Transit Safety Retrofit Package Development

TRP Concept of Operations

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16. Abstract

This document describes the Concept of Operations (ConOps) for the Transit Safety Retrofit Package (TRP). The ConOps describes the current state of operations with respect to the integration of Connected Vehicle technology in transit buses, establishes the reasons for change, and describes the TRP in terms of its features and operations.

To achieve the objective of the study, the TRP project includes developing, testing, installing, and maintaining retrofit packages on three transit buses drawn from the University of Michigan transit fleets; developing two new transit safety applications (Pedestrian Warning and Vehicle Turning Right in Front of a Transit Vehicle); and collecting and providing data from the equipped buses to the Volpe Center for an independent evaluation.

The specific objective of the TRP project is to design and develop safety applications for transit vehicles that can communicate V2V as well as V2I for enhanced transit vehicle and pedestrian safety. Ultimately, it is of interest to determine if DSRC technologies can be combined with on-board applications to provide real-time alerting of pedestrians in crosswalks as well as right turning vehicles in front of the transit vehicle.

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Chapter 1 Scope

This document describes the Concept of Operations (ConOps) for the Transit Safety Retrofit Package (TRP). The ConOps describes the current state of operations with respect to the integration of Connected Vehicle technology in transit buses, establishes the reasons for change, and describes the TRP in terms of its features and operations.

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

The Safety Pilot Model Deployment is a centerpiece of the United States Department of Transportation (U.S. DOT) Connected Vehicle program. It plays a critical role in generating data to support rapidly approaching decisions by the National Highway Safety Administration on the future of Connected Vehicle technology development. Key data include the performance of the various technologies, including DSRC and safety applications, driver adaptations, and the overall crash prevention potential. The TRP project is an important part of the Connected Vehicle program and the Safety Pilot Model Deployment because it provides the only source for retrofitted transit vehicles equipped with safety applications (with respect to DSRC vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications) for participation in the Safety Pilot Model Deployment, a precious, time-constrained opportunity to understand the real-world performance of the transit retrofit packages and safety applications.

The specific objective of the TRP project is to design and develop safety applications for transit vehicles that can communicate V2V as well as V2I for enhanced transit vehicle and pedestrian safety. Ultimately, it is of interest to determine if DSRC technologies can be combined with on-board applications to provide real-time alerting of pedestrians in crosswalks as well as right turning vehicles in front of the transit vehicle.

To achieve the objective of the study, the TRP project includes developing, testing, installing, and maintaining retrofit packages on three transit buses drawn from the University of Michigan transit fleets; developing two new transit safety applications (Pedestrian Warning and Vehicle Turning Right in Front of a Transit Vehicle); and collecting and providing data from the equipped buses to the Volpe Center for an independent evaluation.

The TRP project work is divided into two phases. Phase I consisted of tasks related to the design and development of the hardware and software components needed to implement the TRP during the Safety Pilot. Phase II consists of those activities that are associated with the actual implementation, maintenance, operation, and documenting the performance of the TRP during the Safety Pilot.

Identification

This ConOps document describes the concept of operations for the TRP. Specifically it is focused on describing the concepts for the proposed system. As described previously, the TRP is a sub-component of a larger Connected Vehicle Program as well as the Safety Pilot Model Deployment. This ConOps is restricted to describing the expected functionality, operation, and rationale for existence of the TRP and, while leveraging existing ConOps, does not repeat information contained in other Connected Vehicle or Safety Pilot ConOps. For example, the reader is directed to the Connected Vehicle ConOps for a discussion of security and the conceptualization of how DSRC and other wireless communication protocols might be used within the Connected Vehicle paradigm.[1]

Document Overview

Additional audience members for this document may be transit agencies and bus manufacturers. The intended audience for this ConOps is the system developers, Safety Pilot Test Conductor, and U.S. DOT Connected Vehicle Program Managers who are managing the Safety Pilot Model Deployment. The purposes of this ConOps document are:

- to communicate the need for and expectations of the TRP
- to communicate an understanding of how the TRP will operate during the Safety Pilot Test
- to serve as a basis for system development activities.

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

Chapter 2 (Referenced Documents) describes the external documentation referenced within this document.

Chapter 3 (Current System or Situation) describes the current situation among transit fleets with respect to communicating pedestrian warnings and vehicles turning in front of transit vehicles to transit operators.

Chapter 4 (Justification for and Nature of Changes) describes the justification for and nature of the proposed changes. This chapter identifies deficiencies of the existing situation and the benefits of change.

Chapter 5 (Concepts for the Proposed System) describes the proposed system that will result from the desired changes. This is, necessarily, a high-level description, indicating the operational features of the demonstration system when deployed.

[1] Lockheed-Martin Core System Engineering Team, "Core System, Concept of Operations (ConOps,)," Research and Innovative Technology Administration, Oct. 2011.

Chapter 6 (Operational Scenarios) contains operational scenarios for the demonstration system. A scenario is a step-by-step description of how the proposed system might operate and interact with its users and its external interfaces under a given set of circumstances. The scenarios tie together all parts of the proposed system, the users, and other entities by describing how they interact.

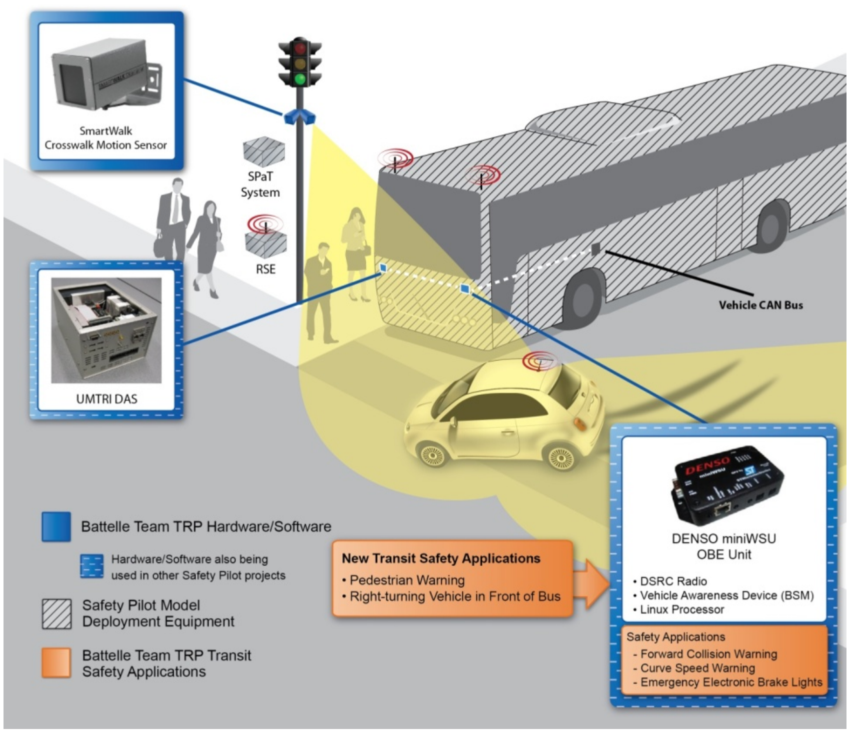
Chapter 7 (Summary of Impacts) describes the operational impacts of the proposed demonstration system on the users, the developers, the maintenance organizations, and the support organizations.

Chapter 8 (Analysis of the Proposed System) describes the benefits, limitations, advantages, disadvantages, and trade-offs considered for the demonstration system.

Appendix A provides definitions for the terms, acronyms and abbreviations used throughout the document.

System Overview

This project is sponsored by the U.S. DOT and has the goal of both supporting the Safety Pilot Model Deployment as well as providing a transit safety retrofit kit for use beyond the Safety Pilot Model Deployment. The proposed system, shown in Figure 1-1, heavily leverages components and approaches already proven and that are being used on many other model deployment vehicles.



Sources: Battelle; UMTRI; http://www.mssedco.com/smartwalk_xp.htm; http://www.densocorp-na.com/technology/vehicle-to-vehicle-vehicle-to-infrastructure-technology.

Figure 1-1. Illustration of the TRP System with All Hardware Components

The TRP includes the following system elements and functionality:

- **TRP OBE Device** – The DENSO miniWSU wireless safety unit (WSU) includes a DSRC radio, supports basic safety message (BSM) communication via 5.9 GHz DSRC, runs safety applications, interfaces with the vehicle controller-area network (CAN) bus, includes a driver-vehicle interface (DVI), and interoperates with other model deployment vehicles and Safety Pilot Model Deployment RSU according to Institute of Electrical and Electronics Engineers (IEEE) 802.11p and 1609.2 standards and the J2735 message standards. This same device is used on the truck retrofit vehicles and is a derivative and fully interoperable with the units being used on Crash Avoidance Metrics Partnership (CAMP) light vehicles and the integrated trucks being used in the model deployment. Moreover, the miniWSU-equipped TRP buses will be interoperable with aftermarket safety device (ASD) and vehicle awareness devices that will comprise the largest number of communicating vehicles in the model deployment.
- **Data Acquisition System** – The University of Michigan Transportation Research Institute (UMTRI) Data Acquisition System (DAS) that is on the integrated and retrofit trucks and ASD light vehicles will be used for this project. The DAS interfaces and stores data from the vehicle CAN bus, video cameras, radar units, and the safety applications. More details about the DAS are included in the Data Acquisition System section in Chapter 5. Although not technically part of the TRP itself, a discussion of the DAS is included for completeness.
- **Crosswalk Motion Sensor** – The MS SEDCO SmartWalk XP unit will be utilized to identify pedestrian presence in intersection crosswalks in support of the Pedestrian Warning safety application to be developed and deployed through this project. These units will be mounted to existing poles at a recommended height of 10–12 feet to discourage vandalism and provide an optimum target area.
- **Safety Applications** – Two new transit safety applications – Pedestrian in Crosswalk Warning (PCW) and Vehicle Turning Right in Front of Bus Warning (VTRW) will be developed as part of this project. Further, three safety applications supported by the DENSO OBE: Forward Collision Warning (FCW), Curve Speed Warning (CSW), and Emergency Electronic Brake Lights (EEBL) will be included in the project. A brief description of the three safety applications that are supported by the DENSO OBE is included in the DSRC Radio section in Chapter 5.

Chapter 2 Referenced Documents

Institute of Electrical and Electronics Engineers (IEEE)

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

Society of Automotive Engineers (SAE)

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

Denso International America

	Aftermarket Safety Device (ASD) User's Guide, Version 1.0

Battelle Drawings/Documents

	Project Management Plan for Transit Safety Retrofit Package Development, Version 4.0

Chapter 3 Current System or Situation

This chapter of the ConOps describes the current state of safety applications in transit vehicles.

Background, Objectives, and Scope

The Federal Transit Administration (FTA) has been examining the potential costs, benefits, and overall business case for integrating safety systems, both hardware and software, into transit buses. In particular, the U.S. DOT investigated some of these issues as part of the Integrated Vehicle Based Safety Systems (IVBSS) Initiative[2]. The objective of that study was to evaluate the business case related to the development and implementation of various transit-based versions of collision avoidance systems in transit vehicles. Subsequent research has been conducted to further investigate the feasibility, state of the practice, and path to implementation, most recently documented in a Final Evaluation Report on Side Object Detection Systems Evaluation.[3] Additionally, there has been significant work conducted related to pedestrian detection and field trials and published papers have been presented summarizing this work.[4]

Side Object Detection

As indicated in Rephlo et. al., “There are a variety of side collision detection and warning systems already on the market and there are many others that are currently being explored through the U.S. DOT’s IVBSS Initiative [and subsequent Connected Vehicle Initiative], which is establishing partnerships with the automotive and commercial vehicle industries to accelerate the introduction of integrated vehicle-based safety systems into vehicles. However, most of the systems that exist and that are under development have been designed for the automotive and trucking industries and focus on highway applications. Without significant modification, these systems are not likely to be suitable for transit buses that typically operate in urban and suburban environments.”[3]

Most of the current systems available for a transit vehicle are based upon detection hardware/sensors that are mounted to the transit vehicle. For example, these sensors consist of a combination of video, millimeter wave, radar, etc. to detect an object such as a vehicle approaching from the side of the transit bus, and as such require significant modifications to the transit vehicle, including wiring and mounting of equipment. These sensors generally work by detecting the distance between the object and the side of the bus by processing the signal received from the sensor in a centralized processor and then providing information to the transit operator via an interface (such as an audible alert or a flashing light-emitting diode [LED]).

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[2] Dunn, Travis; Laver, Richard; Skorupski, Douglas; Zyrowski, Deborah, “Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses,” Federal Transit Administration, 2007.

[3] Rephlo, J.; Miller, S; Haas, R.; Saporta, H; Stock, D.; Miller, D.; Feast, L.; Brown, B.; “Side Object Detection System Evaluation: Final Evaluation Report,” December 2008.

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

Pedestrian Detection

Originally, and continuing to this day, Pedestrian Detection technologies are primarily used as a mechanism to supplement or replace pedestrian calls to the traffic signal controller as initiated via a push button located near the intersection[4]. 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. Most 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*[5] 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.

The other more recent use of Pedestrian Detection systems serve to detect pedestrians who remain in the crosswalk. In this form, Pedestrian Detection is currently being realized in two forms, as an autonomous vehicle-based system, similar to those discussed in the side object detection section above, or as infrastructure-based systems, similar to those used for curbside detection as described above, which can be used as part of the inputs to the timing plan of a signalized intersection. There have been many studies and evaluations of new technologies for vehicle-based platforms for Pedestrian Detection but few of the current on-board sensor technologies being used for Pedestrian Detection at intersections. The current thrust in the industry has been to explore the use of pedestrian detectors mounted on infrastructure components that then interface with the traffic signal controller (i.e., do not communicate directly to the bus). Both of these are explored in greater details in forthcoming sections.

Operational Policies and Constraints

Side Object Detection System

As with any system, the effectiveness of side object detection systems (SODS) is constrained by the type of technology used and its inherent limitations, as well as by the configuration of the system itself (e.g., sensor placement). Three of the major, potential shortcomings of SODS are discussed below, and it is apparent from these shortcomings, SODS is not able to detect and subsequently prevent all object collision types.

Speed Differentials Between Vehicles

The system does not warn of vehicles passing the bus at high speeds. Specifically, SODS did not detect passing vehicles when the speed differential between the bus and the passing vehicle was greater than 15 mph.

[5] Liao, Chen-Feu; Rakauskas, Michael; Rayankula, Avanish; "Development of Mobile Accessible Pedestrian Signals (MAPS) for Blind Pedestrians at Signalized Intersections", University of Minnesota, Center for Transportation Studies, 2011.

Horizontal Constraints

Exact placement of the sensors varies by bus make and model. By design, the rear-most sensor on the bus is typically located 8 to 10 ft. from the front of the bus. This means that any vehicles adjacent to the rear half of the bus would not be detected at highway speeds since the detection distance is 8 ft. at highway speeds and the sensors would therefore only detect objects adjacent to the front 16-18 ft. of a 40-foot bus. In addition, blind spot issues at the rear of the bus where there are no sensors can be a problem.

Height Constraints

The height of the sensors also impacts the effectiveness of the system. Objects that are at the height of the mirror (such as a sign) would not be detected.

Pedestrian Detection

Two primary constraints to the current adoption of pedestrian technologies are:

- the limitations of the technology due to environmental conditions
- the ability of the sensors and corresponding algorithms to operate with 100% accuracy in detection of pedestrian while minimizing 'false' detections.

The technologies presently used for most pedestrian detection applications mostly involve electromagnetic waves of various frequencies and the detection of these waveforms, either emitted or reflected by the pedestrian, and detection by a sensor (i.e., 'camera'). As with any waveform, environmental conditions may affect the transmission and reception of these waveforms. For instance, video detection systems dependent of the visible light spectrum are subject to variations in accuracy based on the lighting conditions.

Similarly, the algorithms necessary to detect and classify objects in the field of view of the various sensor system continue to be refined, but have not yet reached a point where the accuracy rate is sufficient enough without the inclusion of false 'positives', which can have negative effects on traffic signal timing and operations.

This level of acceptance has yet to be determined by agencies, but will need to be a consideration for adoption of technologies in the future.

Description of the Current System or Situation

Side Object Detection

The SODS consists of six ultrasonic transmitters and receivers that detect the distance between the bus and nearby objects. The sensors emit sound waves that register a reading with the sensor when they bounce off of solid objects. A central controller interprets the ultrasonic range data. The SODS interface is composed of three LED displays along with a speaker that audibly alerts the operator when the system detects a potential hazard.

Pedestrian Detection

As noted in the Pedestrian Detection section in Chapter 3, pedestrian detection has currently been deployed, in limited scale, as both vehicle-only or infrastructure-only solutions. Both of these are discussed in greater detail below.

Vehicle-Based

From an onboard vehicle standpoint, many approaches to object detection/collision warning systems, have been evaluated and have demonstrated the capability to detect the presence of objects within the field of view of the sensors mounted on the vehicle. These technologies in use include video, radar, lidar, and ultra-sonic technologies, each with strengths and limitations. Per the 2007 U.S. DOT study, *Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses*[2], which presents an analysis of IVBSS for transit buses, only video systems truly exhibit the ability to distinguish a pedestrian from other obstacle types, and as such, are presently the only approach that has a reliable detection capability. But in less-than-ideal lighting conditions, the effectiveness of video systems also diminishes, leaving its true usefulness in question. Use of visible and infrared video systems helps extend the environment under which it can be used, but it is still limited.

Presently, some of the high-end passenger vehicles and commercial truck manufactures offer systems based on single or a combination of these technologies, but like the infrastructure-based systems, none of these technologies have truly realized widespread adoptions, particularly in the transit community. Of the systems evaluated in the above-cited report, as of 2007, only two were deemed suitable for transit applications such as pedestrian detection, and a recent literature search did not yield any additional advances specific to transit applications.

Infrastructure-Based

In the present Intelligent Transportation System (ITS) community, most of the research and fielded deployments for infrastructure-based pedestrian detection systems focus on either generating the pedestrian call to the signal controller (in lieu of or in addition to a call button press), or to extend an existing pedestrian phase when it is determined that a pedestrian will remain in the intersection beyond termination of the current pedestrian phase. Among the approaches used for this method of detection, microwave and infrared sensors have emerged as two more common technologies. Federal Highway Administration (FHWA) Report # FHWA-RD-00-097, entitled *Evaluation of Automated Pedestrian Detection at Signalized Intersections*[4], includes site profiles for a few deployment locations that use either microwave or infrared technologies as the sensor. These ‘cameras’, if you will, are interconnected with the local traffic signal controller, and are typically wired in parallel with the call button, when used as an alternative to the button, or activated in conjunction with the pedestrian phase of the signal when used to extend the signal.

In these two modes of operations, these technologies have proven to be useful. However, no specific technology has found widespread adoption in this form of pedestrian detection. Current statistics on the number of intersections equipped in this fashion are not available, but given the limited amount of published studies or articles available on this subject, it seems reasonably safe to assume that there is a fairly low penetration of these technologies at this time.

In addition, based on the current algorithms in use and the current practices of integrating these devices with signal controller timing plans, the use of these detector systems to sense ‘illegal’ crossings, (those against the light), are even less commonplace.

Modes of Operation for the Current System or Situation

Side Object Detection

The SODS has four distinct operational modes: stopped, urban slow, urban fast, and highway. A number of factors are considered in determining what mode the system will operate in, including the speed at which the bus is traveling, activation of the turn signal, the distance of the object from the bus, and location of the object relative to the bus.

Stopped Mode occurs when the vehicle is stopped. All six detectors are activated and the detector distance is set to 4 ft. Note that the system does not have an audible alert in this mode.

Urban Slow Mode occurs when the vehicle is traveling at speeds below 15 mph. All six detectors are activated and the detector distance is set to 4 ft. Note that the system does not have an audible alert in this mode.

In the Stopped and Urban Slow Mode the SODS classifies detected objects according to their distance from the detector and provides feedback to the operator based on the severity of the threat:

- Objects greater than 4 ft. away are ignored.
- Objects 3 to 4 ft. from the detector are considered a low threat and result in a slow flash on the LED warning.
- Objects 2 to 3 ft. from the detector are considered a moderate threat and result in a fast flash on the LED warning.
- Objects less than 2 ft. from the detector are considered a high threat and result in a continuous warning light.

Urban Fast Mode occurs when the vehicle is traveling between 15 and 45 mph and one of the turn signals is activated. In this mode the system only detects objects near the sensors on the side of the vehicle for which the turn signal is activated. In this mode, there is no distinction for distance. Any objects detected within 6 ft. of a detector (on the side of the vehicle with the turn signal on) will result in a solid yellow light on the LED display as well as an audible warning. Note that the front sensors are not utilized in this mode.

Highway Mode occurs when a vehicle is traveling over 45 mph and one of the turn signals is activated. The operation is identical to Urban Fast mode, except that the detection distance is increased to 8 ft.

Pedestrian Detection

Vehicle-Based

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

Infrastructure-Based

Pedestrian detection systems implemented using infrastructure-based solutions typically operate in conjunction with the timing controlled by the traffic signal controller. When the controller commences a pedestrian phase, the pedestrian detector system is activated and upon completion of the phase, the detector remains active for a period of time to determine if the pedestrian phase should be extended.

User Classes and Other Involved Personnel

One of the issues to be addressed in this Concept of Operations is determining and defining the system's key stakeholders. By establishing key stakeholders, the system's primary and secondary goals and objectives can be better understood. Additionally, ongoing input can be solicited from these stakeholders to narrow the focus and refine the system's design, resulting in a TRP that will achieve maximum benefit to U.S. DOT and the Safety Pilot Model Deployment. User Groups that these stakeholders fall under for the existing state of operations are described in Table 3-1.

Table 3-1. Summary of User Classes for Existing System(s)

User Group	System Operator	Data Consumer	Maintainer	Beneficiary
Transit Agency	X	X		X
Traffic Managers	X	X		X
Roadway Engineers	X	X		X
Maintenance Staff			X	
Transit Vehicle Driver		X		X
Transit Passengers				X
Pedestrians and Other Drivers				X

Source: Battelle

Transit Agency

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

Traffic Managers

Traffic managers are responsible for the operation of infrastructure-based systems including pedestrian detection cameras. These detectors must be integrated into the signal system software used by the agency, and considered as part of their signal timing plans. Traffic managers can benefit from the information collected by these systems and use this information for subsequent changes to intersection operations.

Roadway Engineers

Roadway engineers are responsible for the design and integration of infrastructure-based detection systems at signalized intersection. They must work closely with the traffic managers to deploy the systems and achieve optimal performance. Roadway engineers can benefit from the information collected by these systems and use this information for subsequent changes to intersection operations.

Maintenance Staff

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

Transit Vehicle Driver

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

Transit Passengers

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

Pedestrians and Other Drivers

Pedestrians and drivers of other vehicles are primary beneficiaries of these systems. The reduction or elimination of any incident involving pedestrians or other drivers can only be considered a positive benefit.

Support Environment

Side Object Detection

Maintenance and support of existing SODS services are conducted by the operating agency. They have most spare parts on hand for the sensors and in-vehicle display units to fix or replace damaged components.

Pedestrian Detection

Vehicle Based

Similar to the support environment for SODS, vehicle-based pedestrian detection is dependent typically on the operating agency, and potentially, depending on the size and needs of the agency, support contracts with the vendor of the detection system. Depending on the policy of the agency and any support contracts with vendors, would determine the necessary level of spare units to have on hand. Maintenance primarily consists of keeping the lenses clear of dirt and debris, and potentially updates to device firmware in order to support updated detection algorithms. Again, the latter is dependent on the support contracts the agency has in place. Most of these systems do not have repairable components, so remove and replace is the expected approach for repair, using tools that would typically be available in a transit maintenance facility.

Infrastructure Based

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

Chapter 4 Justification for and Nature of Changes

The safety of pedestrians and passengers on transit vehicles has been of critical concern to U.S. DOT for several decades. For example, in 2008, FHWA issued a "Pedestrian Safety Guide for Transit Agencies," whose purpose was to help transit agencies improve the safety of pedestrians.[6] Recent incidents such as those similar to that reported by the Star-Ledger on January 7, 2012, citing injuries from transit to pedestrian continue to highlight the issue. In this case, a woman badly hurt by a NJ Transit bus that struck her in the crosswalk was awarded $7.85M in a lawsuit settlement. The frequency and severity of such incidents suggest that further research is needed and changes to the current operations of transit vehicles need to be researched, considered, and implemented.

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

The V2V Safety Application Research Plan as part of the multimodal research program is focused on conducting research, testing, and providing the information needed to understand the safety benefits that could be realized by the deployment of V2V wireless communications technology and the associated applications that are enabled by such technology. The initial research, development, and proof-of-concept testing of crash warnings systems based on wireless 5.9 GHz. DSRC has been focused on light vehicles. The U.S. DOT has been working for several years with light vehicle original equipment manufacturer (OEM) to conduct this foundational research—including participation on standards committees that are tasked with the development and refinement of wireless communications standards (ref. IEEE P1609 Wireless Access in Vehicular Environments (WAVE) standards set), as well as an efficient messaging protocol (ref. Society of Automotive Engineers (SAE) J2735 standard) tailored for use with the DSRC communications medium. The U.S. DOT would like to expand DSRC-based safety application research, and apply the resultant technologies and systems to transit vehicles.

Justification for Changes

Reports of transit vehicles striking pedestrians in crosswalks are pervasive in agency incident/accident reports as well as observable in published literature. For example, 30 pedestrians were killed in Chicago due to vehicle strikes in 2010 with 80 percent of all pedestrian-to-vehicle incidents occurring

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

in crosswalks while the walk signal is active.[7] The Chicago study further indicates that “78 percent of all pedestrian crashes and 80 percent of fatal and serious injury pedestrian crashes from 2005 through 2009 occurred at an intersection,” but also notes that “this is significantly different from national statistics, where 46 percent of crashes are intersection related.” These statistics demonstrate that the issue of vehicles striking pedestrians in crosswalks is a known and prevalent issue in the transportation system that would potentially benefit from further research and the use of technology to address.

The U.S DOT is initiating a multi-modal Safety Pilot Model Deployment, which started in early 2011 and extends into 2014 [8], to demonstrate the capabilities of safety (primarily V2V) equipped vehicles. The Safety Pilot Model Deployment will be a large-scale test of light vehicles, trucks, and transit vehicles—as well as vehicles equipped with vehicle awareness devices and ASDs. The Safety Pilot Model Deployment is intended to test the effectiveness of the safety applications installed in the test vehicles, and the overall effectiveness of the deployed safety system capability. The Safety Pilot Model Deployment will include over 2,600 light, heavy, and transit vehicles, will be operated in a predefined geographic area in Ann Arbor, Michigan, to enhance the interaction of such vehicles in a real-world environment, and will examine the overall interoperability, scalability, user acceptance, reliability, and other implementation issues. The majority of these vehicles participating in the Safety Pilot Model Deployment will be equipped only with vehicle awareness devices, which will broadcast the vehicle’s location, heading, speed, and other information contained in a BSM. Approximately sixty integrated light vehicles, three integrated trucks, 16 retrofitted trucks, 300 aftermarket safety device equipped vehicles, and three retrofit transit vehicles will be fully functional vehicles equipped with all necessary hardware and software for executing various DSRC-enabled safety applications.
In contrast to the (simpler) vehicle awareness devices, the retrofit transit vehicle devices will include DVI functionality as well as support a number of safety applications. The design, development, installation, and testing of the OBE and safety applications for the transit retrofit vehicles is the primary purpose of this project.

The Safety Pilot Model Deployment consists of several phases, including Driver Clinics and Model Deployment. The purpose of the Driver Clinics, (approximately six will be held for light vehicles and two to four for heavy vehicles), is to introduce “naïve” drivers to a set of in-vehicle DSRC-based safety systems and solicit their reaction to those systems. However, because transit vehicle drivers are highly trained and only experienced drivers will be used for the Model Deployment tests, Driver Clinics will not be conducted for transit drivers. Instead, a series of driver training exercises for transit vehicles will be conducted, and this training may include the use of transit vehicle driving simulators.

[7] T.Y. Lin International, “2011 PEDESTRIAN CRASH ANALYSIS”, http://www.cityofchicago.org/content/dam/city/depts/cdot/pedestrian/2011PedestrianCrashAnalysisSummaryReport.pdf, 2011.

[8] Model Deployment officially occurred from August 2012 to August 2013. Pre-Model Deployment activities occurred before August 2012 and Post-Model Deployment activities occurred after August 2013.

The results obtained from the Safety Pilot Model Deployment will be used to:

- provide an observation of driver risk compensation and other unintended consequences
- gauge driver acceptance
- identify factors that could increase safety benefits and minimize possible adverse effects (including refinement of DVI concepts)
- promote the technology to increase deployment
- provide necessary information for possible rulemaking or agency decision by National Highway Traffic Safety Administration (NHTSA).

Description of Desired Changes

The focus of the changes involves both the mechanism and nature of the information being provided to the transit operator. In short, the desire is to test the feasibility of using Connected Vehicle technology for safety enhancements pertaining to pedestrian safety and vehicles turning in front of a transit vehicle.

Priorities Among Changes

A key priority will be to integrate the Connected Vehicle technologies onto an existing transit vehicle. A second priority will be to enhance the Connected Vehicle research through the development and implementation of two new transit-specific safety applications that will be installed in the transit vehicles.

Changes Considered but not Included

There are a number of different possible combinations of technologies that could be explored and researched related to the two safety applications. In particular, reliance upon a completely vehicle mounted system involving radar, milli-meter wave, ultrasonic, etc. technology would be one option. However, because the objective of this project is confined to the Connected Vehicle program and the Safety Pilot Model Deployment in particular the availability and use of DSRC communications was desired. Similarly, technologies for side detection of objects using radar and other systems mounted on buses to detect overtaking vehicles were also considered and not selected in favor of reliance on the BSM DSRC broadcast from the overtaking vehicle.

Assumptions and Constraints

One significant constraint is that the use of Connected Vehicle technology requires DSRC communications both in the transit vehicle as well as the other vehicle overtaking the bus and the infrastructure components. This ConOps assumes that such radio communications are available and being used by all vehicles during the test.

A second assumption is that the requisite CAN bus information can be obtained from the transit vehicle as needed by the safety applications.

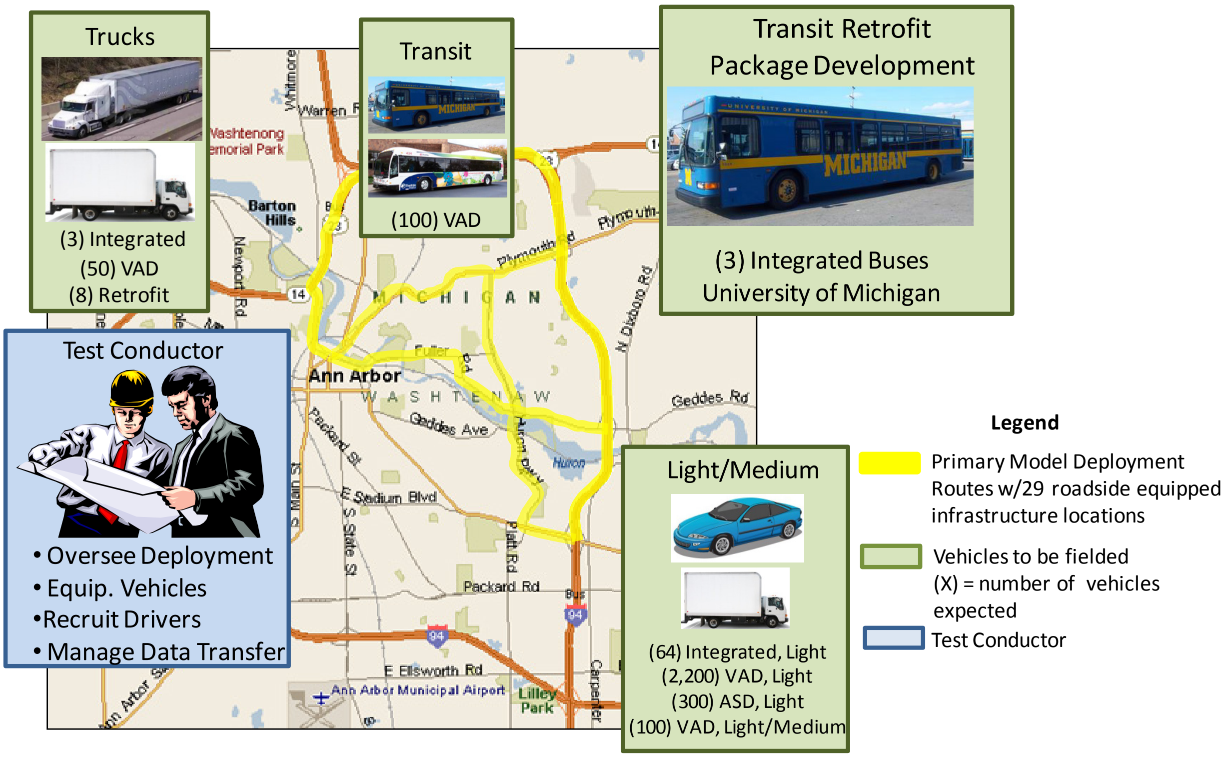
Chapter 5 Concepts for the Proposed System

Background, Objectives, and Scope

Although great strides have been made improving highway safety, traffic crashes remain a major concern in the United States. Statistics from the NHTSA National Center for Statistics and Analysis Fatality Analysis Reporting System (FARS) indicate that there were about 31,000 fatal crashes in 2009, killing about 34,000 people. Developmental connected vehicle telecommunication technology for V2V and V2I data communications can enable major reductions in injuries and fatalities suffered on our roads and highways, as well as enable reductions in traffic congestion and impacts on the environment.

The U.S. DOT is conducting the Safety Pilot Model Deployment in partnership with private industry research and development partners. The purpose of the program is to determine the effectiveness of connected vehicle safety applications at reducing crashes and to understand how drivers respond to the applications under real-world driving conditions. The Safety Pilot includes two key components: (1) Driver Acceptance clinics, initiated in August 8, 2011, that focus on driver responses to in-vehicle alerts and warnings in controlled environments, such as test tracks; and (2) a Model Deployment in Ann Arbor, Michigan, involving approximately 2,800 vehicles of various types containing equipment packages and employing a range of safety applications that hinge on DSRC.

A fundamental goal of the Safety Pilot Model Deployment is to gather real-world data on connected vehicle technology performance and drivers' adaptations to it. The model deployment data will play a critical role in supporting a major decision milestone by NHTSA in 2013 (2014 for heavy vehicles) on the future of Connected Vehicle technology, including possible mandatory deployment, voluntary implementation on new vehicles, or additional research. The Safety Pilot Model Deployment consists of a field test of connected vehicle technology, including V2V and V2I safety and other applications. Figure 5-1 summarizes key components of the model deployment, including setting, vehicle types, and timeline.



Source: Battelle

Figure 5-1. Key Components of the Safety Pilot Model Deployment

As indicated in Figure 5-1, a total of 29 RSE packages of varying types will be deployed on arterial streets and freeways. The different RSE types are expected to include those associated with Signal Phase and Timing (SPaT)-enabled traffic signals, actuated traffic signals, light pole mountings (for curve warning), and freeways.

The model deployment will feature light/medium duty vehicles, trucks, and transit buses. These vehicles will be equipped with any of four types of equipment packages: (1) Integrated Safety Systems, (2) Retrofit packages, (3) Aftermarket Safety Devices (ASD), and (4) vehicle awareness devices (formerly referred to as “Here-I-Am” or HIA devices). Integrated packages provide the highest level of functionality. These packages are built into the vehicles during production, connect to the vehicle CAN buses (CAN or CAN buses); can access proprietary CAN bus data; broadcast and receive BSMs such as vehicle position, speed, heading, and other fundamental information; and process the content of incoming messages to provide drivers warnings through a DVI. Retrofit equipment differs from integrated packages in that they are not integrated during vehicle manufacture and access only the standard, non-proprietary CAN bus data. ASD equipment provides functionality comparable to the retrofit equipment (DVI, safety applications, warnings/alerts and standard, non-proprietary CAN bus data access) but, unlike the retrofit equipment that is custom-developed for specific vehicle types and not available “off the shelf,” ASD equipment is available on the aftermarket and can be installed in any vehicle. A vehicle awareness device provides the lowest level of functionality, restricted to sending BSM over DSRC. A vehicle awareness device does not access the CAN bus, cannot run applications and cannot provide driver alerts through a DVI. Like ASD, the vehicle awareness device is an aftermarket device.

The TRP Development project includes developing, testing, installing, and maintaining retrofit packages on three transit buses drawn from the University of Michigan transit fleet; developing two new transit safety applications (Pedestrian Warning and Vehicle Turning Right in Front of a Transit Vehicle); and collecting and providing data from the equipped buses to the Volpe Center. Execution of these efforts poses many challenges including the need to accelerate schedule, integrate on any of a variety of transit bus makes and models, and perform effectively – interoperating and collecting and preserving data – in a dynamic, complex, real-world environment.

Operational Policies and Constraints

There are a number of operational policies and constraints that are imposed upon the development and operation of the TRP. These policies and constraints primarily stem from the Safety Pilot Model Deployment and include:

- The TRP needs to be very reliable as the model deployment constitutes a limited, critical opportunity to collect data. Action to perform maintenance or repair is required within 24 hours of problem identification.
- The TRP needs to be developed to be consistent with the overall goals, objectives, and implementation schema of the Safety Pilot Model Deployment.
- The TRP represents a retrofit kit to existing transit vehicles. As such, it needs to have the ability to be interoperable with existing transit systems.

Descriptions of the Proposed System

The proposed system will include a number of hardware and software components as described in this section.

Key TRP Development Objectives

- **Design, develop, install, test, and maintain on-board equipment and safety applications for 3 transit retrofit vehicles**
- **Vehicles participate in the Model Deployment and future transit V2V and V2I R&D**
- **Develop and implement *Pedestrian* Warning and *Vehicle Turning Right in Front of a Transit Vehicle* safety applications**
- **Include Data Acquisition System and provide data to Independent Evaluator**

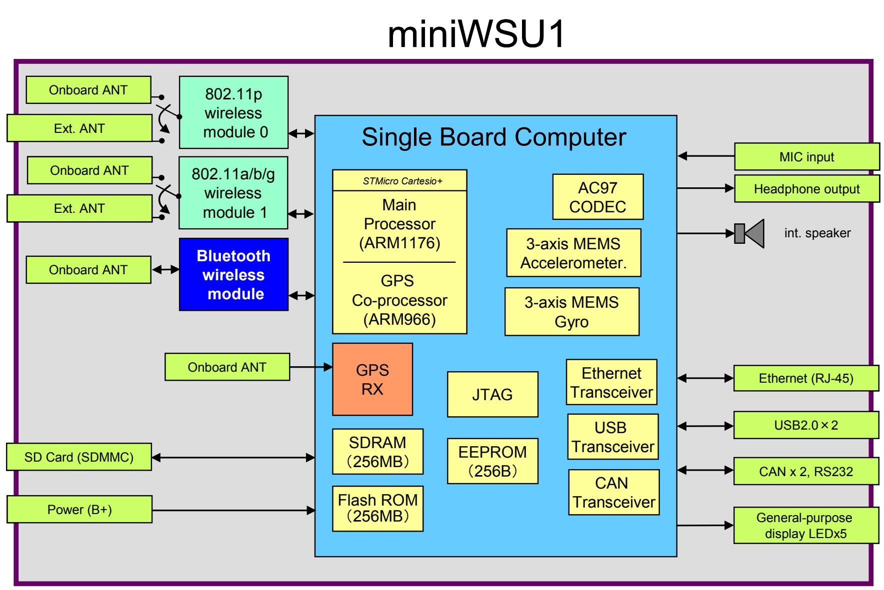
Hardware Components

There are several hardware components that will comprise the TRP. These include both hardware on the transit vehicle (DSRC radio, DAS, and the driver display module), as well as hardware components associated with roadside infrastructure components.

DSRC Radio

The TRP DSRC radio device will consist of the DENSO miniWSU unit (or equivalent); a derivative of the equipment being used on many Safety Pilot vehicles. The DENSO miniWSU solution is a custom computing and communications platform specifically designed for the development, implementation, testing, and evaluation of 5.9 GHz DSRC V2V/V2I applications. The device incorporates ST Microelectronics Cartesio+ chipset with an ARM11 application central processing unit (CPU), embedded Global Positioning System (GPS) receiver, and Atheros WAVE transceivers to facilitate the development of safety and non-safety ITS applications. The software configuration uses Linux as a general purpose operating system (OS). The miniWSU has a plastic molding that is approximately 106mm * 72mm * 25mm in dimension.

The basic hardware architecture for the miniWSU1.0 module is reproduced in Figure 5-2. The miniWSU device incorporates a custom computing platform, GPS positioning receiver, and specialized communications interfaces.



Source: DENSO

Figure 5-2. Schematic of the DSRC Radio – DENSO miniWSU

The electronic architecture of the miniWSU is similar to a Personal Navigation Device (PND), and uses many of the same components found in today's commercial mass production offerings. Power to the miniWSU will be provided both from the un-switched battery voltage bus as well as a battery voltage that is controlled by the ignition switch, if it is available. Figure 5-2 provides the interfaces that are available on the miniWSU, which includes some interfaces that will not be utilized by the TRP system (e.g., RS-232).

The TRP device will be preloaded with the following basic safety applications:

- **Curve Speed Warning (CSW).** CSW aids drivers in negotiating curves at appropriate speeds. This application will use information communicated from RSUs located ahead of approaching curves. The communicated information from RSUs would include curve location, curve speed limits, curvature, bank, and road surface condition. The device would determine, using other vehicle information, such as speed and acceleration whether the driver needs to be alerted. This application requires the ability to receive a message from the RSU.

- **Emergency Electronic Brake Light (EEBL).** The EEBL application enables a host vehicle to broadcast a self-generated emergency brake event to surrounding remote vehicles. Upon receiving such event information, the remote vehicle determines the relevance of the event and provides a warning to the driver if appropriate. This application is particularly useful when the driver's line of sight is obstructed by other vehicles or bad weather conditions (e.g., fog, heavy rain).
- **Forward Collision Warning (FCW).** The FCW application is intended to warn the driver of the host vehicle in case of an impending rear-end collision with a remote vehicle ahead in traffic in the same lane and direction of travel. FCW is intended to help drivers in avoiding or mitigating rear-end vehicle collisions in the forward path of travel.

Additional information regarding the basic safety applications can be found in the DENSO Aftermarket Safety Device User's Guide.

Data Acquisition System

Source: UMTRI

Figure 5-3. Illustration of the UMTRI GEN5 DAS

The DAS will be included on the retrofitted vehicles to support evaluation efforts. Although the DAS is not part of the TRP, a discussion of the DAS is included for completeness. The DAS will consist of the UMTRI GEN5 DAS. The GEN5 DAS application software runs on an UMTRI-configured version of Windows XP Embedded. The DAS can run different applications depending how the "Mode" connector is jumpered or controlled by an external switch. Automatic, Demo, Maintenance, graphical user interface (GUI), Upload, and No CPU are common modes used in testing. In "Automatic", the DAS powers up when the ignition switch is turned on, data are collected until ignition is turned off and then the DAS powers down. In "GUI" mode, an experimenter/operator can start and stop data collection, observe a real-time display, and enter test parameters and other metadata. "Upload" triggers an automatic file transfer to a server. "No CPU" prevents the computer and peripherals from being powered and is used when a vehicle is being serviced or when no data are to be collected.

UMTRI's GEN5 DAS has been updated to a smaller size of 9.5 x 7.5 x 5.2 inches. Figure 5-3 shows the enclosure. This GEN5 DAS is small enough not to affect the drivers' storage space, yet not so small that further miniaturization brings on added cost and technical risk in diagnosing and replacing components.

The DAS can capture hundreds of signals at 10 to 50 Hz, full target tracks from seven radars, five video streams, audio, GPS, and more. Data signal definitions are entered into a metadata database, using a GUI. This database is onboard the vehicle and is also available for analysis tools, enabling configurable and robust adaptation to different experiments. Video is collected onboard the DAS as well. The current system allows up to 8 separate image streams to be recorded separately, with frame size, frame rate, and compression parameters tunable to each image. Video imagery is collected by defining continuous data collection and/or triggered video collection using circular buffering, such that the triggered video (or other data) can be captured at higher rates, if desired. The DAS will, at minimum, be capable of recording up to 10 days of operational data before requiring a download.

Driver Display Platform

Information collected by hardware components will be displayed to the transit operator via an Android-based tablet that will be linked to the DSRC radio and the DAS. This tablet will consist of a Samsung Galaxy Tab™ 8.9 (SCH-I957) as illustrated in Figure 5-4. This tablet can be mounted in various configurations and will include Wi-Fi® 802.11 a/b/g/n, and Bluetooth® Wireless Technology 3.0. This display unit measures 9.09 x 6.21 x 0.34 inches and contains:

- RAM: 1GB, ROM: 59.6GB
- 16GB Internal Memory

A kiosk lockdown utility will be used to limit the available functionality of the tablet during transit bus operations. For example, the Android Market Place will be restricted from user access.

Source: Website, http://www.samsung.com/us/support/owners/product/SGH-I957ZKAATT

Figure 5-4. The Samsung Galaxy Tab (SCH-I957)

Pedestrian Detection

Pedestrian detection will occur through the standard crosswalk button as well as through an automatic detection sensor, the SmartWalk™ XP sensor (see Figure 5-5). This pole-mounted sensor is manufactured by MS SEDCO and specifications for the sensor are provided in Table 5-1.

Source: website, http://www.mssedco.com/smartwalk_xp.htm

Figure 5-5. SmartWalk XP Sensor for Pedestrian Detection

Table 5-1. Specifications of the SmartWalk™ XP Sensor

Model Number	SmartWalk XP
Operating Frequency	24.125 gHz (K-band)
Detection Method	Microprocessor analyzed Doppler microwave detection
Pattern	Adjustable with cover off
Detection Angle	Adjustable
Detection Mode	Selectable: approach-only, depart-only or bidirectional motion
Detection Verification Time	0.1 to 5 seconds
Power Requirements	12 to 24 V AC or DC ± 10%
Power Consumption	1W maximum
Relay Output	Form C, rated at 1 Amp @ 24V DC (N.O. and N.C.)
Output Power	5mW typical, 2mW minimum
Relay Contact Ratings	0.5A:50V AC—1A:24V DC
Operating Temperature	-22°F to 158°F (-30°C to 70°C)
Physical Dimensions	4"W x 4"H x 7"L
Enclosure	Powder coated aluminum
Weight	4 lbs.

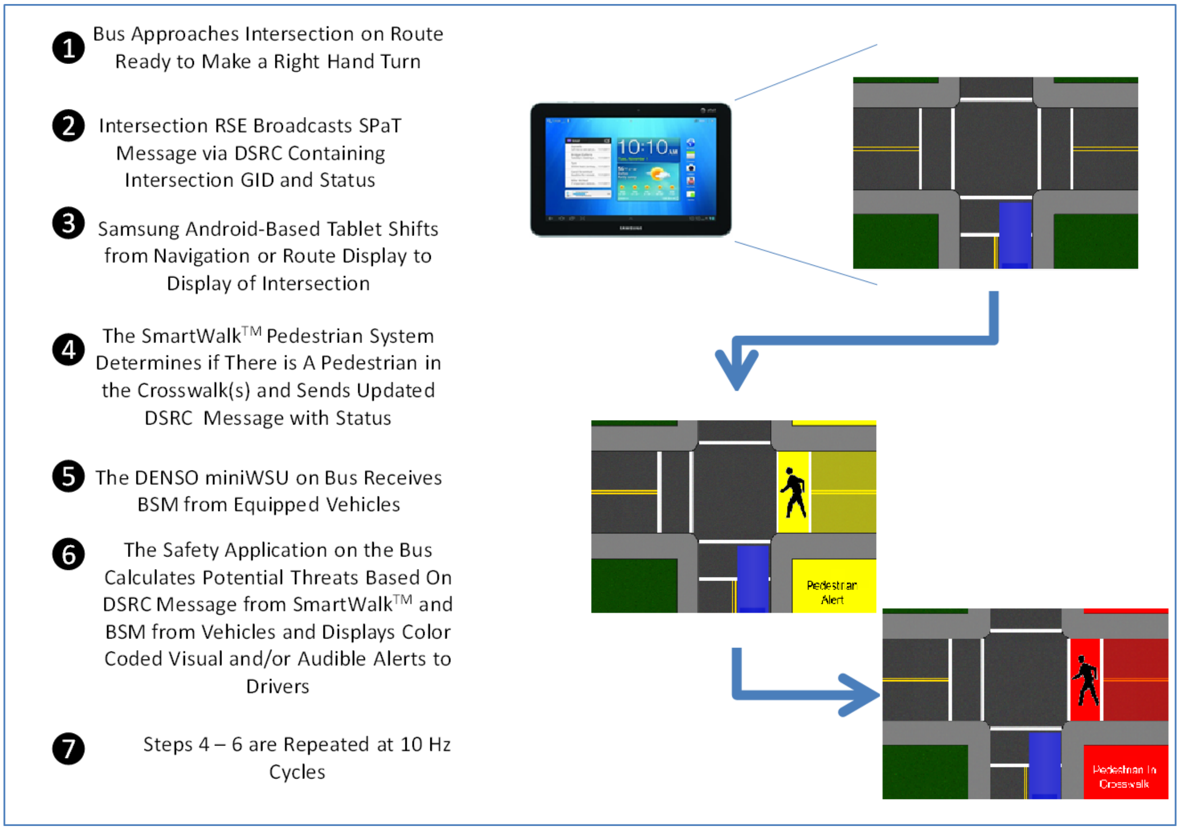
Source: MS SEDCO

Software Components

There are two software applications to the TRP package in addition to those that are included on the DSRC WSU radio unit (described above). The first of these applications improves safety of pedestrians by providing alerting and notification to the transit vehicle operator of a pedestrian in the crosswalk. The second application improves safety for both the passengers of the transit vehicle as well as third-party vehicle occupants by providing warnings and alerts to the transit bus operator of a vehicle passing and navigating through the blind zone and ultimately turning into the transit vehicle's direction of travel.

Software Concepts

Figure 5-6 summarizes the concept of the Pedestrian Warning application. The intersection will be continuously displayed while the bus is "within range" of the intersection and refresh the status of the intersection at 10 Hz cycles and identifying potential hazards using a green, yellow, and red color-coding system. Green would indicate non-hazardous vehicles/signals. For example, the vehicle on the cross street waiting for a red-light would represent a non-hazardous, but identifiable element associated with the intersection (provided the vehicle is broadcasting a BSM via DSRC). Once a pedestrian has pressed the crossing call button, the crosswalk would potentially shift to "yellow" in color and a warning would be issued to the bus driver. Finally, once the pedestrian begins to cross the street, the SmartWalk™ equipment would detect the presence of a person and provide an updated SPaT DSRC message indicating a person in the crosswalk and the warning would be potentially elevated to an alert and displayed in red. Simultaneously, the OBE on the bus would be reading information from the CAN bus and utilizing the BSM core modules to determine the final status of the warning and alert given to the bus driver.



Source: Battelle. Tablet picture from http://www.samsung.com/us/support/owners/product/SGH-I957ZKAATT

Figure 5-6. Illustration of the Pedestrian Detection Application Alerts

The Vehicle Turning Right in Front of a Transit Vehicle application will be based upon the BSM of the other vehicles in combination with the bus' own positional data received from the DENSO WSU module. Table 5-2 summarizes the functionality of the two applications.

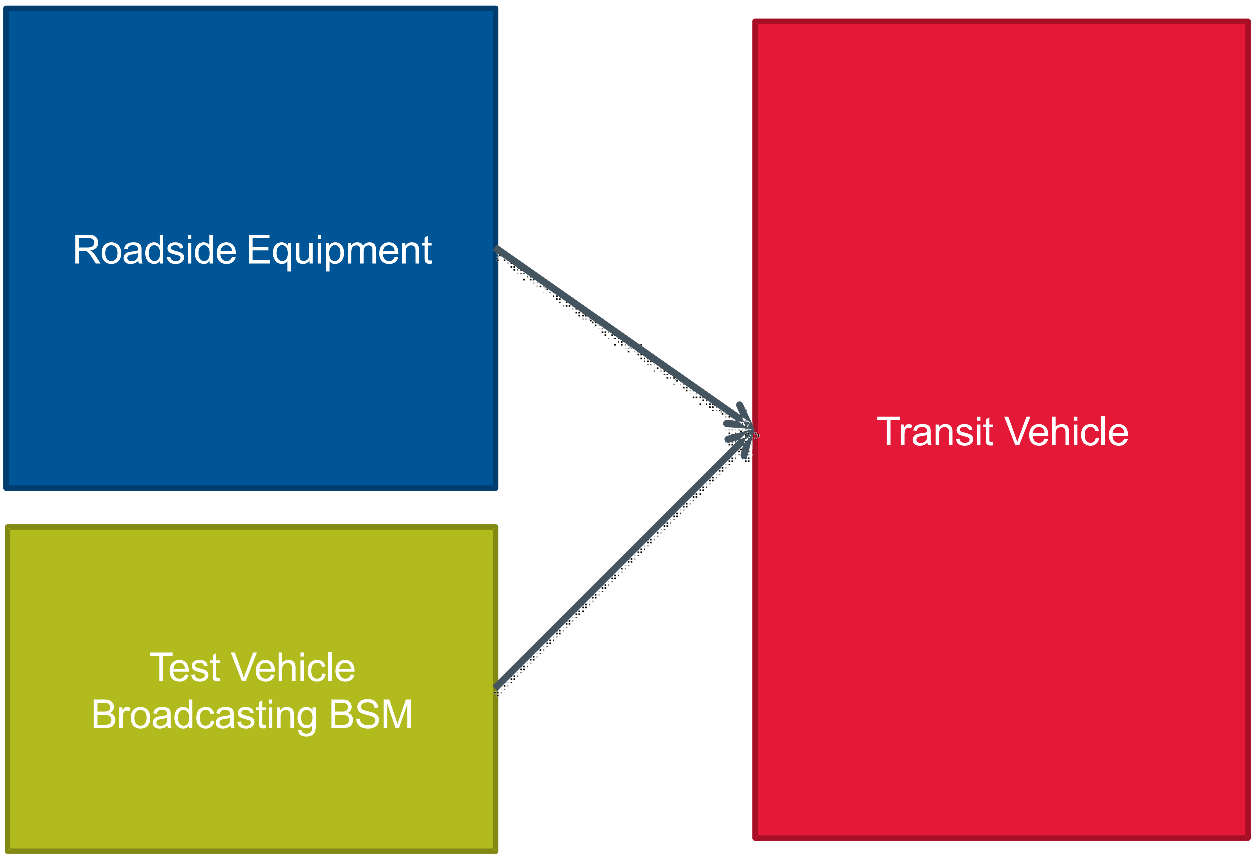
Table 5-2. Summary of Functionality of Applications

Functionality	Applications	
	Pedestrian Warning Application	**Vehicle Turning Application**
Application Input	Obtains information from GPS in the DENSO box (Latitude, Longitude, Timestamp, Heading, Speed, Elevation) Receives Geometric Intersection Description (GID) Map information from DSRC broadcast Receives Notification of Triggering Event (i.e., Call button pushed, pedestrian in crosswalk) via SPaT information from DSRC broadcast	Obtains information from GPS in the DENSO box (Latitude, Longitude, Timestamp, Heading, Speed, Elevation) Receives Notification of Triggering Event (i.e., BSM from equipped vehicles)
Processing	Determine position and status of bus relative to the signal. Determine level of hazard based on crosswalk call button and SmartWalk™ detection. Determine if bus movement, signal phase, and pedestrian activity warrant warning or alert.	Determine the position of the bus relative to other vehicle traffic via the BSM received from DSRC. Determine if heading and status of traffic warrants warning and or alerts to be issued.
Application Output	Provide real-time situational awareness to driver via Samsung Galaxy Tablet	Provide real-time situational awareness to driver via Samsung Galaxy Tablet

Source: Battelle

High-Level System Architecture

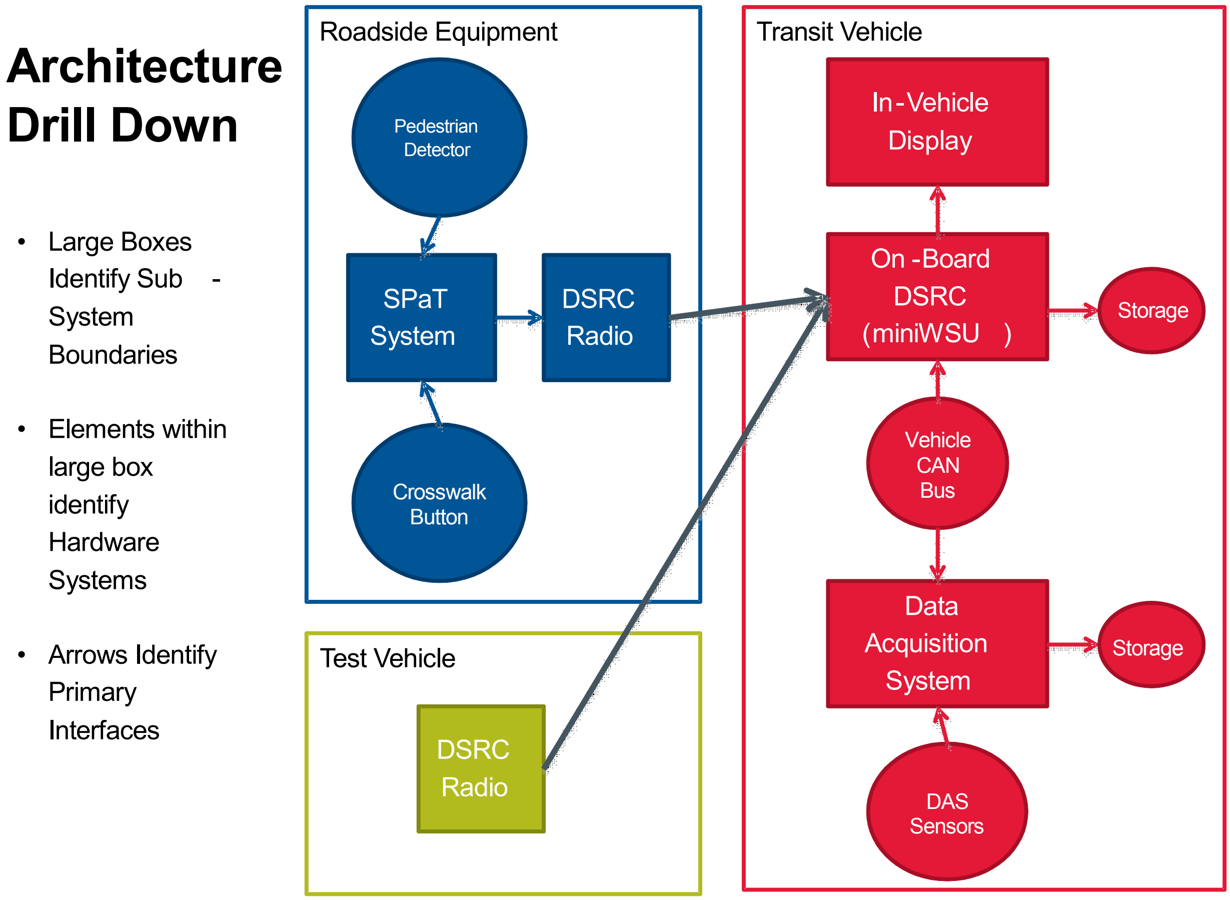
The high-level system architecture is composed of three main subsystems. The relationship of these three subsystems can be seen in Figure 5-7. The first subsystem represents the set of components which will reside on the Transit Vehicle. This subsystem will receive data from the other two subsystems, the RSE and the Test Vehicle.



Source: Battelle

Figure 5-7. High Level System Architecture

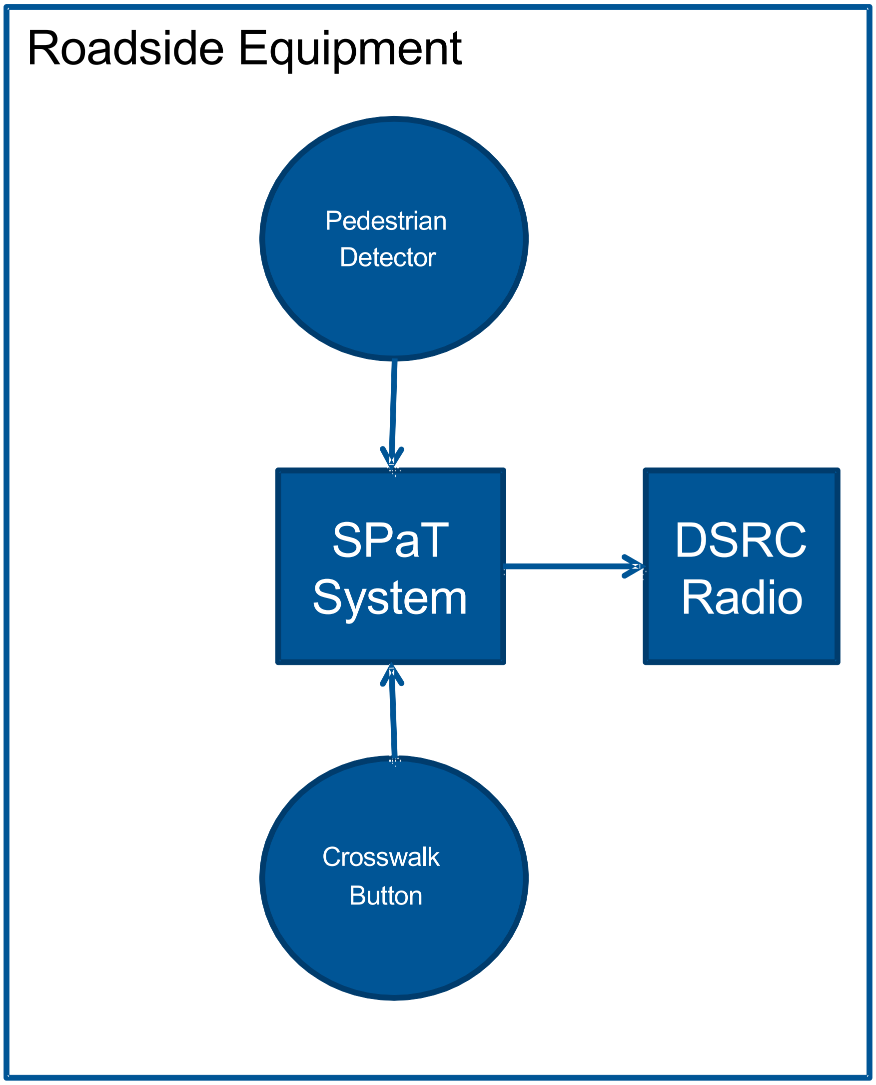
Further detail regarding these three subsystems is provided in Figure 5-8 where the components of each subsystem are shown. The communications between the RSE and the Test Vehicle and the Transit Vehicle are performed over DSRC. The Test Vehicle will be equipped with a single component, a DSRC radio which will be broadcasting a BSM. The BSM will be used by the Transit Vehicle for use in the Vehicle Making Right Turn Warning safety application.



Source: Battelle

Figure 5-8. Architecture Drill Down

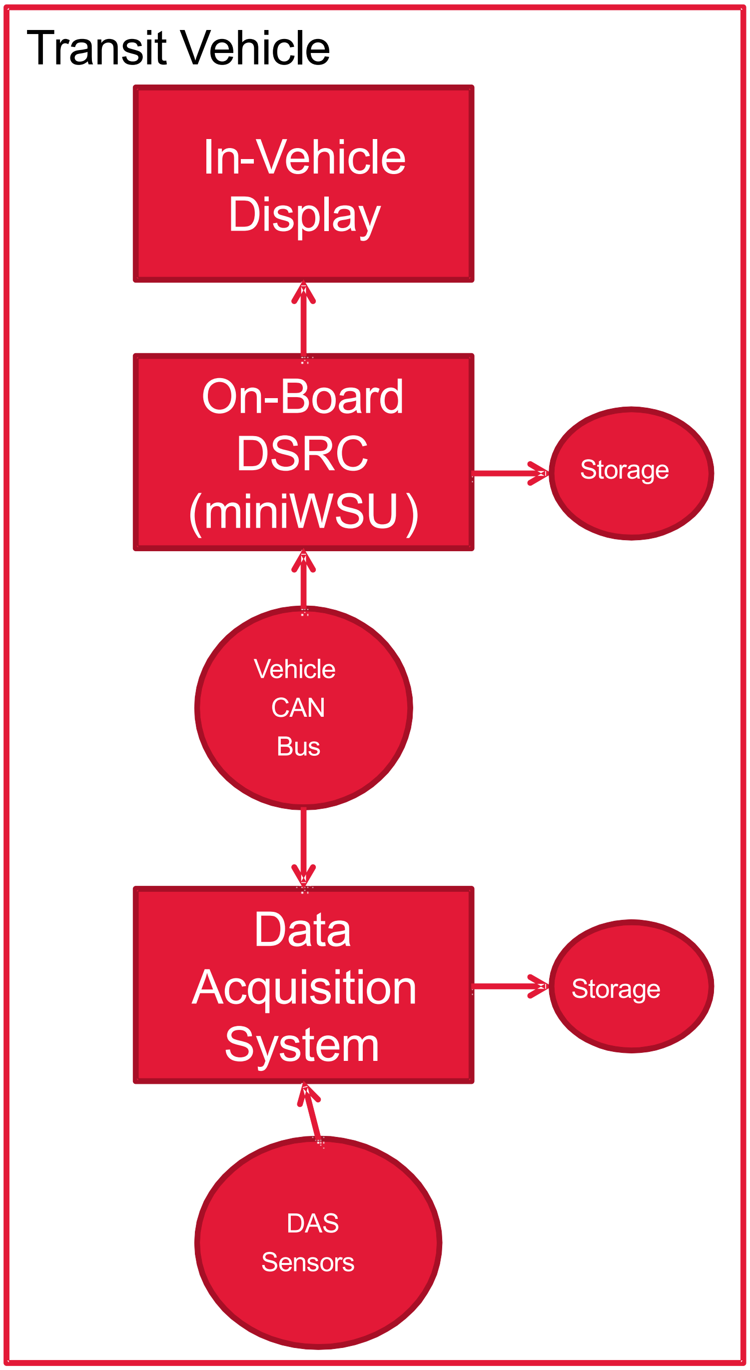
The detailed view of the RSE subsystem is provided in Figure 5-9. This subsystem integrates a Pedestrian detection device, SPaT System, and DSRC Radio into the existing equipment at the intersection. The SPaT System will receive the indications if the Crosswalk button has been pressed and/or there is a Pedestrian in the crosswalk. These data will be incorporated into a SPaT message and broadcast to nearby vehicles via the DSRC radio.



Source: Battelle

Figure 5-9. Roadside Equipment Subsystem Detail

The largest of the three subsystems is the Transit Vehicle subsystem which is further detailed in Figure 5-10. The components on the Transit Vehicle serve two main functions. The first is the equipment needed to serve as the TRP platform. This includes the In-Vehicle Display and the DSRC radio and associated storage. The second function is to record the data needed to evaluate the demonstration of the TRP platform for later evaluation. The equipment needed for this second function is the DAS and the various DAS Sensors and associated storage. Both functions will utilize the Transit Vehicle CAN bus for acquiring needed vehicle telemetry data. The DSRC radio on the Transit Vehicle will receive the broadcast messages (BSM and SPaT) from the two other subsystems and process these messages to determine if the driver should be alerted to a potential safety situation. Visual and audible alerts will be made available to the driver via the In-Vehicle Display.



Source: Battelle

Figure 5-10. Transit Vehicle Subsystem Detail

Modes of Operation

The system has the following modes of operation:

- Powered off mode is characterized by the bus power being completely removed from the system. In this mode the un-switched battery voltage bus as well as a battery voltage that is controlled by the ignition switch is removed.
- Powered down mode where the un-switched battery voltage is powering the miniWSU but the battery voltage that is controlled by the ignition switch is removed. In this mode, the miniWSU continues to monitor the vehicle CAN bus but does not monitor or communicate across its other external interfaces. The tablet is dark.
- Operational mode is characterized by full system operation where the miniWSU is monitoring the radio, CAN bus and GPS, and communicating data to the DAS and Tablet. The tablet is presenting alerts to the driver as indicated by the safety applications.
- Cloaked mode is characterized by full system operation where the miniWSU is monitoring the radio, CAN bus and GPS, and communicating data to the DAS and Tablet. The tablet is not presenting alerts that are indicated by the safety applications to the driver.

User Classes and other Involved Personnel

This section discusses the users and other involved personnel. Because the TRP is adding capability to an existing system, no additional user classes have been identified beyond those of the existing system as shown in Table 3-1. However, coordination with the traffic managers and roadway engineers will need to occur to ensure that the 2-way communications between Infrastructure and Vehicle are supported by the corresponding software updates contained in the Infrastructure.

Support Environment

This section discusses the personnel, facilities, and processes that make up the support environment for TRP system. Because the TRP system deployment is intended for a limited duration, the support environment will contain a streamlined approach.

In terms of the TRP support environment, the personnel supporting the system will be maintainers, Safety Pilot Test Conductor and system developers. Maintenance staff will require the skills to install TRP equipment on transit buses and intersections and the ability to troubleshoot to the subsystem level of the TRP system. The Safety Pilot Test Conductor oversees the operations of the TRP and will need to download the operational data stored on the DAS on each Transit Vehicle periodically on the order of once every 7-10 days. The system developers will provide continuous on-site presence to provide quick responses to equipment issues.

Chapter 6 Operational Scenarios

The following scenarios describe how the system will operate with the primary focus centered on the Transit Driver. Other user classes are minimally affected or not at all.

Transit Driver Scenarios

Unless noted, the transit vehicle is in gear, audio, video, and Transit Bus telemetry being recorded to storage device for these scenarios.

Scenarios 14 through 23 were deleted from a previous version of this document, leaving a gap in scenario numbering in order to retain the original scenario numbers. Scenario 29 and Scenario 30 were added where they logically belong, out of sequence in order to retain the original scenario numbers.

Pedestrian Detection

The following operational scenarios are focused on Pedestrian Detection only.

Scenario 1

Description

- Bus Approaches Signalized Intersection in a lane that is supported by the PCW hardware and software, and stops
- No pedestrians present.

Events

- TRP Safety Software presents the intersection display, and determines that NO message and NO display alert are needed.

Scenario 2

Description

- Bus Approaches Signalized Intersection in a lane that passes through the intersection – not a turn lane
- Scenario variation – Bus Approaches Signalized Intersection in a turn lane that is not supported by the PCW hardware or software.

Events

- TRP Safety Software does not present the intersection display, and determines that NO message and NO display alert are needed.

Scenario 3

Description

- Bus Approaches Signalized Intersection and prepares to make a left-hand turn in a supported left turn lane
- Pedestrian presses crosswalk button (pedestrian at crosswalk to the left of the bus, where the bus needs to turn).

Events

- TRP Safety Software presents the intersection display as the bus enters the supported lane
- Pedestrian pushes cross-walk button
- Button actuates signal controller
- Signal controller sends signal to SPaT System
- SPaT System creates SPaT Message Blob
- RSU Radio receives blob, encodes it, transmits it with Geometric Intersection Description (GID)
- Transit vehicle receives GID and SPaT message
- TRP OBE radio decodes message, sends message to TRP Safety Software
- TRP Safety Software determines message and displays Pedestrian Detected alert to Transit Driver.

Scenario 4

Description

- Bus Approaches Signalized Intersection and prepares to make a left-hand turn in a supported turn lane
- Pedestrian presses crosswalk button (pedestrian at crosswalk to the right of the bus, away from where the bus needs to turn)
- Scenario variation – Bus Approaches Signalized Intersection and prepares to go straight.

Events

- TRP Safety Software presents the intersection display as the bus enters the supported lane
- Pedestrian pushes cross-walk button
- Button actuates signal controller
- Signal controller sends signal to SPaT System
- SPaT System creates SPaT Message Blob
- RSU Radio receives blob, encodes it, transmits it with GID
- Transit vehicle receives GID and SPaT message

- TRP OBE radio decodes message, sends message to TRP Safety Software
- TRP Safety Software determines that NO message and NO display alert are needed.

Scenario 5

Description

- Bus Approaches Signalized Intersection and prepares to make a left-hand turn
- Pedestrian DOES NOT press crosswalk button, BUT proceeds into intersection and is detected by Pedestrian Detection System (pedestrian at crosswalk to the left of the bus, where the bus needs to turn).

Events

- TRP Safety Software presents the intersection display as the bus enters the supported lane
- Pedestrian begins to cross intersection
- Pedestrian detected by Pedestrian Detection System
- Pedestrian Detection System sends signal to SPaT System Box
- SPaT System creates SPaT Message Blob
- RSU Radio receives blob, encodes it, transmits it with GID
- Transit vehicle receives GID and SPaT message
- TRP OBE radio decodes message, sends message to TRP Safety Software
- TRP Safety Software determines message and displays Pedestrian Detected alert to Transit Driver.

Scenario 6

Description

- Bus Approaches Signalized Intersection and prepares to make a left-hand turn
- Pedestrian DOES NOT press crosswalk button, BUT proceeds into intersection and is detected by Pedestrian Detection System (pedestrian at crosswalk to the right of the bus, away from where the bus needs to turn).

Events

- TRP Safety Software presents the intersection display as the bus enters the supported lane
- Pedestrian begins to cross intersection
- Pedestrian detected by Pedestrian Detection System
- Pedestrian Detection System sends signal to SPaT System Box
- SPaT System creates SPaT Message Blob
- RSU Radio receives blob, encodes it, transmits it with GID
- Transit vehicle receives GID and SPaT message

- TRP OBE radio decodes message, sends message to TRP Safety Software
- TRP Safety Software determines that NO message and NO display alert are needed.

Scenario 7

Description

- Bus Approaches Signalized Intersection and prepares to make a right-hand turn
- Pedestrian presses crosswalk button (pedestrian at crosswalk to the left of the bus, away from where the bus needs to turn).

Events

- TRP Safety Software presents the intersection display as the bus enters the supported lane
- Pedestrian pushes crosswalk button
- Button actuates signal controller
- Signal controller sends signal to SPaT System
- SPaT System creates SPaT Message Blob
- RSU Radio receives blob, encodes it, transmits it with GID
- Transit vehicle receives GID and SPaT message
- TRP OBE radio decodes message, sends message to TRP Safety Software
- TRP Safety Software determines that NO message and NO display alert are needed.

Scenario 8

Description

- Bus Approaches Signalized Intersection and prepares to make a right-hand turn
- Pedestrian presses crosswalk button (pedestrian at crosswalk to the right of the bus, where the bus needs to turn).

Events

- TRP Safety Software presents the intersection display as the bus enters the supported lane
- Pedestrian pushes crosswalk button
- Button actuates signal controller
- Signal controller sends signal to SPaT System
- SPaT System creates SPaT Message Blob
- RSU Radio receives blob, encodes it, transmits it with GID
- Transit vehicle receives GID and SPaT message
- TRP OBE radio decodes message, sends message to TRP Safety Software
- TRP Safety Software determines message and displays Pedestrian Detected alert to Transit Driver.

Scenario 9

Description

- Bus Approaches Signalized Intersection and prepares to make a right-hand turn
- Pedestrian DOES NOT press crosswalk button, BUT proceeds into intersection and is detected by Pedestrian Detection System (pedestrian at crosswalk to the left of the bus, away from where the bus needs to turn).

Events

- TRP Safety Software presents the intersection display as the bus enters the supported lane
- Pedestrian pushes crosswalk button
- Button actuates signal controller
- Signal controller sends signal to SPaT System
- SPaT System creates SPaT Message Blob
- RSU Radio receives blob, encodes it, transmits it with GID
- Transit vehicle receives GID and SPaT message
- TRP OBE radio decodes message, sends message to TRP Safety Software
- TRP Safety Software determines that NO message and NO display alert are needed.

Scenario 10

Description

- Bus Approaches Signalized Intersection and prepares to make a right-hand turn
- Pedestrian DOES NOT press crosswalk button, BUT proceeds into intersection and is detected by Pedestrian Detection System (pedestrian at crosswalk to the right of the bus, where the bus needs to turn).

Events

- TRP Safety Software presents the intersection display as the bus enters the supported lane
- Pedestrian begins to cross intersection
- Pedestrian detected by Pedestrian Detection System
- Pedestrian Detection System sends signal to SPaT System Box
- SPaT System creates SPaT Message Blob
- RSU Radio receives blob, encodes it, transmits it with GID
- Transit vehicle receives GID and SPaT message
- TRP OBE radio decodes message, sends message to TRP Safety Software
- TRP Safety Software determines message and displays Pedestrian Detected alert to Transit Driver.

Right Turning Vehicle

The following operational scenarios are focused on Right Turning Vehicles only.

Scenario 29

Description

- Bus approaches and stops within a geo-fenced bus stop
- No target vehicle presents to the left of the transit vehicle while it is departing from the bus stop.

Events

- TRP Safety Software determines that the transit vehicle is within a geo-fenced area and presents the bus Right Turning Vehicle Ready screen
- The Right Turning Vehicle Ready screen is removed after the bus departs the geo-fenced area.

Scenario 30

Description

- Bus approaches and stops within a geo-fenced bus stop
- The bus driver takes his foot off the foot brake in preparation for bus stop departure
- Target vehicle starts behind the bus, pulls out to pass the bus on the left and intends on continuing straight.

Events

- Target vehicle broadcasting BSM approaches bus behind and on the left-hand side of bus
- Target vehicle records its GPS position and calculates it's heading
- Target vehicle broadcasts BSM via DSRC
- Transit bus receives BSM from Target Vehicle
- WSU receives the BSM, classifies the target vehicle with respect to the transit vehicle position and forwards the classification and target vehicle heading BSM information to TRP Safety Software
- WSU sends Transit Bus Telemetry information to TRP Safety Software
- TRP Safety Software tracks target classification progression, determines that the target vehicle has transitioned from the “behind” to the “behind left” classification and displays Possible Right Turning Vehicle visual and audible alert to Transit Driver.
- Target vehicle transitions to “ahead left” classification, TRP Safety Software calculates the differential heading and determines that the target vehicle is not indicating an intent to veer right

Scenario 11

Description

- Bus approaches and stops within a geo-fenced bus stop
- The bus driver takes his foot off the foot brake in preparation for bus stop departure
- Target vehicle starts behind the bus, pulls out to pass the bus on the left and turns into the path of the bus and veers right in preparation to either return to the lane of the transit vehicle or make a right-hand turn in front of the transit vehicle.

Events

- Target vehicle broadcasting BSM approaches bus behind and on the left-hand side of bus and turns into the path of the bus
- Target vehicle records its GPS position and calculates it's heading
- Target vehicle broadcasts BSM via DSRC
- Transit bus receives BSM from Target Vehicle
- WSU receives the BSM, classifies the target vehicle with respect to the transit vehicle position and forwards classification and target vehicle heading BSM information to TRP Safety Software
- WSU sends Transit Bus Telemetry information to TRP Safety Software
- TRP Safety Software tracks target classification progression, determines that the target vehicle has transitioned from the "behind" to the "behind left" classification and displays Possible Right Turning Vehicle visual and audible alert to Transit Driver.
- Target vehicle transitions to "ahead left" classification and turns into the path of the transit vehicle
- TRP Safety Software displays Right Turning Vehicle visual and audible alert to Transit Driver

Scenario 12

Description

- Bus approaches and stops within a geo-fenced bus stop
- The bus driver takes his foot off the foot brake in preparation for bus stop departure
- Target vehicle starts to the left of the bus to pass the bus on the left and intends on continuing straight.

Events

- Target vehicle broadcasting BSM approaches bus on left-hand side of bus
- Target vehicle records its GPS position and calculates it's heading
- Target vehicle broadcasts BSM via DSRC
- Transit bus receives BSM from Target Vehicle

- WSU receives the BSM, classifies the target vehicle with respect to the transit vehicle position and forwards classification and target vehicle heading BSM information to TRP Safety Software
- WSU sends Transit Bus Telemetry information to TRP Safety Software
- TRP Safety Software tracks target classification progression, determines that the target vehicle has transitioned from the “behind left” to the “ahead left” classification, and determines that NO message and NO display alert are needed.

Scenario 13

Description

- Bus approaches and stops within a geo-fenced bus stop
- The bus driver takes his foot off the foot brake in preparation for bus stop departure
- Target vehicle starts to the left of the bus to pass the bus on the left, and turns away from the path of the bus and prepares to make a left-hand turn.

Events

- Target vehicle broadcasting BSM approaches bus on left-hand side of bus
- Target vehicle records its GPS position and calculates it’s heading
- Target vehicle broadcasts BSM via DSRC
- Transit bus receives BSM from Target Vehicle
- WSU receives the BSM, classifies the target vehicle with respect to the transit vehicle position and forwards classification and target vehicle heading BSM information to TRP Safety Software
- WSU sends Transit Bus Telemetry information to TRP Safety Software
- TRP Safety Software tracks target classification progression, determines that the target vehicle has transitioned from the “behind left” to the “ahead left” classification, and determines that NO message and NO display alert are needed.

Suppressed Alerts

Scenario 24

Description

- Bus approaches and stops within a geo-fenced bus stop and is out of forward gear (driver intends to stay within the bus stop)
- Target vehicle starts behind the bus, pulls out to pass the bus on the left and veers right in preparation to either return to the lane of the transit vehicle or make a right-hand turn in front of the transit vehicle.
- Scenario variation: Bus approaches and stops within a geo-fenced bus stop and driver continues to engage the footbrake.
- Scenario variation: Target vehicle starts behind the bus, pulls out to pass the bus on the left and intends on continuing straight

Events

- Target vehicle broadcasting BSM approaches bus on left-hand side of bus
- Target vehicle records its GPS position and calculates it's heading and velocity
- Target vehicle broadcasts BSM via DSRC
- Transit bus receives BSM from Target Vehicle
- WSU forwards BSM information to TRP Safety Software
- WSU sends Transit Bus Telemetry information to TRP Safety Software
- TRP Safety Software determines that NO message and NO display alert are needed.

Basic Safety Applications (EEBL, FCW, CSW)

Scenario 25

Description

- Target vehicle(s) stopped either directly in front or some distance ahead (in same or adjacent lane) of Transit Bus.

Events

- Target vehicle broadcasting BSM in front of bus
- Target vehicle records its GPS position and calculates it's heading and velocity
- Target vehicle broadcasts BSM via DSRC indicating an EEBL event
- Transit bus receives BSM from Target Vehicle
- WSU forwards BSM information to TRP Safety Software
- WSU sends Transit Bus Telemetry information to TRP Safety Software
- TRP Safety Software determines message and display of EEBL alert are needed.

Scenario 26

Description

- Target vehicles slowly moving in front of Transit Bus, in the same lane and direction of travel.

Events

- Target vehicle broadcasting BSM in front of bus
- Target vehicle records its GPS position and calculates it's heading and velocity
- Target vehicle broadcasts BSM via DSRC
- Transit bus receives BSM from Target Vehicle
- WSU forwards BSM information to TRP Safety Software
- WSU sends Transit Bus Telemetry information to TRP Safety Software
- TRP Safety Software determines message and display of FCW alert are needed.

Scenario 27

Description

- Bus Approaches Highway Curve
- Curve equipped with RSU.

Events

- RSU broadcasts CSW Traveler Information Message via DSRC
- Transit bus receives message from RSU
- WSU forwards RSU information to TRP Safety Software
- WSU sends Transit Bus Telemetry information to TRP Safety Software
- TRP Safety Software determines message and display of CSW alert are needed.

Operational Mode

Scenario 28

Description

- Bus in operation outside of all geo-fenced bus stops, outside of all Geometric Intersection Description boundary definitions, and without an active caution or warning condition from a Basic Safety Application.

Events

- Transit vehicle receives in-range GID, SPaT, and TIM messages from RSU, and the BSM from other DSRC-equipped vehicles
- TRP Safety Software determines that NO message and NO display alert are needed
- TRP tablet displays default screen with indications that the intra-system communications is healthy (two green circles displayed in the lower right corner of the screen).

Traffic Managers Scenarios

There are no operational differences for this user class.

Roadway Engineers Scenarios

There are no operational differences for this user class.

Maintenance Staff Scenarios

The operational scenario for the Maintenance Staff includes the repair or replacement of equipment that has malfunctioned or failed (e.g., TRP OBE, Pedestrian Detectors).

Transit Passengers Scenarios

There are no operational differences for this user class.

Pedestrians and Other Drivers Scenarios

There are no operational differences for this user class.

Transit Operator Union Scenarios

There are no operational differences for this user class.

Safety Pilot Test Conductor Scenarios

The Test Conductor oversees the operations of the Safety Pilot Model Deployment, of which TRP is a part, and will need to download the operational data stored on the DAS on each Transit Vehicle periodically on the order of once every month.

Chapter 7 Summary of Impacts

Implementation of the TRP will support the Safety Pilot Model Deployment. The subsections below identify potential operational impacts, organization impacts, and impacts during the development as well as ways of measuring these impacts.

Operational Impacts

This section describes the impacts that the TRP will have on entities that operate the system as well as the users that use the technologies and applications that will be deployed in the connected vehicle environment. Operational impacts of the TRP project will include capabilities that are beneficial to users, developers, operations and maintenance personnel.

The most significant operational impact of the Transit Safety Retrofit Program will be enabling new applications that provide benefits to the transportation system to improve safety. Expected benefits include:

- Reduction in number of Transit Bus accidents with Pedestrians in crosswalks at signalized intersection
- Reduction in number of Transit Bus accidents with other vehicles
- Reduction in number of Transit Bus speed-related incidents at roadway curves
- Data Collection from TRP-Equipped Buses will help in refining and improving the new safety applications.

The primary impacts to operators and maintenance personnel are the new hardware and software that will be deployed to perform functions listed in Chapter 5. The hardware will include Pedestrian Detectors, In-Vehicle Displays, DSRC Radios, DAS, etc. that will need to be maintained. Expected operational impacts include:

- Three Transit Vehicles removed from service for installation of equipment and for software updates
- Training of operators and maintenance staff to maintain TRP System
- Maintenance required to download data from DAS periodically.

Organizational Impacts

This section addressed the impacts the new system will have on operators of the TRP.
The organizational impacts will affect primarily the Transit Bus Drivers and the maintenance staff. Training should include both classroom and hands-on training on each subsystem as well as operations and maintenance training. Classroom training provides the student with the concept of operations, relationships, features, and an introduction to the hardware and software interfaces. Hands-on training allows the student to work with hardware components and software applications to practice basic operator and maintainer tasks.

Because the TRP initially will be installed on relatively few transit vehicles, the existing maintenance staff will likely be tasked with additional duties to maintain the system. However, if this results in increased workload, hiring of extra staff may need to be evaluated.

Impacts During Development

This section addresses the impacts that the TRP will experience while the system is being developed. During the development phases, there will likely be a need for continuous coordination and planning with the Safety Pilot Test Conductor. The activities may include site visits to inspect the test intersection, scheduling of equipment installation, and coordination of testing activities.

Additional impacts may include the following:

- Development of rules and controls needed for operational implementation
- System documentation updates
- Involvement in studies, meetings, and discussions prior to design and implementation
- Involvement in reviews and demonstrations, evaluation of revised operating capabilities, development or modification of safety applications, and required training
- Involvement in TRP bench and field interoperability testing
- Impact of new interface to Transit Bus Driver
- Program Schedule delays due to one or more of the following:
    - Delay in identifying the specific SPaT protocols to be used at TRP study intersections
    - Delay in client installation of roadside infrastructure necessary to support TRP applications
    - Delay in identifying Independent Evaluator's specific data needs.

Chapter 8 Analysis of the Proposed System

Various improvements, disadvantages and limitations, and alternatives and trade-offs considered are covered in this chapter.

Summary of Improvements

The TRP will provide new capabilities as described in Chapter 4. These new capabilities will offer improvements over the current system. Most directly, the TRP will provide transit operators with better situational awareness related to pedestrians in crosswalks, vehicles turning in front of the transit vehicle, and for other conditions including excessive speeds during curves and vehicles stopping in front of the transit vehicle. This improved situational awareness will enable the transit operator to have better decision making and will ultimately reduce the number of such incidents encountered by transit operators.

The TRP adds two new safety applications along with the inclusion of three basic safety applications that will increase the situational awareness for Transit Bus Drivers. The two new safety applications are Pedestrian Detection in Crosswalk and Right Turing Vehicle in front of Transit Vehicle. The three basic safety applications are Curve Speed Warning, Emergency Electronic Brake Light, and Forward Collision Warning.

- **Pedestrian Detection in Crosswalk.** Pedestrian Detection in Crosswalk application aids Transit Bus Drivers by alerting them if there are pedestrians in the left-hand turning crosswalk or the right-hand turning crosswalk.
- **Right Turning Vehicle in front of Transit Vehicle.** Right Turning Vehicle in front of Transit Vehicle application aids Transit Bus Drivers as they are pulling away from a bus stop by alerting them when there is a potential that another vehicle that is passing on the left will veer right in preparation to enter the lane of the transit vehicle or to make a right-hand turn in front of the transit vehicle.
- **Curve Speed Warning (CSW).** CSW aids drivers in negotiating curves at appropriate speeds. This application will use information communicated from RSUs located ahead of approaching curves. The communicated information from RSUs would include curve location, curve speed limits, curvature, bank, and road surface condition. The device would determine, using other vehicle information, such as speed and acceleration whether the driver needs to be alerted. This application requires the ability to receive a message from the RSU.
- **Emergency Electronic Brake Light (EEBL).** The EEBL application enables a host vehicle to broadcast a self-generated emergency brake event to surrounding remote vehicles. Upon receiving such event information, the remote vehicle determines the relevance of the event and provides a warning to the driver if appropriate. This

application is particularly useful when the driver's line of sight is obstructed by other vehicles or bad weather conditions (e.g., fog, heavy rain).

- **Forward Collision Warning (FCW).** The FCW application is intended to warn the driver of the host vehicle in case of an impending rear-end collision with a remote vehicle ahead in traffic in the same lane and direction of travel. FCW is intended to help drivers in avoiding or mitigating rear-end vehicle collisions in the forward path of travel.

Disadvantages and Limitations

This section provides a summary of the disadvantages and/or limitations of the proposed system. The TRP is being deployed on three transit buses with RSE at two locations (one intersection for PCW and one curve for CSW). There were also a limited number of bus stops with near side locations (prior to an intersection) for the VTRW application. A total of 17 geo-fenced bus stops were defined along the Commuter North and South routes. Because the amount of systems being deployed is low, the main disadvantage is that the amount of operational data being collected may be somewhat limited. This limited set of data may not provide adequate substantiation for the benefits of the new safety applications.

The technologies included in the study also have limitations inherent to them. While processing speed has greatly increased with mobile devices, there will still be inherent latencies from when a pedestrian or vehicle of interest is identified to when the alert is presented to the transit operator. It remains to be seen whether these latencies are such that they prevent a meaningful real-time notification to the transit operator. Additionally, the pedestrian safety application is highly dependent upon the ability of the pedestrian detector to successfully identify when a pedestrian is present in a crosswalk, while at the same time reducing false positives and false negatives. Studies evaluating pedestrian detection are ongoing as this technology is still relatively innovative and not as mature as other technologies being employed as part of the Safety Pilot Model Deployment.

The deployment schedule is somewhat accelerated. Design decisions will favor schedule versus a universal approach. The result may be that the TRP may not be implemented in such a way that would allow easy deployment to other Transit Vehicles. Stated in another way, the TRP may not be a one-size fits all solution and that additional development may be needed to support the ability to install the TRP to other Transit Vehicles.

Alternatives and Trade-offs Considered

Throughout the development of the ConOps, a number of alternatives and trade-offs have been considered that will affect the definition of the TRP. These include:

- Consideration of the nature and type of pedestrian detection methods for identifying pedestrians in crosswalks (i.e., considering a crossing request to not be the equivalent of a sensor detection).
- The identification of bus routes and bus stops that can support right-turning vehicles for the VTRW application. Bus stops must be located ahead of an available right turn in order to demonstrate the ability of the VTRW application to issue a warning when an RV makes a right turn in front of the transit vehicle.

- The availability of BSMs and DSRC communications on the infrastructure (i.e., tied to the traffic signal), the transit vehicle, and other vehicles has been assumed. Infrastructure-based sensors or transit vehicle mounted sensors (such as radar, video, etc.) were considered as they have been employed in other studies for similar safety benefits. However, as the focus of the Safety Pilot is on V2V and V2I communications, it was determined that the study would rely upon V2V and/or V2I communications for detecting pedestrians and right turning vehicles.
- The CAN bus protocols for transit vehicles in the Safety Pilot Model Deployment follow a standard format, can be accessed, and have all of the required parameters needed for both the embedded safety applications as well as the two new applications. There are two common CAN bus protocols J1939 and the legacy 1708. The first is the current protocols while the 1708 is historic, but present on all transit vehicles for the next two years. That is, for the Safety Pilot Model Deployment, all transit vehicles have 1708 while only some have J1939, but within two years, all new transit vehicles will be J1939 only.
- Pedestrian detection will only occur at one selected intersection.
- The TRP DSRC Radio will be installed earlier than the DAS, but the described scenarios reflect a completely operational system. The decision to install the TRP DSRC Radio prior to the DAS increases the complexity of the system design in that it requires that on-board storage separate from the DAS unit be designed and included during the operational period when the DAS has yet to be installed. However, this complexity was accepted in return for maximizing the data collection period for the embedded safety applications given the field period and the limited number of intersections and transit vehicles.

APPENDIX A. Acronyms and Abbreviations

ASD	Aftermarket Safety Device
BSM	Basic Safety Message
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller-Area Network
ConOps	Concept of Operations
CPU	Central Processing Unit
CSW	Curve Speed Warning
DAS	Data Acquisition System
DSRC	Dedicated Short-Range Communication
DVI	Driver-Vehicle Interface
EEBL	Emergency Electronic Brake Light
FARS	Fatality Analysis Reporting System
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GID	Geometric Intersection Description
GPS	Global Positioning System
GUI	Graphical User Interface
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act
ITS	Intelligent Transportation System
IVBSS	Integrated Vehicle Based Safety Systems
IVI	Intelligent Vehicle Initiative
LED	Light-emitting Diode
NHTSA	National Highway Traffic Safety Administration
OBE	On-Board Equipment
OEM	Original Equipment Manufacturer
OS	Operating System
PND	Personal Navigation Device
R&D	Research & Development

RFP	Request for Proposal
ROM	Read-only Memory
RSE	Roadside Equipment
RSU	Roadside Unit
SAE	Society of Automotive Engineers
SODS	Side Object Detection Systems
SPaT	Signal Phase and Timing
TEA-21	Transportation Equity Act for the 21st Century
TRP	Transit Safety Retrofit Package
UMTRI	University of Michigan Transportation Research Institute
U.S. DOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
WAVE	Wireless Access in Vehicular Environments
WSU	Wireless Safety Unit

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