HOSPITAL BY EMS.
36	BUS MOVING ON LEFT TURN. FEMALE PEDESTRIAN AGE 30 CROSSING ROADWAY FROM RIGHT TO LEFT RIGHT OF BUS. PEDESTRIAN STRUCK RIGHT SIDE MIDSECTION OF BUS AND FELL TO ROADWAY CLEAR OF BUS. PEDESTRIAN CLAIMED UNKNOWN INJURY AND WAS REMOVED BY EMS TO AN AREA HOSPITAL.
37	BUS MOVING ON LEFT TURN. MALE PEDESTRIAN AGE 67 CROSSING ROADWAY FROM LEFT TO RIGHT FRONT OF BUS. LEFT FRONT CORNER OF BUS STRUCK PEDESTRIAN. PEDESTRIAN FELL TO ROADWAY. LEFT FRONT WHEEL OF BUS STRUCK PEDESTRIAN. PEDESTRIAN CLAIMED INJURY TO RIGHT LEG AND WAS REMOVED BY EMS TO AN AREA HOSPITAL.
38	BUS MOVING ON LEFT TURN. MALE PEDESTRIAN(28)WALKING RIGHT TO LEFT IN CROSSWALK LEFT OF BUS. LEFT FRONT SIDE OF BUS STRUCK MALE.MALE CLAIMED VARIOUS INJURIES. OPERATOR CALLED FOR ASSISTANCE. OPERATOR CLAIMED TRAUMA, AND BECAME ILL, FALLING TO SIDEWALK CLEAR OF BUS. OPERATOR CLAIMED HEAD INJURY. EMS REMOVED MALE AND OPERATOR TO AREA HOSPITAL.
39	THE BUS TURNED RIGHT ONTO COURT STREET FROM NIAGARA SQUARE (CIRCLE)ON A STEADY GREEN LIGHT. A PEDESTRIAN STEPPED OFF THE CURB WALKING INTO THE RIGHT REAR (BEHIND THE REAR WHEELWELL) SIDE OF THE BUS. BUS VIDEO SHOWS THAT THE PEDESTRIAN DID NOT LOOK AND BEGAN CROSSING ON "DO NOT WALK" SIGN FOR FOOT TRAFFIC.
40	BUS ATTEMPTING LEFT TURN. WHEEL CHAIR PEDESTRIAN CROSSING STREET. DRIVER STATES THAT PEDESTRIAN WAS NOT VISIBLE AND CONTACT WAS MADE.
41	V1 ATTEMPTED LEFT TURN AND STOPPED BEFORE MAKING CONTACT WITH PEDESTRIAN IN CROSSWALK
42	V1 ATTEMPTED LEFT HAND TURN OFF SENECA MANOR DRIVE ONTO HUDSON AVENUE AND STRUCK PEDESTRIAN AT OR NEAR CROSSWALK CAUSING SEVERE PHYSICAL INJURY TO PEDESTRIAN.
43	BUS TURNING LEFT FROM DORRANCE TO WASHINGTON STRUCK A PEDESTRIAN IN CROSS WALK.
44	BUS WAS MAKING RIGHT TURN, AND DID NOT NOTICE PEDESTRIAN IN CROSSWALK. BUS MADE CONTACT WITH PEDESTRIAN AROUND THE FRONT DOOR OF THE BUS.
45	COACH 5466 WAS TRAVELING OUTBOUND HEADING SOUTH ON FILLMORE STREET. AS THE COACH MADE A RIGHT TURN ON A GREEN TRAFFIC SIGNAL FROM FILLMORE STREET ONTO UNION STREET, A PEDESTRIAN AT THE NORTHWEST CORNER STARTED WALKING SOUTH IN THE WESTERLY CROSSWALK. THE RIGHT CORNER OF THE COACH'S FRONT BUMPER ALLEGEDLY MADE CONTACT WITH THE PEDESTRIAN, WHO INITIALLY REFUSED AID. HE CHANGED HIS MIND, COMPLAINED ABOUT SHOULDER AND CHEST PAIN, AND WAS TRANSPORTED TO SAN FRANCISCO GENERAL HOSPITAL.
46	ACCORDING TO THE INFORMATION, THE OPERATOR WAS MAKING A LEFT TURN WHEN CONTACT OCCURRED WITH A PEDESTRIAN CROSSING THE STREET IN AN UNMARKED CROSSWALK AT AN INTERSECTION.
47	BUS WAS MAKING LEFT TURN AND STRUCK PEDESTRIAN IN CROSSWALK. PEDESTRIAN SUFFERED INJURIES TO HIS LEFT WRIST.
48	BUS TURNED LEFT ON GREEN LIGHT FROM WEBSTER ST. ONTO EASTBOUND UNIVERSITY AVE. AND LEFT SIDE OF COACH MADE CONTACT WITH PEDESTRIAN IN CROSSWALK WHO THEN FELL UNDER PATH OF TURNING COACH

No.	Description
49	ON SATURDAY A BUS MADE A LEFT TURN AND HIT FIVE PEDESTRIANS IN THE CROSSWALK. THE PEDESTRIANS HAD THE LIGHTED "WALK" SIGNAL AND THE RIGHT-OF-WAY. TWO OF THE PEDESTRIANS DIED AT THE SCENE. ONE WAS SERIOUSLY INJURED. TWO MORE SUSTAINED INJURIES BUT WERE TREATED AT THE HOSPITAL AND RELEASED THAT NIGHT.
50	BUS WAS NEGOTIATING A LEFT TURN FROM SOUTH HERITAGE DRIVE (WESTBOUND) TO EAST CAMPUS DRIVE (SOUTHBOUND) ON A GREEN LIGHT. THE BUS STOPS FOR 2-PEDESTRIANS CROSSING EAST CAMPUS DRIVE (WEST TO EAST). OPERATOR OF THE BUS DOESN'T SEE A THIRD PEDESTRIAN AND PROCEEDS WITH THE TURN STRIKING THE PEDESTRIAN WITH THE LEFT/DRIVER'S SIDE OF THE BUS KNOCKING THE PEDESTRIAN TO THE GROUND.
51	BUS WAS NEGOTIATING A LEFT HAND TURN AS AN ELECTRIC WHEELCHAIR PEDESTRIAN WAS CROSSING THE STREET. THE BUS DID NOT SEE THE PERSON CROSSING AND STRUCK THE WHEELCHAIR.
52	METROBUS WAS TRAVELING SOUTHBOUND ON ALABAMA AVE. IN THE CURB LANE. HE WAS ATTEMPTING A RIGHT TURN ONTO WESTBOUND IRVING ST. AS HE WAS TURNING THE BUS AN INTOXICATED PEDESTRIAN TRIED TO CROSS THE STREET OUTSIDE OF THE CROSSWALK AND THE BUS' LEFT FRONT HEADLIGHT ASSEMBLY MADE CONTACT WITH THE PEDESTRIAN'S FRONT UPPER TORSO WHICH CAUSED THE PEDESTRIAN TO FALL BACKWARDS TO THE PAVEMENT.

Note: *: description modified from its NTD source to protect transit agency specific information.

3.1.2 Motor Bus Collisions with Pedestrians at Intersections, Bus Going Straight

According to the NTD, in 2010, 130 of the 449 (28.9%) pedestrian collisions resulting in injuries occurred when the bus was traveling straight through an intersection. These collisions may be avoided by alerting the motor bus driver to the presence of pedestrians in the crosswalk that the vehicle will be traversing.

Table 3-3 shows sample descriptions of motor bus crashes with pedestrians when the motor bus was going straight at an intersection. These real-world descriptions help readers of this document better understand the situation described above.

Table 3-3: Sample Description of Motor Bus Crashes with Pedestrians when the Bus is Going Straight at an Intersection *(Source: 2010 NTD)*

No.	Description
1*	BUS WAS HEADING DOWN ADAM STREET AND THERE WERE 2 PEDESTRIANS IN THE CROSSWALK AND THE DRIVER HIT THE 1ST PEDESTRIAN, WHILE CAUSING THE 2ND PEDESTRIAN TO FALL.
2	RIGHT FRONT BUMPER OF BUS CONTACTS PEDESTRIAN THAT STEPPED OUT ONTO CROSSWALK.
3	PEDESTRIAN WITH HOODED SWEATER DID NOT SEE BUS WHILE CROSSING STREET. BUS MADE CONTACT WITH PEDESTRIAN.
4	BICYCLIST FAILED TO STOP FOR RED LIGHT & CROSSED PATH OF BUS COMING THRU INTERSECTION. UNSURE IF CONTACT WAS MADE BETWEEN BIKE & BUS. GIRL SPILLED BIKE, GOT UP WITH NO APPARENT INJURIES. MEDICAL TRANSPORT FOR PRECAUTIONARY REASONS.
5*	V-1 BUS WESTBOUND ON WASHINGTON STREET COLLIDED WITH PARTY-2 AND PARTY-3 SOUTHBOUND IN THE CROSSWALK.
6*	V-1(BUS) WAS TRAVELING WESTBOUND ON MADISON APPROACHING 11TH AVE. IN THE #2 LANE. AS V1 ENTERED THE INTERSECTION, 2 PEDESTRIANS (P-2 & P-3) WALKING SOUTH ON 11TH AVE., ENTER THE CROSSWALK WITHOUT YIELDING TO THE APPROACHING BUS, CAUSING IMPACT TO THE FRONT RIGHT SIDE WINDSHIELD.
7	V-1 (BUS)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 ACROSS VERMONT AVE. ON A RED LIGHT, COLLIDING WITH V-1.

No.	Description
8*	V-1 (BUS) WAS E/B #2 LANE OF ADAM AVE, APPROACHING THE INTERSECTION WITH HALLDALE AVENUE. P-2 BICYCLIST WAS N/B ON HALLDALE AVENUE APPROACHING THE INTERSECTION. P-2 ROAD HIS BICYCLE INTO THE PATH OF V-1, RODE APPROXIMATELY HALFWAY ACROSS THE INTERSECTION, THEN MADE A U-TURN AND RODE BACK S/B INTO THE PATH OF THE APPROACHING BUS, COLLIDING WITH IT.
9	VEHICLE #1 (BUS) WESTBOUND 8TH ST #3 LANE, APPROACHING GRANDVIEW ST. VEHICLE #2 (BICYCLE) WAS NORTHBOUND GRANDVIEW ST APPROACHING 8TH ST. V-2 SUDDENLY CROSSED 8TH ST, DIRECTLY IN FRONT OF V-1, STRIKING THE RIGHT FRONT CORNER OF VEHICLE.
10	THE BUS WAS TRAVELING EAST ON FAYETTE ST. A WOMAN WHO WAS WEARING HEADPHONE ATTEMPTED TO CROSS THE STREET. THE OPERATOR STATED HE TRIED TO AVOID HITTING THE PEDESTRIAN BUT WAS NOT SUCCESSFUL.
11	BUS STOPPED FOR LIGHT. WHEN LIGHT CHANGED BUS PROCEEDED AHAED AND STRUCK A PEDESTRIAN IN CROSSWALK WHO WAS CROSSING AGAINST THE LIGHT, CROSSING TWO LANES OF TRAFFIC BEFORE REACHING THE AREA OF THE FRONT OF THE BUS.
12	BUS HIT PEDESTRIAN RUNNING ACROSS THE STREET. PEDESTRIAN WAS IN THE CROSSWALK AND HAD A RED LIGHT. BUS HAD GREEN LIGHT.
13*	BUS WAS TRAVELING SOUTH ON VERMONT ST. THE LIGHT WAS GREEN AT 6TH ST. A PEDESTRIAN WITH THEIR HOOD UP WAS CROSSING 6 ST. IN THE SAME DIRECTION. AS THE BUS APPROACHED THE PEDESTRIANS PATH WAS MERGING WITH THE BUS AND THE BUS HIT THE PEDESTRIAN WITH THE FRONT RIGHT CORNER OF THE BUS.
14	BUS MOVING STRAIGHT. MALE CYCLIST AGE 31 MOVING ON CROSS STREET RIGHT TO LEFT RIGHT OF BUS. FRONT OF BUS STRUCK CYCLIST, CAUSING HIM TO FALL TO PAVEMENT UNDER FRONT BUMPER OF BUS. CYCLIST CLAIMED INJURIES.
15	BUS HAD A GREEN LIGHT AND A LADY THAT WAS JOGGING AND NOT PAYING ATTENTION RAN INTO THE SIDE OF THE BUS. HER CROSSWALK SIGNAL WAS DON'T WALK.
16	BUS MADE CONTACT WITH THREE CHILDREN CROSSING THE STREET, KILLING ONE AND INJURING TWO.
17	BUS MOVING STRAIGHT. BICYCLIST CHANGING LANES FROM LEFT TO RIGHT FROM CROSS STREET LEFT OF BUS. BICYCLIST WENT THROUGH RED TRAFFIC LIGHT. FRONT TIRE OF BIKE STRUCK L/F OF BUS. CYCLIST FELL TO PAVEMENT CLEAR OF BUS, CLAIMING HEAD INJURY.
18	BUS MOVING. FEMALE PEDESTRIAN AGE 72 WALKING ACCROSS STREET FROM RIGHT TO LEFT IN PATH OF BUS. RIGHT SIDE FRONT BUMPER OF BUS STRUCK PEDESTRIAN, CLAIMED INJURY AND WAS REMOVED TO HOSPITAL BY EMS.
19	OPERATOR REPORTS VIA THE PHONE A PEDESTRIAN WAS CROSSING IN FRONT OF THE BUS FROM THE STREET SIDE TO THE CURB SIDE.
20*	FEMALE WAS RUNNING ACCROSS THE STREET AT 6TH AVE. AND ENOS PLACE WHEN SHE WAS STRUCK BY THE BUS.
21	BUS WAS TRAVELING EAST ON FORBES AVENUE WHEN HE WITNESSED A PEDESTRIAN STAGGERING IN THE MIDDLE OF THE ROAD. HE SAID THAT HE SLOWED DOWN TO LET HIM GET ACROSS. THEN AS THE BUS PROCEEDED TO START TO GO, HE HEARD BANGING ON THE SIDE OF THE BUS AND SAW THE MAN. HE STATED THAT HE THEN SAW HIM FALL TO THE GROUND. HE IMMEDIATELY STOPPED THE BUS. I WOULD LIKE TO ADD THAT THE BUS HAD THE STEADY GREEN LIGHT DURING THIS INCIDENT AND THE ACTOR HAD A STRONG ODOR OF ALCOHOL EMANATING FROM HIS PERSON ACCORDING TO THE MEDICS.
22	PEDESTRIAN WAS WALKING ACROSS THE STREET IN DARK COLORED CLOTHS WITH A HOOD OVER HIS HEAD, AND DID NOT SEE OR HEAR THE BUS APPROACHING. PEDESTRIAN MADE CONTACT WITH THE FRONT OF THE BUS AND WAS KNOCKED TO THE GROUND (WINDSHIELD ON BUS WAS BROKEN). PEDESTRIAN SUSTAINED ONLY MINOR INJURIES.
23	PEDESTRIAN CROSSING THE ROADWAY IN A CROSSWALK WHEN THEY WERE STRUCK BY A COACH.
24*	ACCORDING TO THE OPERATOR AND TWO WITNESSES ON TEH BUS, THE BUS WAS TRAVELING EASTBOUND ON WILLIAM AT 6TH ST, WHEN AN INTOXICATED SUBJECT STARTED CROSSING THE STREET AGAINST THE RED LIGHT. THE BUS STOPPED TO AVOID THE PEDESTRIAN. HOWEVER, AS THE PEDESTRIAN WALKED ACROSS THE FRONT OF THE BUS HE FELL AND HIT THE LEFT FRONT CORNER OF THE BUS THAT HAD STOPPED TO ALLOW HIM TO CROSS.
25*	BUS WAS TRAVELING WESTBOUND ON LIBERTY ST IN THE OUTSIDE, CURB LANE THROUGH THE INTERSECTION OF MAIN ON A GREEN LIGHT. A PEDESTRIAN PUSHING A SHOPPING CART AND TRAVELING NORTHBOUND ON THE FARSIDE OF THE INTERSECTION WAS CROSSING LIBERTY ST. OPERATOR DID NOT SEE THE PEDESTRIAN CROSSING LIBERTY ST UNTIL IT WAS TOO LATE AND THE BUS HIT THE PEDESTRIAN.
26	PEDSTRIAN WALKING WEST ACROSS STREET WAS HIT BY THE SIDE OF A PASSING BUS.

Note: *: description modified from its NTD source to protect transit agency specific information.

3.1.3 Motor Bus Collisions with Pedestrians at Mid-Block Crossings

Table 3-4 provides a summary of motor bus collisions with pedestrians. Of the 449 collisions in 2010, 25.9% of these collisions occurred at mid-block locations when the motor bus was going straight. It should be noted that these pedestrian collisions that occurred mid-block are not only limited to locations where there are marked pedestrian crossings, but also include pedestrian jaywalking and any instances other than using a marked crosswalk that led to a collision.

Table 3-4: 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%**

Table 3-5 shows sample descriptions of motor bus crashes with crossing person(s) at a mid-block location. These real-world descriptions help readers of this document better understand the situation described above.

Table 3-5: Sample Description of Motor Bus Crashes with Crossing Pedestrian(s) at a Mid-block Location *(Source: 2010 NTD)*

No.	Description
1*	BUS HAD LEFT A STOPPED POSITION AT A STOP BAR PAINTED ON THE PAVEMENT EAST OF FARMERS’MARKET. SIMULTANEOUSLY, THE PEDESTRIAN WAS BEGINNING TO CROSS THE LOT WEST OF THE BUS'S LOCATION. DRIVER OF BUS STATES HE WAS LOOKING TO HIS RIGHT AS HE WAS TRAVELLING WEST AND DIDT NOT SEE THE PEDESTRIAN UNTIL THE POINT OF IMPACT. ALL PASSENGERS OF THE BUS SAW THE PEDESTRIAN IN THE PVA (WESTGATE)
2	BUS WAS TRAVELING IN THE RIGHT LANE OF DAVIE BLVD WHEN A BICYCLIST TRAVELING IN THE BIKE LANE CUT IN FRONT OF THE BUS AND COLLIDED WITH THE FRONT WINDSHIELD. THE BUS SWERVED TO THE LEFT AND CROSSED THE MEDIAN BEFORE COMING TO A STOP.
3*	V-1 (BUS) WAS S/B #1 LANE OF CENTRAL AVENUE, SOUTH OF THE INTERSECTION OF WASHINGTON STREET. P-2 (AN UNKNOWN PEDESTRIAN) RAN ACROSS CENTRAL AVENUE, SOUTH OF THE INTERSECTION, FROM EAST TO WEST, FAILING TO YIELD TO V-1 AS IT APPROACHED HIM. THE PEDESTRIAN WAS STRUCK BY THE LEFT SIDE MIRROR OF V-1 AS THE BUS PASSED BY.
4	BUS MOVING; PEDESTRIAN CROSSING RIGHT TO LEFT ON RIGHTSIDE OF BUS; PEDESTRIAN STRUCK BUS; PEDESTRIAN CLAIMED INJURY; EMS; HOSPITAL
5	BUS MOVING STRAIGHT. MALE CYCLIST AGE 16 MOVING ON ADAM STREET FROM RIGHT TO LEFT, RIGHT OF BUS. PART OF BICYCLE STRUCK R/F OF BUS. CYCLIST CLAIMED INJURY
6	BUS MOVING STRAIGHT. PED AGE 87 CROSSING ROADWAY FROM RIGHT TO LEFT FRONT OF BUS IS STRUCK BY BUS. PED FELL TO PAVEMENT, AND CLAIMED ARM AND HEAD INJURIES.
7	BUS MOVING STRAIGHT. PEDESTRIAN CROSSING ROADWAY RIGHT TO LEFT, RIGHT OF BUS. RIGHT FRONT OF BUS STRUCK PED. PED CLAIMED INJURY; REMOVED TO HOSPITAL BY EMS.
8	OPERATOR V1 TRAVELING SOUTHBOUND ON HUDSON AVENUE AT APPROXIMATELY 10MPH. OPERATOR V1 WAS DISTRACTED FROM TALKING TO CUSTOMER WHEN HE TURNED TO SEE A PEDESTRIAN CROSSING IN FRONT OF THE BUS. THE FEMALE PEDESTRIAN HAD TURNED FACING AWAY FROM V1 AFTER BEING DISTRACTED BY THE SOUNDING HORN OF ANOTHER MOTORIST. OPERATOR OF V1 COULD NOT STOP IN TIME AND SIDESWIPED THE PEDESTRIAN.

No.	Description
9	AS THE BUS CROSSED THROUGH THE INTERSECTION OF BROAD ST. AND WASHINGTON ST.(NORTH-BOUND),THE DRIVER NOTICED A MAN ON THE NW SIDE OF THE ROADWAY, STANDING STATIONARY. AS THE DRIVER CONTINUED NORTHBOUND, THE DRIVER CONTINUED TO SCAN THE ROADWAY; LOOKING LEFT,RIGHT, AHEAD OF HER VEHICLE, AND BEHIND HER VEHICLE. THE DRIVER CONTINUED TO MONITOR THE POSITION OF THE MAN STANDING ON THE SIDE OF THE ROAD. THE MAN CONTINUING TO STAND STATIONARY, INDICATING TO THE DRIVER OF HIS INTENTIONS TO STAY WHERE HE WAS. ALL OF A SUDDEN, THE MAN SPRINTED IN FRONT OF THE BUS. THE DRIVER HIT THE MAN WITH THE BUS, DAMAGING THE PASSENGER-SIDE WINDSHIELD AND THE BIKE RACK. IN ORDER TO AVOID RUNNING-OVER THE MAN, THE DRIVER SWERVED TO THE LEFT (AFTER IMPACT).
10	FROM THE MIDDLE OF THE ROAD, THE PEDESTRIAN RAN ACROSS TWO LANES OF BUSY TRAFFIC RIGHT IN FRONT OF THE BUS WHICH WAS IN THE "BUS ONLY" LANE AND WAS STRUCK BY THE BUS.
11	BUS STRUCK PEDESTRIAN AS HE WAS RUNNING ACROSS THE STREET ATTEMPTING TO CATCH THE BUS
12*	BUS STRUCK PEDESTRIAN CROSSING IN THE CROSSWALK AT JEFFERSON SUBWAY STATION

Note: *: description modified from its NTD source to protect transit agency specific information.

3.2 Existing ITS Solutions to Mitigate Motor Bus Collisions with Pedestrians

The following are three 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) 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.[3]

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.[4]

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."*[5]

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.[6]

Figure 3-1: Mobileye's Pedestrian Detection System *(Source: Mobileye)* [6]

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[7]. 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 mobility-impaired pedestrians 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 SmartWalkTM XP sensor was used to detect the presence of a pedestrian in the crosswalk, as depicted in Figure 3-2.

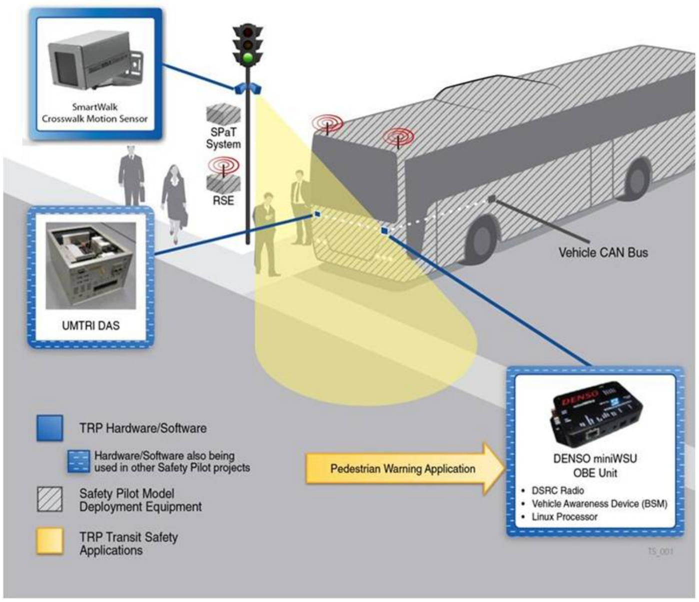

Figure 3-2: Illustration of the Pedestrian Warning Application from the TRP with All Hardware Components *(Source: Transit Retrofit Package ConOps, 2012)*

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*[8] 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.

A key component in the Transit Vehicle Pedestrian-Cyclist Crossing Safety Application relies on consistent and accurate pedestrian/cyclist detection at intersections and mid-block locations. At signalized crossing, pedestrian detection through push button has been widely deployed throughout the U.S. Where buttons exist, pedestrians push them as a way to communicate with respective signal controllers to activate appropriate pedestrian crossing phase and/or time to cross the street. Anecdotally, lots of people don't bother to press the button at pedestrian crossings. The usage of push buttons increases when pedestrians perceive a clear need and benefit in doing so, such as in heavy vehicular traffic locations or clearly shortened wait time associated with pushing the button. According to the National Center for Safe Routes to School[9], only about 50 percent of pedestrians actually push the buttons based on a FHWA research project. A FHWA study[10] released in 2001 observed seven (7) crossings in Windsor, Ontario and reported that of all signal cycles with pedestrians arrived during that cycle, an average of 32% of the time someone pushed the pedestrian button.

3.3.1 Usage of Automated Pedestrian Detection (APD)

As the movement of livable and walkable communities continues to gain its momentum, pedestrian/cyclist safety at crossings will continue to be a top priority transportation issue. Technological advances and increased knowledge about pedestrian behaviors have made innovative solutions possible. One example of such is the emergence of automated pedestrian detection (APD) technologies. An on-line survey conducted by the University of Manitoba in 2009[11] revealed that a majority of respondents who deployed APD in their jurisdiction used APD to activate flashing beacons or in-pavement lights at crossings. In contrast, relative fewer jurisdictions used APD for signal phase activation and/or extension purposes. A 2008 FHWA (Federal Highway Administration) Pedestrian Safety Report to Congress[12] 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.

In order to take advantage of the connected environment, the Transit Bus – Pedestrian/Cyclist Crossing Safety Application is expected to incorporate automated pedestrian detection (APD) capability. APD provides continuous and real-time recognition (e.g., location, direction of travel, speed) of pedestrians/cyclists movements within or near crossings. This information enhances situation awareness by the safety application, which in turns computes and determines appropriate alerts/warnings to transit bus drivers and/or pedestrians/cyclists 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 3-3.

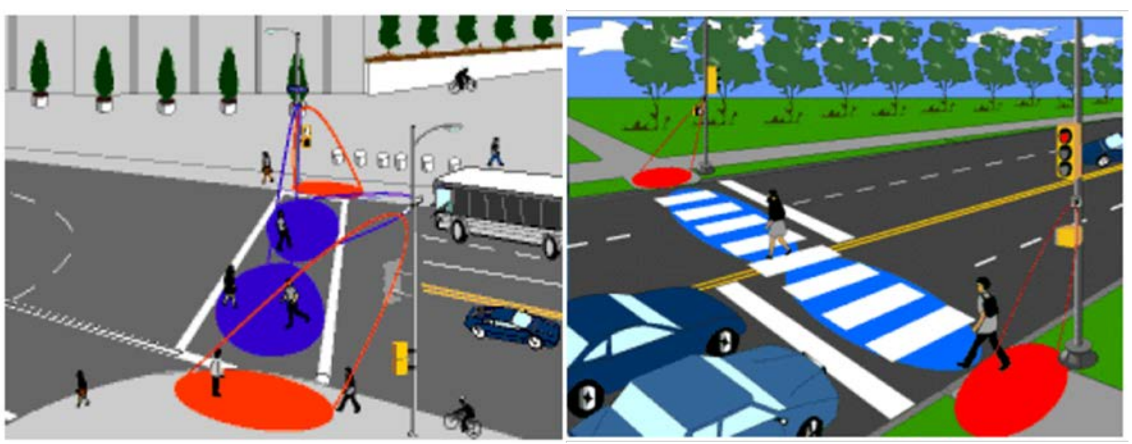

Figure 3-3: Placement of Automated Pedestrian Detection Devices and Detection Zones at Intersection and Mid-block Crosswalk Locations (Source: FHWA, 2006[13])

3.3.2 Effectiveness of APD

Hughes et al. (2001)[14] 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. 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)[15] 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. Sites that received detectors were selected because of poor pedestrian compliance and high volumes of pedestrians with impairments. 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)[16] evaluated video pedestrian detection systems in San Francisco and Miami. 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 and bicyclists.

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 to cross the street, or pedestrians may walk into the detection zone and leave without crossing the street.

Table 3-6 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 exhausted list of technology and supplier choices, and the USDOT holds no particular preference for these identified manufacturers/products.

Table 3-6: Comparison of Major APD Technology Options[15, 17]

	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 intersection and mid-block crossings. 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/stations with good sight distance and alignment (e.g., not on steep grades or on horizontal curves) can reduce pedestrian related collisions. ITS solutions have 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 cues originating from the transit vehicle to warn pedestrians of the bus' presence.

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 intersection and mid-block crossings. 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.
2. **Transit vehicles do not communicate with infrastructure located at an intersection or mid-block crossing, and vice versa.** More robust solutions to improve safety at intersection and mid-block crossings 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 to provide advanced warnings.
3. **Intersections and pedestrian crossings 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 pedestrian crossings 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 and movement of a pedestrian in a crosswalk.

4. **If deployed at crosswalks, current infrastructure-based pedestrian detection systems are likely to produce unnecessary alarms unless the presence of the transit vehicle is known.** While pedestrian detection systems can be deployed at crosswalks, these systems should warning 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 and intended movement (such as speed and direction of travel) of the motor bus and pedestrian in relation to the crosswalk.

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 Chapter 3, 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.

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., traffic signals) with data from the vehicle (e.g., position, speed, brake status). For this particular transit safety application, V2I communications offer an environment rich in vehicle and infrastructure data that can be used by applications residing in the motor bus to provide drivers with alerts to avoid collisions with pedestrians and cyclists in a crossing at intersection or mid-block locations.

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.

Figure 4-1 illustrates the concept of data transmission to/from a transit vehicle in the connected vehicle environment. In context of the Transit Bus-Pedestrian/Cyclist Crossing Safety Warning application, V2I communication would enable transit vehicles to communicate with infrastructure located at an intersection or mid-block pedestrian crossing. For example, transit vehicles may send BSMs to infrastructure about the vehicle's location, speed, braking status, and intended direction of travel (going straight, turning right, or turning left). Likewise, data originating from the crossing (e.g., the presence of a pedestrian in the roadway) may be sent to transit vehicles approaching an intersection pedestrian crossing

Connected vehicle technologies, as they relate to the Transit Bus-Pedestrian/Cyclist Crossing Safety Warning 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 both the mechanism and nature of the information being provided to the motor bus from infrastructure (e.g., pedestrian detectors at crosswalks) and 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 pedestrian crossings. A key priority will be to integrate the connected vehicle technologies onto an existing transit vehicle and at signalized and unsignalized intersections and mid-block pedestrian crossings.

This Operational Concept builds upon the lessons learned from the TRP and expand the capabilities of the PCW application to include all crosswalks (if detection is available), as well as unsignalized intersections and mid-block crossings.

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 pedestrian crossings. In particular, solutions to improve the physical design of the transit vehicle were not considered. A 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 by other USDOT programs.

5 Transit Bus-Pedestrian/Cyclist Crossing Safety Application

5.1 Application Overview

The Transit Bus-Pedestrian/Cyclist Crossing Safety Application is intended to provide proper alerts to transit bus drivers of a likely traffic conflict with pedestrians or cyclists while they are crossing the roadway in a crosswalk. V2I applications can leverage technologies that detect the presence of a pedestrian or cyclist crossing the roadway in a crosswalk, including mid-block pedestrian/bike path crossings. When a pedestrian or cyclist is detected, a RSU would send a message to nearby buses that a pedestrian or cyclist is in the roadway. The application could be applied at signalized and unsignalized locations.

This application would build upon the Transit Safety Retrofit Package (TRP) Pedestrian in Signalized Crosswalk Warning, by adding alerts to bus drivers for non-turning conflicts with pedestrians and conflicts with bicyclists crossing at intersections and midblock (e.g., at an intersecting pedestrian/bicycle path). TRP currently does not provide warnings to buses going straight through an intersection and for conflicts with bicyclists. In addition, TRP is limited to signalized intersections that transmit a SPaT message. An issue that may need to be addressed is the potential lack of power at unsignalized intersections and mid-block crossings. New pedestrian warning messages may need to be developed without relying on a SPaT transmission for unsignalized crossing locations; including utilizing and adapting the TIM message set.

Throughout this chapter, the general term "pedestrian" will be used to encompass both pedestrians and bicyclists. The Operational Concept discusses the following scenarios:

- **Scenario 1:** This scenario describes a motor bus approaching a signalized intersection that it will be traveling straight through. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.
- **Scenario 2:** This scenario describes a motor bus approaching a signalized intersection where it will be turning. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.
- **Scenario 3:** This scenario describes a motor bus going straight at an unsignalized intersection. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application

processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.

- **Scenario 4:** This scenario describes a motor bus turning at an unsignalized intersection. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.
- **Scenario 5:** This scenario describes a motor bus traveling towards an unsignalized, mid-block pedestrian crossing. Pedestrian detection infrastructure detects the presence of a pedestrian in the crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.

Figure 5-1 depicts a high-level system architecture for the Transit Bus-Pedestrian/Cyclist Crossing Safety application. Included are five 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 transit vehicle.
- **Transit Vehicle.** The Transit Vehicle actor is a motor bus that provides the sensory, processing, storage, and communications functions necessary to support safe operations. DSRC radio communications allow the Transit Vehicle actor to disseminate information about its status (i.e., current speed, acceleration, braking, and average emissions) and receive pedestrian/cyclist safety critical information, (e.g., pedestrian location and direction of travel) from the Roadside Unit actor.
- **Roadside Unit.** 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 intersection and mid-block locations near crosswalks. These RSUs will provide necessary infrastructure information (e.g., pedestrian detection, SPaT, TIM, MAP, etc.) to the Transit Vehicle Actor for processing and triggering alerts to the Transit Vehicle Driver 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 or near a pedestrian crossing area that enables this application. These devices may include automated pedestrian detectors, traffic signal controllers, SPaT interface devices, etc. It could also include devices located near crosswalks that provide warning to pedestrians and cyclists, either visual or audio, of approaching transit vehicles, if warranted.
- **Pedestrian.** The Pedestrian actor consists of any and all types of pedestrians who would be utilizing intersection crosswalks, including bicyclists.

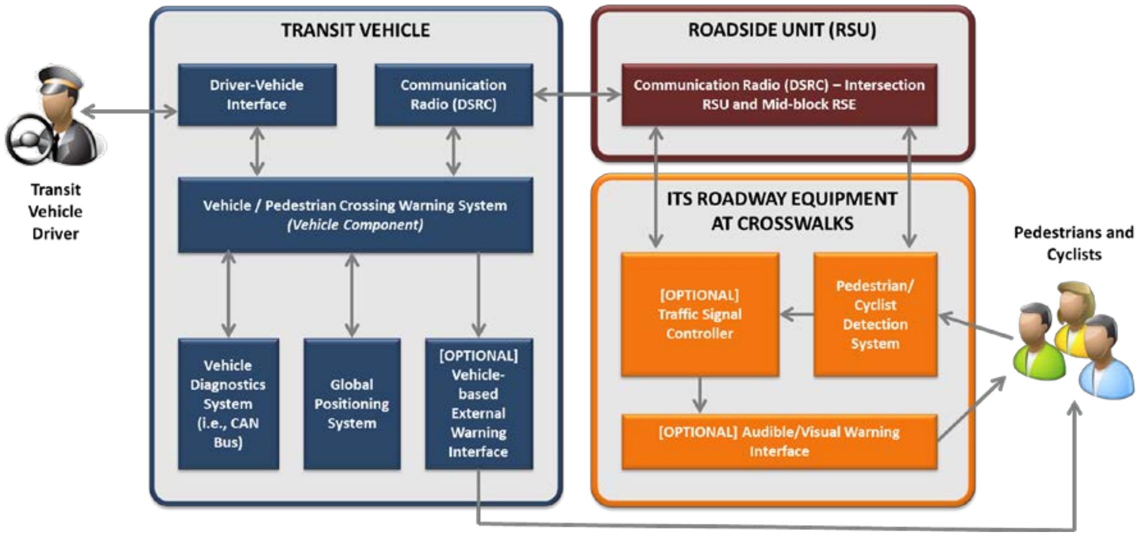

Figure 5-1: Transit Bus-Pedestrian/Cyclist Crossing Safety Application (*Source*: *USDOT, 2014*)

5.2 Transit Bus-Pedestrian/Cyclist Crossing 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.
- **[OPTIONAL] Vehicle-based External Warning System.** The optional subsystem receives input from the Vehicle/Pedestrian Warning System and if needed broadcast appropriate alerts or warnings (audible and/or visual) to external pedestrians and cyclists about heightened collision risk, such as horns, special lighting, annunciator, etc..

- **Vehicle/Pedestrian Warning System *(Vehicle Component)*.** The Vehicle/Pedestrian Warning System (Vehicle Component) allows the vehicle to use data from vehicle systems, vehicle sensors, and messages received from infrastructure to determine if there is potential for a collision between the transit vehicle and a pedestrian or cyclist. It also supports the creation of messages that may be sent to the DVI Subsystem, the DAS Subsystem or to the Communication Radio Subsystem for dissemination to the RSE unit.

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 unit to collect data, such as pedestrian detection information, from ITS Roadway Equipment. for dissemination to the equipped transit vehicles. The Communications Radio (DSRC) Subsystem transmits essential pedestrian detection and other available infrastructure-based information (such as Signal Phasing and Timing, or SPaT) to the Transit Vehicle and provides the capability to receive messages using DSRC communications. Additionally, it could also allow the RSU to collect messages from vehicles to support safety applications at pedestrian/cyclist crossings, as appropriate. An RSU is a device that:
  - Contains multiple radio sets for localized communication over 5.9GHz, compliant with FCC regulations for DSRC
  - Contains an integrated GPS receiver for positioning and UTC time,
  - Contains a PoE capable Ethernet interface that supports IPv4 and IPv6 connectivity, compliant with 802.3at, and is housed in a dedicated, NEMA 4X-rated enclosure.

5.2.3 ITS Roadway Equipment Subsystems

The ITS Roadway Equipment actor includes four subsystems:

- **Pedestrian Detection System.** The Pedestrian Detection Sensors Subsystem allows the infrastructure to detect the presence of pedestrians in crosswalk areas where they may be in danger of being hit by transit vehicles.
- **[OPTIONAL] Traffic Signal Control and SPaT System.** When provided, this Traffic Signal Control and SPaT Subsystem enables integration of traffic (pedestrian) signal phasing and timing message, with other vehicle- and infrastructure-based information to support more specific and targeted safety solutions. The subsystem could also directly receive information from the pedestrian detection system to adjust signal timing in real-time (such as extending the walk phase) to accommodate pedestrians that need extra time to safely cross the street. In the near-term, a SPaT interface device is required to integrate and convert data into the proper format. In the long-term, it will be integral to the signal controller.
- **[OPTIONAL] Audio/Visual Warning Interface.** This optional Audio/Visual Warning Interface Subsystem includes components installed near the pedestrian crosswalks to provide alerts/warnings to pedestrians and cyclists. These alerts/warnings may be visual or audio alerts.

5.3 Assumptions

One significant assumption is that the use of Connected Vehicle technology for the Transit Vehicle-Pedestrian/Bicycle Crossing Safety Application requires DSRC both in the transit vehicle and at infrastructure located near pedestrian/cyclist crossings. 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 CAN bus information can be obtained from the transit vehicle as needed by the safety applications. Section 6 describes a scenario where these sensors may be leveraged.

6 Scenarios

This chapter describes the scenarios for the Transit Vehicle-Pedestrian/Cyclist Crossing Warning 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.

The five scenarios are described, including:

- Scenario 1. Motor Bus Approaching a Signalized Intersection, Going Straight
- Scenario 2. Motor Bus Approaching a Signalized Intersection, Turning
- Scenario 3. Motor Bus Approaching an Unsignalized Intersection, Going Straight
- Scenario 4. Motor Bus Approaching an Unsignalized Intersection, Turning
- Scenario 5. Motor Bus Approaching an Unsignalized Mid-Block Pedestrian/Bicycle Crossing

All of the scenarios assume that the Transit Vehicle is not violating a traffic signal or stop sign, as other V2I applications would account for those situations. Transit Vehicle drivers are responsible for safely navigating through the intersection and avoid other motor vehicles, cyclists, pedestrians and fixed objects not located within the crosswalks. All pedestrian detection is done by infrastructure, not by the Transit Vehicle, and only covers the area of the designated crosswalk and adjacent sidewalk area. Additionally, when describing the scenarios, the generic term "pedestrian" is used to refer to both pedestrians and bicyclists. The Pedestrian Detection system could possibly pinpoint exact location of pedestrians, but must at least know which crosswalks have pedestrians present. Pedestrians may be violating the "walk/don't walk" signals provided at signalized intersections.

6.1 Scenario #1: Motor Bus Approaching a Signalized Intersection, Going Straight (Infrastructure Detects Pedestrian)

Description: This scenario describes a motor bus approaching a signalized intersection that it will be traveling straight through. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.

Actors. Transit Vehicle (depicted in blue); RSE unit (depicted in red); and Pedestrian Detection Equipment (depicted in orange); Pedestrians; and Transit Vehicle Driver.

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

- Transit Vehicles are equipped with communication radios to transmit messages or receive messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- The Transit Vehicle's onboard system meets minimum performance requirements (e.g., SAE J2945) as needed by the subject safety application.
- CAN bus information can be obtained from the Transit Vehicle as needed by the safety application (e.g., SAE J1939); 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.
- The Transit Vehicle is equipped with a DVI to warn the motor bus driver of potential collisions with pedestrians.
- A Channel Plan is in place to allow the RSU to transmit and receive BSMs and other messages.
- A Security Credential Management System is in place to allow RSEs to check BSMs and other messages.
- RSUs are equipped with communication radios to transmit messages or receive messages from infrastructure and vehicle. In this scenario, messages are transmitted and received using DSRC.
- A set of sensors is located at the intersection to detect the presence of pedestrians in the crosswalks. The system is able to identify which crosswalks have a pedestrian present and can relay this information to the safety application.

Preconditions. The following preconditions apply to this scenario:

- The motor bus is traveling in a lane that continues straight, and has a green light. The onboard application is able to determine the intended direction of travel.
- Pedestrians present are in the designated path of the bus, within the area of detection.
- Signalized intersection is equipped with pedestrian signals and push buttons that are linked to the traffic controller.

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

1a) Pedestrian approaches the near-side or far-side crosswalk from where the bus is approaching. The pedestrian uses the pedestrian signal push button to indicate their desire to cross the near-side or far-side crosswalk. The presence of pedestrian may also be detected/confirmed through the use of curbside detector.

1b) Pedestrian decides not to wait for the "walk signal" and crosses when they do not have the right of way. One of the pedestrian detectors located at the signalized intersection detects that there is a pedestrian in the near-side or far-side crosswalk, potentially in danger of being struck by a Transit Vehicle traveling in the perpendicular direction.

2) The pedestrian detector continues to monitor and transmit the pedestrian's relative location, speed and direction of travel within the crosswalk to the RSE. The SPaT information, including the pedestrian's presence, is relayed to the RSU located at the intersection.

3) The RSU located at the intersection broadcasts the SPaT information, including the pedestrian presence information, and MAP information to vehicles in the vicinity of the intersection via DSRC at a rate of 10 hertz.

4) The OBE of the Transit Vehicle receives the data from the RSE as the vehicle approaches the intersection. Data obtained from the Transit Vehicle's CAN bus is collected by the Vehicle/Pedestrian Safety Warning System, as well as the information obtained from the RSE transmission.

5a) Based on trajectory data obtained from the CAN bus and GPS, intersection geometry obtained from the MAP message, and signal phasing and pedestrian presence information obtained from the SPaT message, the Vehicle/Pedestrian Safety Warning System determines that the Transit Vehicle is going to cross the crosswalk that the pedestrian has indicated (via the push button) they are intending to use. The Vehicle/Pedestrian Safety Warning System sends an audible and/or visual caution message to the driver via the DVI to warn the driver that there may be a pedestrian crossing the path of the bus.

5b) Based on trajectory data obtained from the CAN bus and GPS; intersection geometry obtained from the MAP message; and signal phasing and pedestrian presence information obtained from the SPaT message, the Vehicle/Pedestrian Safety Warning System determines that the Transit Vehicle is going to cross the crosswalk where a pedestrian is being detected and continuously monitored. The Vehicle/Pedestrian Safety Warning System sends an audible and/or visual warning, including an indication of ordinal risk level to the driver via the DVI to warn the driver that there is a pedestrian crossing the path of the bus.

6) The application repeats this process until the Transit Vehicle has passed beyond the crosswalk.

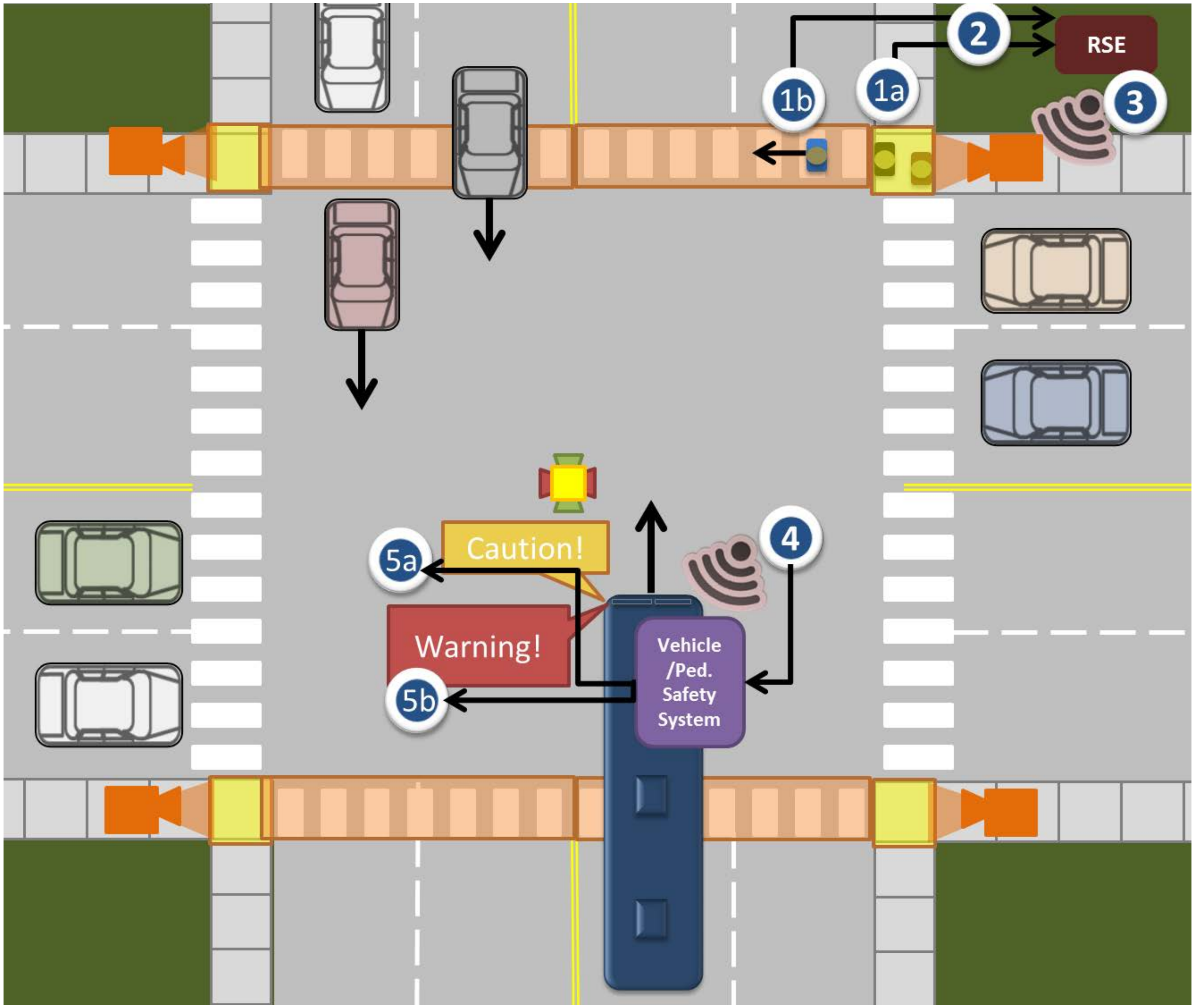

Figure 6-1: Scenario 1 - Signalized Intersection, Bus Traveling Straight *(Source: USDOT, 2014)*

6.2 Scenario #2: Motor Bus Approaching a Signalized Intersection, Turning

Description: This scenario describes a motor bus approaching a signalized intersection where it will be turning. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.

Actors. Transit Vehicle (depicted in blue); RSE unit (depicted in red); and Pedestrian Detection Equipment (depicted in orange); Pedestrians; and Transit Vehicle Driver

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

- Transit Vehicles are equipped with communication radios to transmit messages or receive messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- The Transit Vehicle's onboard system meets minimum performance requirements (e.g., SAE J2945).
- CAN bus information can be obtained from the Transit Vehicle as needed by the safety application (e.g., SAE J1939).
- Positioning data is accurate to provide lane level position of the Transit Vehicle using global positioning (GPS) technology.
- The Transit Vehicle is equipped with a DVI to warn the motor bus driver of potential collisions with pedestrians.
- A Channel Plan is in place to allow the RSE to receive BSMs and other messages.
- A Security Management System is in place to allow RSEs to check BSMs and other messages.
- RSE units are equipped with communication radios to transmit messages or receive messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- A set of pedestrian detectors is located at the intersection to detect the presence of a pedestrian in the crosswalks and curbsides. The system is able to identify which of the four crosswalks has a pedestrian presence and can relay this information to the Warning System.

Preconditions. The following preconditions apply to this scenario:

- The motor bus is traveling in a lane that permits a left or right turn, and has a green light. The onboard application is able to determine the intended direction of travel.
- Pedestrians present are in the designated path, within the area of detection.
- Signalized intersection is equipped with pedestrian signals and push buttons that are linked to the traffic controller.

Flow of Events. The flow of events, corresponding to Figure 6-2, where the bus is turning left, is included below. It should be noted that similar flow of events also applies when the bus is turning right.

1a) Pedestrian approaches the near-side or left-side (or right-side for a right-turning bus) crosswalk in the direction to where the bus is approaching. The pedestrian uses the pedestrian signal push button to indicate their desire to cross the crosswalk. The presence of pedestrian may also be detected/confirmed through the use of curbside detector.

1b) Pedestrian receives the “walk signal” or decides not to wait for the “walk signal” and starts crossing. One of the pedestrian detectors located at the signalized intersection detects that there is a pedestrian in the near-side or left-side (or right-side for a right-turning bus) crosswalk, potentially in danger of being struck by the Transit Vehicle.

2) The pedestrian detector continues to monitor and transmit the pedestrian’s relative location, speed and direction of travel within the crosswalk to the RSE. The SPaT information, including the pedestrian’s presence, is relayed to the RSU located at the intersection.

3) The RSE unit located at the intersection broadcasts the SPaT information, including the pedestrian presence information, and MAP information to vehicles in the vicinity of the intersection via DSRC at a rate of 10 hertz.

4) The OBE of the Transit Vehicle receives the data from the RSE as the vehicle approaches the intersection. Data obtained from the Transit Vehicle’s CAN bus is collected by the Vehicle/Pedestrian Safety Warning System, as well as the information obtained from the RSE transmission.

5a) Based on trajectory data obtained from the CAN bus and GPS, intersection geometry obtained from the MAP message, and signal phasing and pedestrian presence information obtained from the SPaT message, the Vehicle/Pedestrian Safety Warning System determines that the Transit Vehicle is going to cross the crosswalk that the pedestrian has indicated (via the push button) they are intending to use. The Vehicle/Pedestrian Safety Warning System sends an audible and/or visual caution message to the driver via the DVI to warn the driver that there may be a pedestrian crossing the path of the bus.

5b) Based on trajectory data obtained from the CAN bus and GPS; intersection geometry obtained from the MAP message; and signal phasing and pedestrian presence information obtained from the SPaT message, the Vehicle/Pedestrian Safety Warning System determines that the Transit Vehicle is going to cross the crosswalk where a pedestrian is being detected and continuously monitored. The Vehicle/Pedestrian Safety Warning System sends an audible and/or visual warning, including an indication of ordinal risk level to the driver via the DVI to warn the driver that there is a pedestrian crossing the path of the bus.

6) The application repeats this process until the Transit Vehicle has passed beyond the crosswalk.

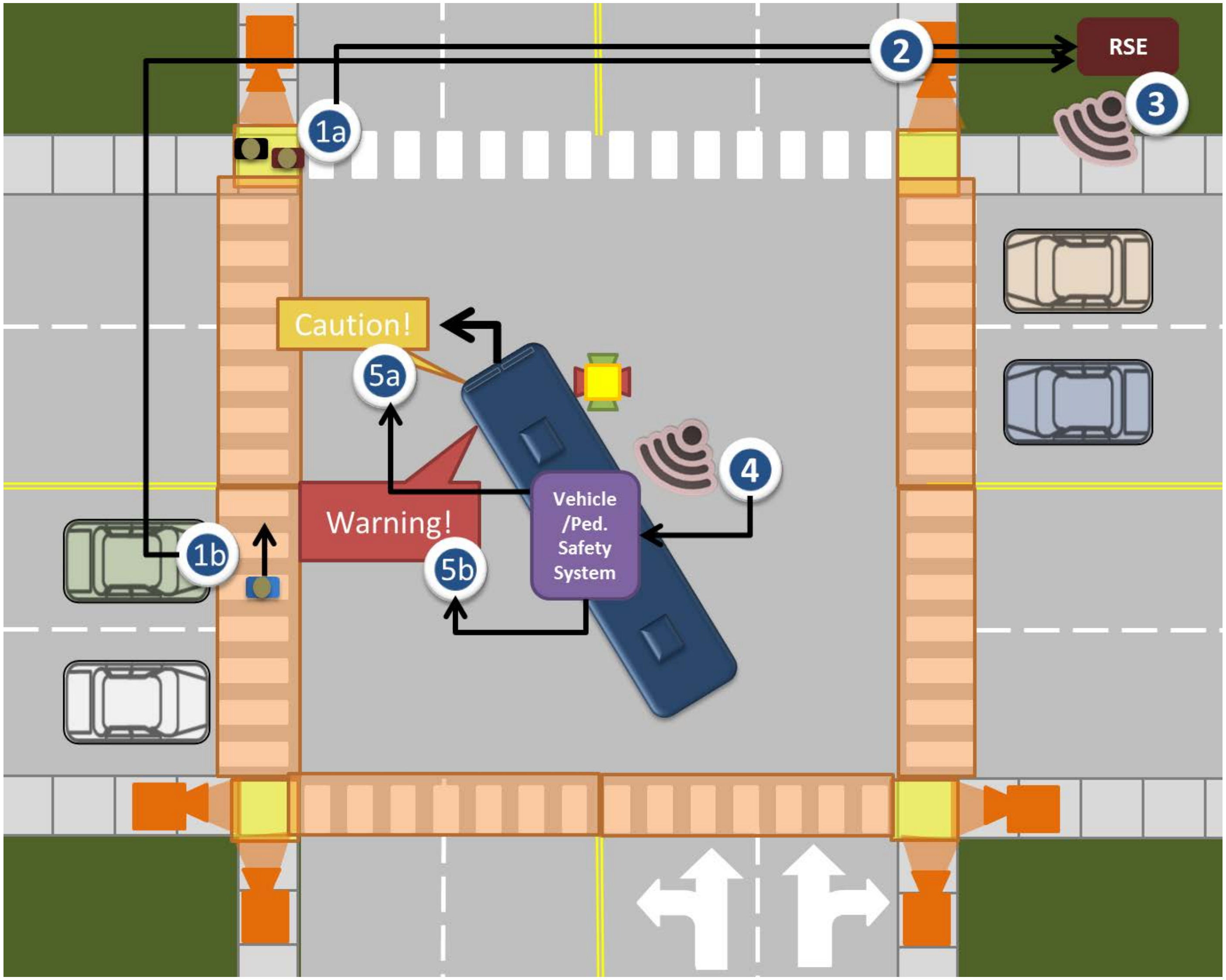

Figure 6-2: Scenario 2 - Signalized Intersection, Bus Turning *(Source: USDOT, 2014)*

6.3 Scenario #3: Motor Bus Approaching an Unsignalized Intersection, Going Straight (Infrastructure Detects Pedestrian)

Description: This scenario describes a motor bus going straight at an unsignalized intersection. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.

Actors: Transit Vehicle (depicted in blue); RSE unit (depicted in red); and Pedestrian Detection Equipment (depicted in orange); Pedestrians; and Transit Vehicle Driver

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

- Transit Vehicles are equipped with communication radios to transmit messages or receive messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- The Transit Vehicle's onboard system meets minimum performance requirements (e.g., SAE J2945).
- CAN bus information can be obtained from the Transit Vehicle as needed by the safety applications (e.g., SAE J1939).
- Positioning data is accurate to provide lane level position of the Transit Vehicle using global positioning (GPS) technology.
- The Transit Vehicle is equipped with a DVI to warn the motor bus driver of potential collisions with pedestrians.
- A Channel Plan in place to allow the RSE to receive BSMs and other messages.
- A Security Management System in place to allow RSEs to check BSMs and other messages.
- RSE units are equipped with communication radios to transmit messages or receive messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- A set of pedestrian detectors is located at the intersection to detect the presence of a pedestrian in the crosswalks. The system is able to identify which of the four crosswalks has a pedestrian presence and can relay this information to the Warning System.

Preconditions. The following preconditions apply to this scenario:

- The motor bus is traveling in a lane that continues straight. The onboard application is able to determine the intended direction of travel.
- The intersection may or may not be regulated by stops or yield signs.
- Pedestrians present are in the designated crosswalk, within the area of detection.

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

1a) Pedestrian approaches the near-side or far-side crosswalk from where the bus is approaching. One of the pedestrian detectors directed at the corner sidewalk detects that there may be a pedestrian waiting to cross the near-side or far-side crosswalk, potentially in danger of being struck by a Transit Vehicle traveling in the perpendicular direction.

1b) Pedestrian begins to cross the near-side or far-side crosswalk. One of the pedestrian detectors located at the intersection then detects that there is a pedestrian in the near-side or far-side crosswalk, potentially in danger of being struck by a Transit Vehicle traveling in the perpendicular direction.

2) The pedestrian detector continues to monitor and transmit the pedestrian’s relative location, speed and direction of travel within the crosswalk to the RSE. The TIM information, including the pedestrian’s presence, is relayed to the RSU located at the intersection.

3) The RSU located at the intersection broadcasts the TIM message with the pedestrian presence information and MAP information to vehicles in the vicinity of the intersection via DSRC at a rate of 10 hertz.

4) The OBE of the Transit Vehicle receives the data from the RSE as the vehicle approaches the intersection. Data obtained from the Transit Vehicle’s CAN bus is collected by the Vehicle/Pedestrian Safety Warning System, as well as the information obtained from the RSE transmission.

5a) Based on trajectory data obtained from the CAN bus and GPS, intersection geometry obtained from the MAP message, and pedestrian presence information obtained from the TIM message, the Vehicle/Pedestrian Safety Warning System determines that the Transit Vehicle is going to cross the crosswalk where there may be a pedestrian present. The Vehicle/Pedestrian Safety Warning System sends an audible and/or visual caution message to the driver via the DVI to warn the driver that there is a pedestrian crossing the path of the bus.

5b) Based on trajectory data obtained from the CAN bus and GPS, intersection geometry obtained from the MAP message, and pedestrian presence information obtained from the TIM message, the Vehicle/Pedestrian Safety Warning System determines that the Transit Vehicle is going to cross the crosswalk where there is a pedestrian detected. The Vehicle/Pedestrian Safety Warning System sends an audible and/or visual warning to the driver via the DVI to warn the driver that there is a pedestrian crossing the path of the bus.

6) The application repeats this process until the Transit Vehicle has passed beyond the crosswalk.

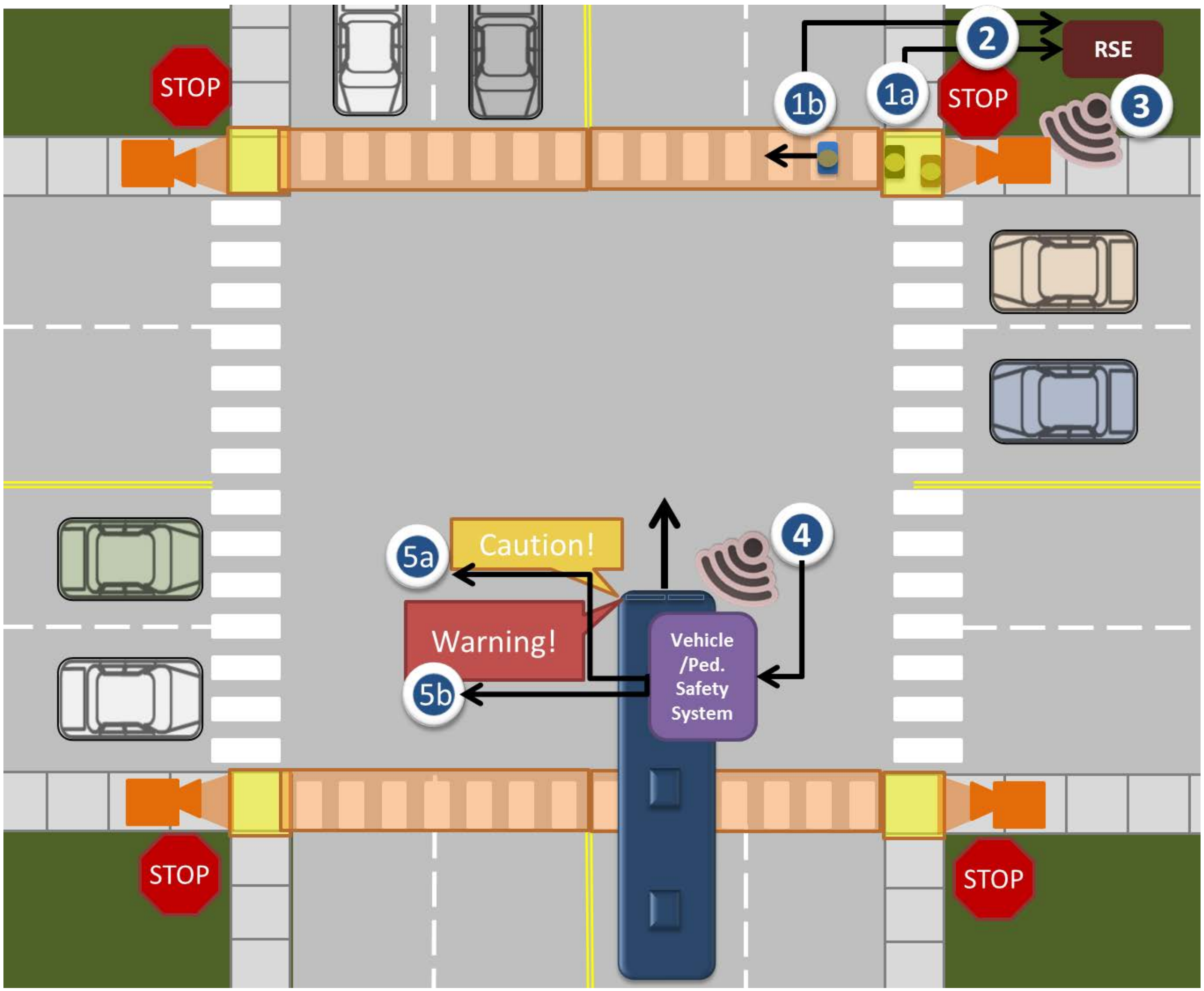

Figure 6-3: Scenario 3 - Unsignalized Intersection, Bus Traveling Straight *(Source: USDOT, 2014)*

6.4 Scenario #4: Motor Bus Approaching an Unsignalized Intersection, Turning (Infrastructure Detects Pedestrian)

Description: This scenario describes a motor bus turning at an unsignalized intersection. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.

Actors. Transit Vehicle (depicted in blue); RSE unit (depicted in red); and Pedestrian Detection Equipment (depicted in orange); Pedestrians; and Transit Vehicle Driver

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

- Transit Vehicles are equipped with communication radios to transmit messages or receive messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- The Transit Vehicle's onboard system meets minimum performance requirements (e.g., SAE J2945).
- CAN bus information can be obtained from the Transit Vehicle as needed by the safety applications (e.g., SAE J1939).
- Positioning data is accurate to provide lane level position of the Transit Vehicle using global positioning (GPS) technology.
- The Transit Vehicle is equipped with a DVI to warn the motor bus driver of potential collisions with pedestrians.
- A Channel Plan in place to allow the RSE to receive BSMs and other messages.
- A Security Management System in place to allow RSEs to check BSMs and other messages.
- RSE units are equipped with communication radios to transmit messages or receive messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- A set of pedestrian detectors is located at the intersection to detect the presence of a pedestrian in the crosswalks. The system is able to identify which of the four crosswalks has a pedestrian presence and can relay this information to the Warning System.

Preconditions. The following preconditions apply to this scenario:

- The motor bus is traveling in a lane that permits a left or right turn. The onboard application is able to determine the intended direction of travel.
- The intersection may or may not be regulated by stops or yield signs.
- Pedestrians present are in the designated crosswalk, within the area of detection.

Flow of Events. The flow of events, corresponding to Figure 6-4, where the bus is turning left, is included below:

1a) Pedestrian approaches the near-side or left-side (or right-side for a right-turning bus) crosswalk from where the bus is approaching. One of the pedestrian detectors directed at the sidewalk corner detects that there may be a pedestrian waiting to cross the crosswalk, potentially in danger of being struck by a Transit Vehicle.

1b) Pedestrian decides to cross the near-side or left-side (or right-side for a right-turning bus) crosswalk. One of the pedestrian detectors located at the intersection then detects that there is a pedestrian in the crosswalk, potentially in danger of being struck by a Transit Vehicle.

2) The pedestrian detector continues to monitor and transmit the pedestrian's relative location, speed and direction of travel within the crosswalk to the RSE. The TIM information, including the pedestrian's presence, is relayed to the RSU located at the intersection.

3) The RSE unit located at the intersection broadcasts the TIM information, including the pedestrian presence information, and MAP information to vehicles in the vicinity of the intersection via DSRC at a rate of 10 hertz.

4) The OBE of the Transit Vehicle receives the data from the RSE as the vehicle approaches the intersection. Data obtained from the Transit Vehicle's CAN bus is collected by the Vehicle/Pedestrian Safety Warning System, as well as the information obtained from the RSE transmission.

5a) Based on trajectory data obtained from the CAN bus and GPS, intersection geometry obtained from the MAP message, and pedestrian presence information obtained from the TIM message, the Vehicle/Pedestrian Safety Warning System determines that the Transit Vehicle is going to cross the crosswalk where there may be a pedestrian present. The Vehicle/Pedestrian Safety Warning System sends an audible and/or visual caution message to the driver via the DVI to warn the driver that there is a pedestrian crossing the path of the bus.

5b) Based on trajectory data obtained from the CAN bus and GPS, intersection geometry obtained from the MAP message, and pedestrian presence information obtained from the TIM message, the Vehicle/Pedestrian Safety Warning System determines that the Transit Vehicle is going to cross the crosswalk where there is a pedestrian detected. The Vehicle/Pedestrian Safety Warning System sends an audible and/or visual warning to the driver via the DVI to warn the driver that there is a pedestrian crossing the path of the bus.

6) The application repeats this process until the Transit Vehicle has passed beyond the crosswalk.

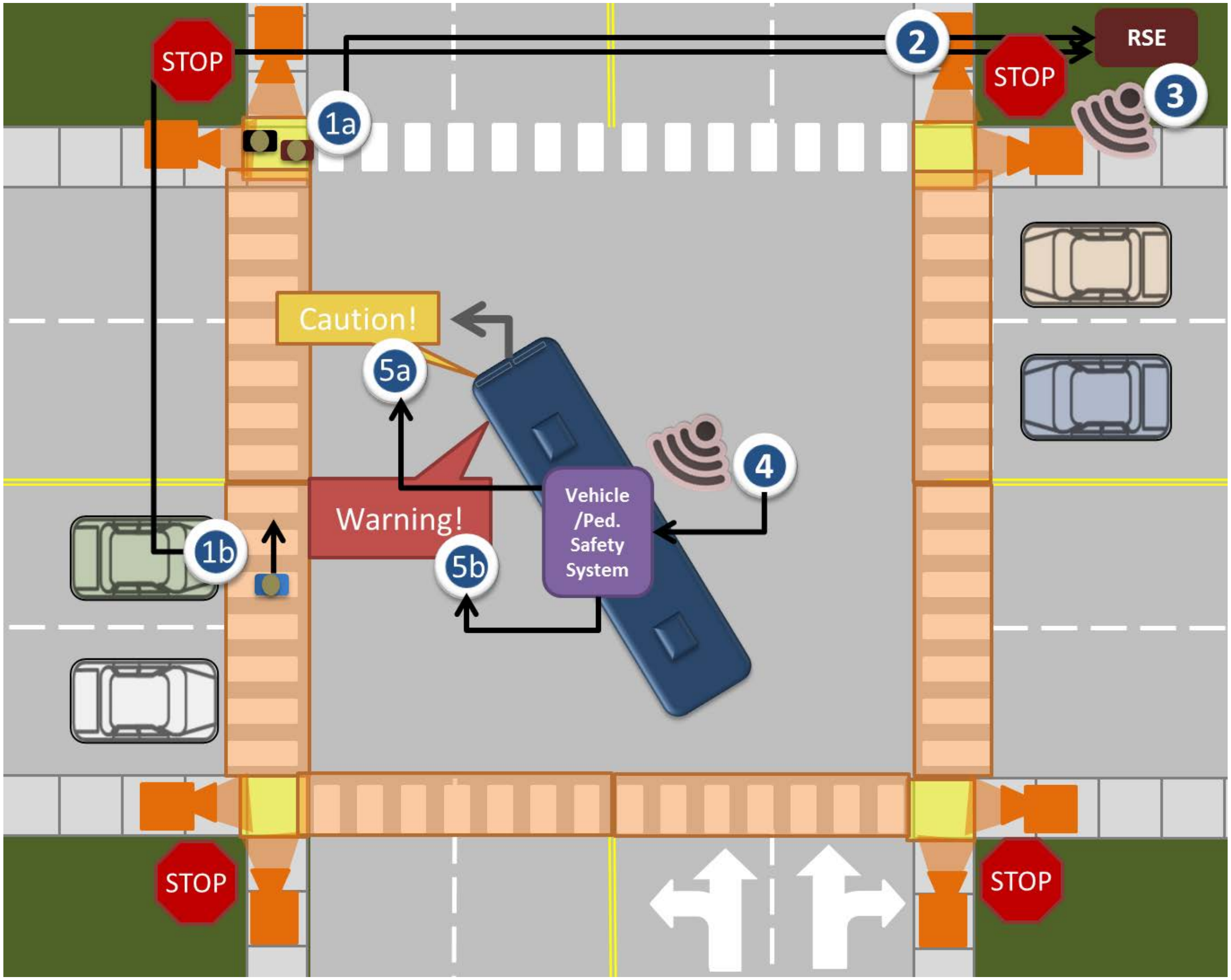

Figure 6-4: Scenario 4 - Unsignalized Intersection, Bus Turning *(Source: USDOT, 2014)*

6.5 Scenario #5: Motor Bus Approaching a Mid-Block Pedestrian/Bicycle Crossing (Infrastructure Detects Pedestrian/Bicyclist)

Description: This scenario describes a motor bus traveling towards an unsignalized, mid-block pedestrian crossing. Pedestrian detection infrastructure detects the presence of a pedestrian in the crosswalk that the motor bus will be crossing. A RSU broadcasts the pedestrian detection information through DSRC, where it is received by the motor bus OBE. The application processes the message and other relevant data to provide the motor bus driver with an alert of a potential conflict with a pedestrian in the roadway.

Actors. Transit Vehicle (depicted in blue); RSE unit (depicted in red); and Pedestrian Detection Equipment (depicted in orange); Pedestrians; and Transit Vehicle Driver

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

- Transit Vehicles are equipped with communication radios to transmit messages or receive messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- The Transit Vehicle's onboard system meets minimum performance requirements (e.g., SAE J2945).
- CAN bus information can be obtained from the Transit Vehicle as needed by the safety applications (e.g., SAE J1939).
- Positioning data is accurate to provide lane level position of the Transit Vehicle using global positioning (GPS) technology.
- The Transit Vehicle is equipped with a DVI to warn the motor bus driver of potential collisions with pedestrians.
- A Channel Plan in place to allow the RSE to receive BSMs and other messages.
- A Security Management System in place to allow RSEs to check BSMs and other messages.
- RSE units are equipped with communication radios to transmit messages or receive messages from infrastructure. In this scenario, messages are transmitted and received using DSRC.
- A set of pedestrian detectors is located at the crossing to detect the presence of a pedestrian near or in the crosswalk. The system is able to relay this information to the Warning System.

Preconditions. The following preconditions apply to this scenario:

- The motor bus is traveling in a lane that intersects a mid-block crossing.
- Pedestrians/bicyclists are present on the pedestrian/bicycle path/trail near the crossing or are in the designated crosswalk, within the area of detection.

Flow of Events. The flow of events, corresponding to Figure 6-5, is included below:

1a) Pedestrian approaches the mid-block crossing. One of the pedestrian detectors located at the intersection detects that there may be a pedestrian waiting to cross the roadway, potentially in danger of being struck by a Transit Vehicle traveling in the perpendicular direction.

1b) **P**edestrian then begins to cross the roadway. One of the pedestrian detectors located at the crossing detects that there is a pedestrian in the crosswalk, potentially in danger of being struck by a Transit Vehicle traveling in the perpendicular direction.

2) The pedestrian detector continues to monitor and transmit the pedestrian’s relative location, speed and direction of travel within the crosswalk to the RSE. The TIM information, including the pedestrian’s presence, is relayed to the RSU located at the intersection.

3) The RSE unit located at the crossing broadcasts the TIM information, including the pedestrian presence information, and MAP information to vehicles in the vicinity of the crossing via DSRC at a rate of 10 hertz.

4) The OBE of the Transit Vehicle receives the data from the RSE as the vehicle approaches the crossing. Data obtained from the Transit Vehicle’s CAN bus is collected by the Vehicle/Pedestrian Safety Warning System, as well as the information obtained from the RSE transmission.

5a) Based on trajectory data obtained from the CAN bus and GPS, intersection geometry obtained from the MAP message, and pedestrian presence information obtained from the TIM message, the Vehicle/Pedestrian Safety Warning System determines that the Transit Vehicle is going to cross the crosswalk where there may be a pedestrian present. The Vehicle/Pedestrian Safety Warning System sends an audible and/or visual caution message to the driver via the DVI to warn the driver that there is a pedestrian crossing the path of the bus.

5b) Based on trajectory data obtained from the CAN bus and GPS, intersection geometry obtained from the MAP message, and pedestrian presence information obtained from the TIM message, the Vehicle/Pedestrian Safety Warning System determines that the Transit Vehicle is going to cross the crosswalk where there is a pedestrian detected. The Vehicle/Pedestrian Safety Warning System sends an audible and/or visual warning to the driver via the DVI to warn the driver that there is a pedestrian crossing the path of the bus.

6) The application repeats this process until the Transit Vehicle has passed beyond the crosswalk.

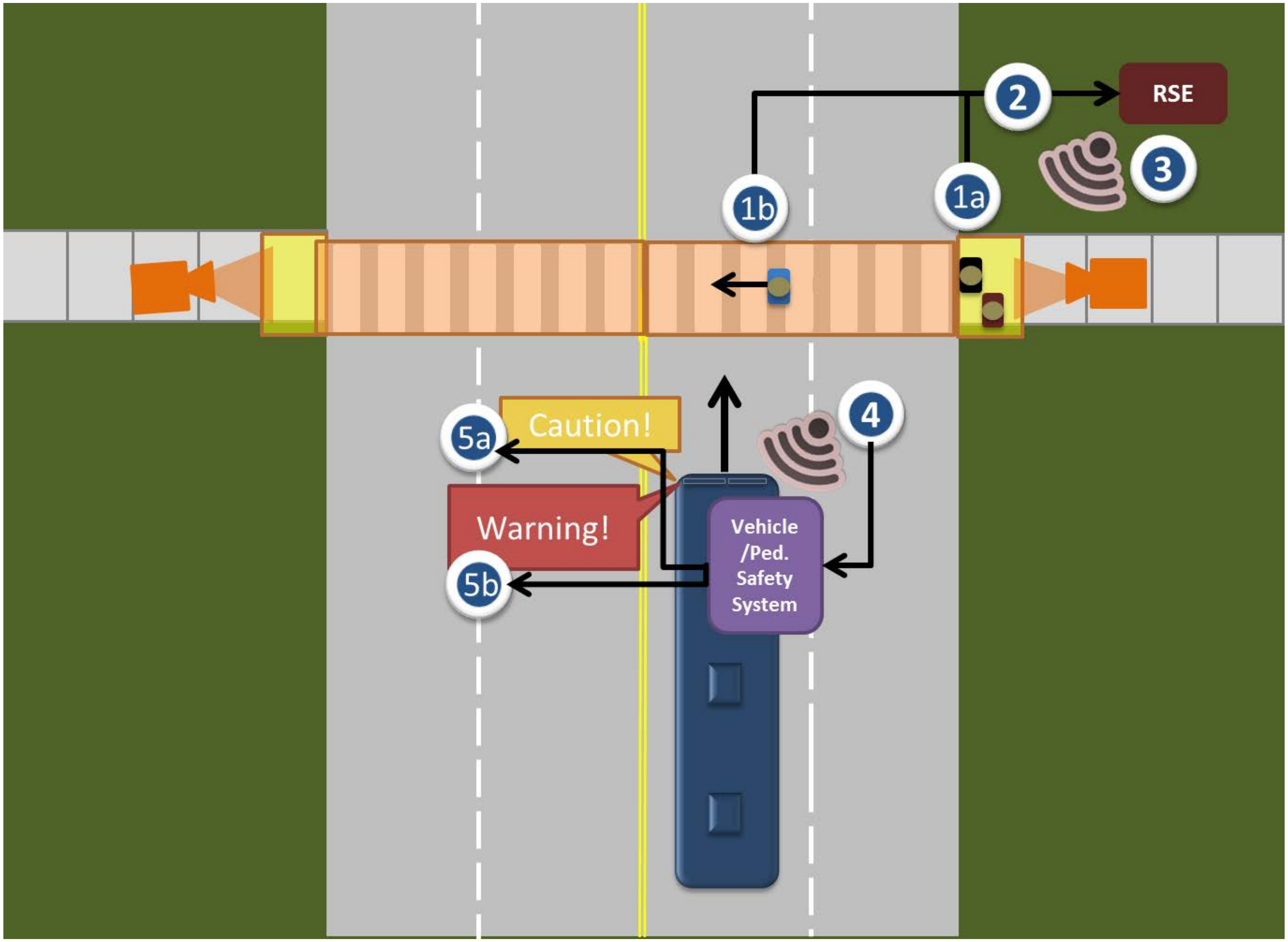

Figure 6-5: Scenario 5 - Bus at a Mid-Block Crossing *(Source: USDOT, 2014)*

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APPENDIX A. List of Acronyms

Acronym	Meaning
AASHTO	American Association of State Highway and Transportation Officials
ABS	Antilock Braking System
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
FCC	Federal Communications Commission
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FOD	Forward Object Detection
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
LDW	Lane Departure Warning
LED	Light-Emitting Diode
NHTSA	National Highway Traffic Safety Administration

Acronym	Meaning
NTD	National Transit Database
ODS	Object Detection System
PDS	Pedestrian Detection System
RCW	Rear Collision Warning
RITA	Research and Innovative Technology Administration
ROD	Rear Object Detection
RSE	Roadside Equipment
RSU	Roadside Unit
SAE	Society of Automotive Engineers
SOD	Side Object Detection
TRP	Transit Retrofit Package
USDOT	U.S. Department of Transportation
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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