Assessment of the Use of Light Vehicle Safety Applications for Transit

U.S. Department of Transportation

Notice

Technical Report Documentation Page

1. Report No. FHWA-JPO-12-088	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Assessment of the Use of Light Vehicle Safety Applications for Transit – Final Report		5. Report Date September 2012	
		6. Performing Organization Code	
7. Authors: Nigel Astell (Delcan), Elisabeth Bedsole (SAIC), RT Carter (SAIC), Susan Cox (Delcan), Robert Haas (SAIC), Dan Stock (SAIC), Weidong Xiang (University of Michigan Connected Vehicle Proving Center).		8. Performing Organization Report No.	
9. Performing Organization Name and Address Science Applications International Corporation 8301 Greensboro Drive, MS E-12-3 McLean, Virginia 22102		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. DTFH61-06-D-00005, Task T-11-024	
12. Sponsoring Agency Name and Address U.S. Department of Transportation Research and Innovative Technology Administration ITS Joint Program Office Federal Transit Administration 1200 New Jersey Avenue, SE Washington, DC 20590		13. Type of Report and Period Covered	
		14. Sponsoring Agency Code	
15. Supplementary Notes Jeffrey Spencer (Co-GTM, USDOT), Steve Mortensen (Technical Lead, FTA), and Yehuda Gross (Co-GTM, USDOT RITA ITS JPO).			

16. Abstract
This assessment evaluates the applicability of the current light vehicle safety applications for use on transit vehicles in revenue service operation. This assessment includes the following elements:

- A review of light vehicle safety applications and selection of six of those applications for further review, based on their potential applicability to transit.
- A detailed study of those six light vehicle safety applications and identification of key control parameters and other factors related to those applications that could impact their application to transit.
- An assessment of the applicability of each of the selected light vehicle safety applications to transit, including identification of changes that would be required to those applications in order to apply them to transit vehicles.

17. Key Words Connected vehicle, transit vehicle safety applications, light vehicle safety applications		18. Distribution Statement No restrictions.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No of Pages 48	22. Price N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

Table of Contents

List of Figures

List of Tables

Glossary of Acronyms

ASD	Aftermarket safety devices
BSM	Basic safety messages
BSW+LCW	Blind Spot Warning plus Lane Change Warning
CAN	Controller area network
CAMP	Crash Avoidance Metrics Partnership
CLW	Control loss warning
DNPW	Do not pass warning
DSRC	Dedicated short range communications
EEBL	Emergency electronic brake light
FCW	Forward collision warning
FTA	Federal Transit Administration
IMA	Intersection movement assist
VSC-A	Vehicle safety communication applications
RSE	Roadside equipment
VSCC	Vehicle safety communications consortium
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle

Executive Summary

Over the last 10 years, a significant amount of work has been done to develop light vehicle safety applications, and the United States Department of Transportation (USDOT) is on the verge of testing many of those applications in a Safety Pilot that is taking place in Ann Arbor, Michigan. The Federal Transit Administration (FTA) recognizes that the Safety Pilot provides an opportunity to test transit vehicle safety applications, and some transit buses used at the Safety Pilot will be equipped with three basic safety applications (Emergency Electronic Brake Light (EEBL), Forward Collision Warning (FCW), and Curve Speed Warning (CSW)) and two transit-specific safety applications (pedestrian in crosswalk warning and vehicle turning right in front of bus warning). In general, however, more research has been conducted on light vehicle safety applications than for transit safety applications. The potential exists to develop transit vehicle basic safety applications by leveraging the work already performed on light vehicle safety applications.

Light vehicle safety applications on a host vehicle work by acquiring information about nearby vehicles (remote vehicles) from basic safety messages (BSMs) broadcast from each remote vehicle using dedicated short range communications (DSRC), acquiring information about the nearby roadway infrastructure (e.g., signal phase) from other messages broadcast from roadside equipment (RSE), monitoring information about the host vehicle, evaluating that information to determine any conflicts between the host vehicle and a remote vehicle or between the host vehicle and the roadway environment, and generating warnings if such conflicts are detected.

However, transit vehicles and their operations differ in important ways from light vehicles that could impact whether a safety application designed for light vehicles would operate effectively for transit vehicles. These differences can be divided into several categories:

- **Physical differences**. Transit vehicles are longer and wider than light vehicles, and some transit vehicles are articulated, so follow different paths when turning. This affects the risks to which a transit vehicle is exposed (e.g., larger blind spots) and the way a safety application must operate (e.g., must recognize the longer distance between the center of the vehicle and the front of the vehicle when determining the potential for a conflict).

- **Performance differences**. Transit vehicles typically accelerate and decelerate less rapidly than light vehicles and make wider turns. This affects the risks to which a transit vehicle is exposed (e.g., longer stopping distances increase the risk of rear-ending a leading vehicle) and the way a safety application must operate (e.g., must recognize longer stopping distances to determine when to issue a red light warning).

- **Operational differences**. Transit vehicles are operated differently than light vehicles, making frequent roadside stops, which exposes them to different risks than those experienced by most light vehicles. This affects the risks to which a transit vehicle is exposed (e.g., a "right-turn-in-front" crash scenario is much more common with transit vehicles than light vehicles).

- **Equipment differences**. The equipment onboard transit vehicles interconnects differently than the equipment on light vehicles, so that hardware that integrates with the controller area network (CAN) bus on a light vehicle may not be able to obtain vehicle data on a transit vehicle. This affects the design of the hardware that would host a vehicle safety application.

Based on data found in the *Vehicle Safety Communications Project Final Report,* expert opinion, and other sources, the conclusion is that there are no specific technical reasons that the basic framework of the existing light vehicle safety applications cannot be adapted to work on transit vehicles. As noted, there are specific issues that must be addressed during development and

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final   **1**

within an overall connected vehicle system; however, the barriers to successful implementation of safety applications for transit are minimal overall. To summarize:

- The most challenging aspect of implementing DSRC-based safety applications on transit buses is line of sight for DSRC signals. Between the urban environments that transit vehicles frequently operate in and the different vehicle configurations that will interfere with line of sight, this is a problem that will require modified hardware platforms, most likely with several DSRC transmitters/receivers, in order to address.
- Front and rear collision avoidance applications require minimal modification to work on transit vehicles.
  - One adaptation may be the requirement to have front and back DSRC receivers/transmitters to communicate successfully with other vehicles. This is a hardware/underlying framework issue as opposed to an application issue, however.
- The most challenging aspect of adapting the applications lies within the blind-spot warning concept. Current safety applications are not able to deal with a "beside" category that could stretch up to 40' as opposed to the 10' normally accounted for.
  - This only impacts certain applications and certain transit safety scenarios.
  - The BSM dataset does contain length information, but the current implementation of the application uses a very limited definition of "beside" that is only suitable for light vehicles not towing trailers.
  - Addressing this challenge may require changes to what information is routinely broadcast as part of the BSM every tenth of a second.

Overall the potential to build from existing work rather than "re-invent the wheel" is very strong. Even though each manufacturer will design and implement their own transit safety applications, there is the potential for these manufacturers to benefit from the experiences of those that designed and implemented light vehicle safety applications. There are larger issues with DSRC and the BSM datasets that will need to be considered. These are identified within the report and are discussed, but their overall resolution is beyond the scope of this project.

Chapter 1.   Introduction

1.1. Background

USDOT is actively pursuing research, development, and testing of technologies for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, collectively referred to as connected vehicles. These technologies will establish the infrastructure needed to support a host of new applications that result in improvements in transportation safety and mobility and decreases in the environmental impacts of transportation activities. For example, each vehicle will use V2V communication to broadcast a basic safety message (BSM) containing information about its position, speed, recent path history, etc. to other nearby vehicles. These BSM broadcasts can support a host of safety applications, such as a lane change warning system that warns a driver if they are starting to change lanes while another vehicle is beside them.

This connected vehicle research has made considerable progress in developing the technologies and standards needed to support connected vehicle operations. The Federal Communication Commission (FCC) has allocated spectrum at 5.9 GHz to support transportation safety, dedicated short range communication (DSRC) standards have been defined to support safety-related communications at this frequency, and messaging standards have been defined to specify the messages that will be used in DSRC communications. This work established the basic framework for V2V and V2I communications.

Additional work has been conducted to investigate how best to take advantage of these V2V and V2I communication capabilities to support safety applications. USDOT has a cooperative agreement with the Crash Avoidance Metrics Partnership (CAMP) to investigate how to use connected vehicle capabilities to support crash avoidance countermeasures in passenger vehicles. The CAMP work addressed numerous technical challenges related to connected vehicle safety applications, such as accurate vehicle positioning, communication security, and reliable and efficient DSRC communications. One end product of this work has been the development and testing of six V2V and one V2I prototype safety applications.

This progress led USDOT to release a request for applications for the development and production of aftermarket safety devices (ASD) – devices that can be installed in light vehicles and provide a mature set of V2V and V2I safety applications. USDOT is also sponsoring a Safety Pilot Model Deployment in Ann Arbor, Michigan, where the CAMP and ASD safety applications can be tested in real-world operation.

While there has been significant progress towards development of V2V and V2I safety applications, much of the focus of this work has been on light vehicles. Recognizing this, USDOT sponsored a project to assess the applicability of the current light vehicle safety applications to transit vehicles in revenue service operations. This report describes the results of that assessment.

1.2. Assessment Objectives

The objective of this assessment is to evaluate the applicability of the current light vehicle safety applications for use on transit vehicles in revenue service operation. This assessment included the following elements:

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | 1

- A review of light vehicle safety applications and selection of applications for further review based on their potential applicability to transit.

- A detailed study of those six light vehicle safety applications and identification of key control parameters and other factors related to those applications that could impact their application to transit.

- An assessment of the applicability of each of the selected light vehicle safety applications to transit, including identification of changes that would be required to those applications in order to apply them to transit vehicles.

1.3. Overview of the Assessment Approach

The starting point for this assessment was (a) documentation on the CAMP safety applications and (b) information on transit bus crash scenarios of particular interest to the transit industry provided by transit industry stakeholders. This documentation was reviewed and a thorough understanding of both the light vehicle safety applications and the transit bus crash scenarios was attained. A webinar with the Transit Connected Vehicle Stakeholder Steering Group was hosted that focused on why specific crash scenarios were important to transit operations and on the specific characteristics of each scenario. An effort was made to interview those developing the CAMP safety applications and the ASDs to obtain more detailed information about the safety applications not included in the available documentation, but these interviews were not very productive because the developers considered many of the details proprietary.

This report assessing the applicability of the current light vehicle safety applications to transit was developed based on the understanding of the crash scenarios of interest to the transit community and the available safety applications.

1.4. Overview of this Document

This document presents the results of an assessment of the applicability of the current light vehicle safety applications for use on transit vehicles in revenue service operation. This assessment is presented in the following sections:

Section 2 describes the light vehicle safety applications, focusing on the applications developed by CAMP, and identifies the six applications that were assessed for use in transit vehicles.

Section 3 describes the results of the assessment of those six light vehicle safety applications.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final   2

Chapter 2. Selection of Light Vehicle Safety Applications for Transit

2.1. Overview of Connected Vehicle Safety Operations

The current generation of V2V safety applications is built around the broadcast of BSMs. Each vehicle periodically broadcasts a BSM via a DSRC that announces the vehicle's current position and recent path history. This allows vehicles receiving those BSMs to develop situational awareness information about the locations of nearby vehicles and their directions of travel. Each vehicle is also required to broadcast additional BSMs when certain events occur, like when a vehicle rapidly decelerates or quickly changes its direction of travel. V2V safety applications can use this information in different ways to alert drivers to hazards involving nearby vehicles; for example:

- **A vehicle tracks the position of the leading vehicle** and warns the driver if there is a risk of rear-ending the leading vehicle.
- **A vehicle at an intersection tracks the movement of other vehicles** approaching the intersection and warns the driver if it is unsafe to enter the intersection because of a high likelihood of a crash with other vehicles also entering the intersection.
- **A vehicle beginning to change lanes could alert its driver** of the presence of an adjacent vehicle when there was a potential for a collision.
- **A vehicle following a vehicle that issues a hard-braking BSM could alert its driver** of the potential for a rear-end collision.
- **An out-of-control vehicle (as evidenced by loss of traction, for example) broadcasts an out-of-control warning** to alert other drivers to the risk of collision with the out-of-control vehicle.

Connected vehicle systems may also support V2I safety applications that involve transmission of other messages from roadside infrastructure to vehicles. Some examples include:

- **Red-light running warning systems**, in which a signal controller is integrated with a DSRC transmitter to broadcast information describing the intersection geometry and the current signal phase and timing. A vehicle warns the driver if there is risk that it could run the red light.
- **Curve speed warning systems**, in which a DSRC transmitter broadcasts information about a nearby curve and safe speeds for the curve so the vehicle can warn its driver if it is entering the curve going too fast.

This is only a sample of the many applications envisioned that make use of the V2V and V2I communication enabled by connected vehicle technologies to improve safety and mobility.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **3**

2.2. Overview of Light Vehicle Safety Applications[1]

Much of the work on connected vehicle safety applications for light vehicles has been performed by the Vehicle Safety Communications Consortium (VSCC), a consortium of seven automakers (BMW, Daimler-Chrysler, Ford, GM, Nissan, Toyota, and VW) formed in 2002. Early work by the VSCC is summarized in Table 2-1. The VSCC identified 36 vehicle safety applications that could be supported by V2V and V2I communications.

Table 2-1. Light Vehicle Safety Applications

Intersection Collision Avoidance Applications		
• Traffic Signal Violation Warning • Intersection Collision Warning • Pedestrian Crossing Information Warning	• Stop Sign Violation Warning • Stop Sign Movement Assist	• Left Turn Assist • Blind Merge Warning
Public Safety Applications		
• SOS Services • Post-crash Warning	• Approaching Emergency Vehicle Warning	• Approaching Emergency Vehicle Warning
Sign Extension Applications		
• In-vehicle Signage Warning • Wrong Way Driver Warning • In-vehicle Amber Alert Warning	• Curve Speed Warning • Low Bridge Warning	• Curve Speed Warning • Low Bridge Warning
Vehicle Diagnostics and Maintenance Applications		
• Safety Notice Recall	• Just-in-time Repair Notification	
Information from Other Vehicles Applications		
• Cooperative Forward Collision Warning • Lane Change Warning • Visibility Enhancer • Road Condition Warning • Pre-crash Sensing • Cooperative Glare Reduction • Adaptive Headlamp Aiming	• Cooperative Vehicle-Highway Automation System (Platoon) • Road Condition Warning • Blind Spot Warning • Cooperative Collision Warning • Highway / Railroad Collision Warning	• Emergency Electronic Brake Lights • Highway Merge Assistant • Cooperative Adaptive Cruise Control • Vehicle-to-Vehicle Road Feature Notification

This work was continued by a second consortium called Vehicle Safety Communications 2 (VSC2) Consortium, consisting of Ford Motor Company, General Motors Corporation, Honda R&D Americas, Mercedes-Benz Research and Development North America, and Toyota Motor Engineering and Manufacturing North America. Each of the VSC2 participants developed a test system designed around the following critical system framework modules:

---

[1] Most of the information in this section was summarized from the Vehicle Safety Communications – Applications (VSC-A) Final Report: Appendix Volume 1 System Design and Objective Test (DOT HS 811 492B) produced by CAMP VSC2 for NHTSA.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **4**

- **Vehicle safety communication applications (VSC-A) main**. Manages system startup and shutdown.
- **CAN sensor data handler**. Interfaces with the vehicle CAN gateway device to receive and transmit CAN messages.
- **GPS sensor data handler**. Interfaces with a GPS receiver to receive GPS data.
- **Wireless message handler**. Interfaces to the DSRC radio(s) to transmit and receive messages via DSRC.
- **Security module**. Manages security certificates needed to sign and encrypt DSRC messages and verify signatures attached to DSRC messages.
- **Path history module**. This module maintains information about a vehicle's recent position history and computes a concise representation of that position history.
- **Host vehicle path prediction module**. This module estimates a vehicle's future path (based solely on vehicle position, speed, and acceleration data).
- **Target classification module**. This module monitors position information received from nearby vehicles and assigns each vehicle to one of 16 classifications based on the vehicle's altitude, direction of travel, and position relative to the vehicle performing the classification. The 16 target classifications are depicted in Figure 2-1.
- **Threat arbitration**. Prioritizes threat warnings for generating driver alerts.
- **Driver vehicle interface notifier**. Determines the format(s) to be used for driver alerts (e.g., visual, audible).
- **Engineering graphical user interface**. Provides a graphical user interface that can be used to monitor and configure the system.
- **Data logging and visualization tool interface**. Interfaces with an external data logging and visualization tool.
- **Error handler**. Monitors VSC-A modules, rebooting modules that appear to be malfunctioning.
- **Scenario replicator**. Supports archiving of data inputs (e.g., CAN, GPS, and DSRC data) and later data playback for debugging and demonstrations.

In addition, the following seven vehicle safety applications were developed to work within the framework defined by these modules:

- **Cooperative intersection collision avoidance system – violation** (CICAS-V), in which a vehicle monitors its position and speed relative to stop sign and traffic signal locations and traffic signal phase and timing information, then warns its driver if a risk of a stop sign or traffic signal violation is detected.
- **Emergency electronic brake lights (EEBL)**, in which a vehicle broadcasts an emergency brake event message when the driver of that vehicle brakes hard. Vehicles that receive the message warn drivers if risk exists of a collision with the braking vehicle.
- **Forward collision warning (FCW)**, in which a vehicle monitors the position, speed, and deceleration of vehicles ahead of it to warn its driver if a risk of rear-end collision exists.
- **Blind spot warning plus lane change warning (BSW + LCW),** in which a vehicle monitors the position and speed of vehicles adjacent to and behind itself to warn the driver if a nearby vehicle is in the blind spot or if there is a risk of collision when a vehicle is changing lanes.
- **Do not pass warning (DNPW)**, in which a vehicle monitors the position and speed of vehicles ahead (traveling both in the same and opposing directions) and warns the driver if there is a risk that a passing maneuver could result in a crash with an oncoming vehicle.
- **Intersection movement assist (IMA)**, in which a vehicle at an intersection monitors vehicles traveling in intersecting directions and warns the driver if it is unsafe to enter the intersection.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **5**

- **Control loss warning (CLW)**, in which a vehicle broadcasts a loss of control event message when the vehicle is out of control. Vehicles receiving the message can warn their drivers of a nearby, out-of-control vehicle.

Different Altitude

Same Direction of Travel (same altitude)

Opposite Direction of Travel (same altitude)

Intersecting Direction of Travel (same altitude)
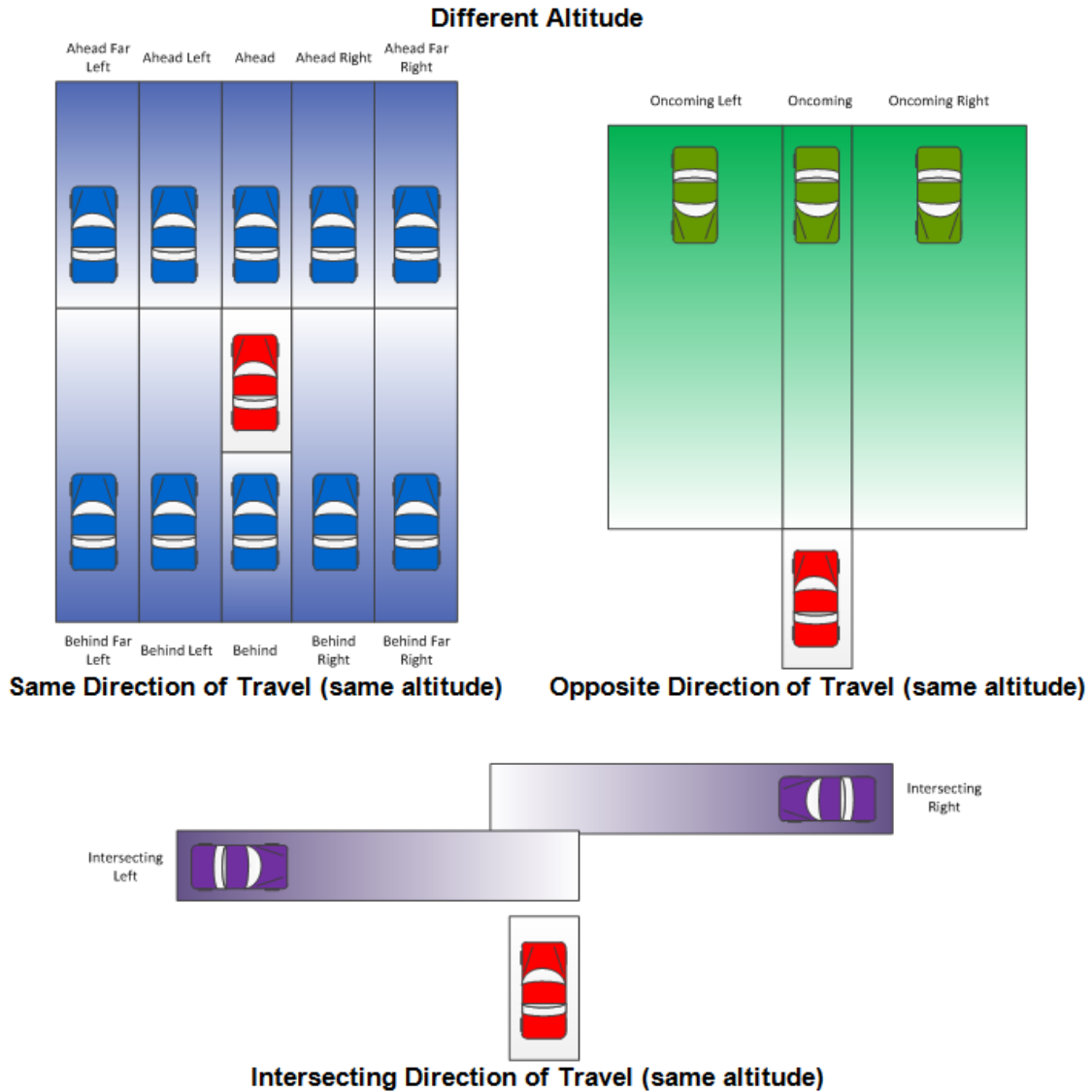
Figure 2-1. The VSC2 Target Classification Categories

The general approach for implementing an application within this framework is to associate each application with a set of target classifications. Then, the application receives information (from BSMs) for each vehicle in the associated target classifications. The application integrates this information with information about the host vehicle (e.g., position and path from the host vehicle path prediction module, driver actions from the CAN sensor data handler) to determine if a threat alert should be generated. The threat arbitration module assimilates all active threat alerts and

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | 6

determines which alerts should be provided to the driver. The driver vehicle interface notifier communicates these threats to the driver.

2.3. Selection of Light Vehicle Safety Applications for Transit

Of the seven light vehicle safety applications identified at the end of the previous section, one (CICAS-V) was eliminated from consideration for this report in order to focus on applications that depend on V2V communication. The remaining six applications are:

- Emergency electronic brake lights (EEBL).
- Forward collision warning (FCW).
- Blind spot warning plus lane change warning (BSW + LCW).
- Do not pass warning (DNPW).
- Intersection movement assist (IMA).
- Control loss warning (CLW).

The remainder of this report will focus on these applications and their potential usage on transit vehicles.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final   **7**

Chapter 3. Assessment of the Applicability of Light Vehicle Safety Applications for Transit

In a general sense, many light vehicle safety applications should be applicable to transit vehicles; the sequence of events leading to a crash is likely similar whether or not the vehicles involved include a transit vehicle. The specific design of a light vehicle safety application might prevent it from being used for transit, however. For example, a forward collision warning (FCW) system for transit would need to consider the lower deceleration rates of transit vehicles compared to those of light vehicles. If this parameter cannot easily be adjusted in a FCW application developed for light vehicles, then it could not be used for transit. This section of the report reviews the differences in vehicle operations between transit and light vehicles and identifies those that could impact the applicability of light vehicle safety applications for transit.

The challenge in adapting existing light vehicle safety applications to transit vehicles lies less in the different standards they use for their internal system and more in the four dimensions of the vehicle. While the standard height, width, and length are obvious elements, the movement of the vehicle through time is a function of its mass and velocity. (This is a fancy way of saying that a transit vehicle is slower to pick up speed and slower to come to a halt.) These vehicles' physical characteristics affect how the transit vehicle interacts with other traffic and the roadway itself.

One key question at this point is whether to restrict these results to what can be accomplished within the current framework of connected vehicle applications. For example, in the current generation of light vehicle safety applications, each application estimates the future path of the vehicles around it based on the current and past history information that is broadcast by each vehicle. The applications then use that information to anticipate potential collisions. An alternate approach would be for each vehicle to broadcast future path information for itself. This alternate approach could be more effective in situations when a vehicle's recent path history does allow accurate prediction of its future movements – like when a transit bus is pulling out from a bus stop. However, this report only considers transit safety applications that can be implemented within current framework of connected vehicle safety applications, so this alternative approach is not expanded upon here.

A second key question is which vehicle is affected by the application modification. Looking at the right turn in front crash scenario,[2] the most effective solution is to provide a warning to both the light vehicle driver and the transit vehicle driver. This report will focus on transit-side applications in which warnings will be given to the transit driver.

Finally the job of a transit vehicle driver is more involved than that of a light vehicle driver. Transit vehicle drivers already need to monitor different systems, passengers, and radio communications in addition to driving. Keeping this in mind, all inputs to the driver are simple

---

[2] This crash scenario is defined in Section 3.1.2.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | 8

warnings and are limited. Preventing driver overload and habituation are key to long-term success.

3.1. Review of Differences between Light and Transit Vehicle Operations

In-service transit vehicles operate differently than light vehicles, and these differences can impact the effectiveness of a safety application designed for light vehicles if it is used on transit vehicles. This section identifies differences that could impact the applicability of light vehicle safety applications to transit, dividing up those differences into three categories, each addressed in the following three sub-sections.

3.1.1. Differences in Vehicle Operating Characteristics

This category refers to differences in the physical and kinematic characteristics of transit and light vehicles and differences in the way these two types of vehicles are used. The differences identified as potentially impacting safety applications include:

- **Vehicle length**. Transit vehicles are typically much longer than light vehicles. This affects many safety-related factors.
  - *Size and location of blind spots*. This could impact how target classification should work – with the VSC2 target classification, there is no "beside" category; a "beside" category might be appropriate for transit vehicles.
  - *Representing vehicle position in basic safety messages (BSM)*. Because a light vehicle is relatively short, the position of a light vehicle is well-represented by the vehicle center and heading. For a long transit vehicle – particularly an articulated vehicle – this representation may not suffice for some safety applications.
  - *Path tracking in curves*. Transit vehicles in curves follow a more complicated path than light vehicles.
- **Vehicle width**. Because of its width, a transit vehicle provides more line-of-sight restrictions for drivers trying to see around transit vehicles. Also, the larger width of transit vehicles could impact target classification algorithms.
- **Vehicle height**.
  - *Line of sight restrictions*. Because of its height, a transit vehicle provides more line-of-sight restrictions for drivers trying to see around transit vehicles – particularly for drivers of following vehicles attempting to see traffic signals.
- **Vehicle weight**. Transit vehicles are heavier than light vehicles, which contributes to the lower rates of acceleration and deceleration for transit vehicles. The higher weight also means that crashes involving a transit vehicle and a light vehicle can result in more serious injuries than a similar crash between two light vehicles.
  - *Vehicle acceleration rate*. Transit vehicles have lower acceleration rates than light vehicles, so movement models that are part of light vehicle safety applications must be modified to consider these lower rates. For example, intersection clearance times are longer for transit vehicles than light vehicles, which could affect the IMA application.
  - *Vehicle deceleration rate*. Transit vehicles have lower deceleration rates than light vehicles, so movement models that are part of light vehicle safety applications must be modified to consider these lower rates. For example, stopping distances are longer for transit vehicles, which could affect the emergency electronic brake light (EEBL) application.
- **Transit routes**.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final   **9**

- o *Frequent stops.* Transit vehicles make frequent stops and have a subsequent need to merge back into traffic following a stop. While this does not affect the operation of a safety application, it does affect the frequency of exposure of transit vehicles to crash risks.
- o *Vehicle future path is often known.* Many transit vehicles follow fixed routes, so the future path prediction element could be improved by integrating route information into the algorithm.
- **Data availability**. One of the challenges faced when developing connected vehicle applications for use at the V2V and V2I Technology Test Bed was that, even though most vehicles use the CAN bus to distribution information between in-vehicle devices, custom software was required to interpret the CAN data for each vehicle make and model. Additional software will be required to access vehicle data from the data buses on transit vehicles.

3.1.2. Differences in Crash Characteristics

This category of differences refers to differences in the types of crashes in which transit vehicles are typically involved. These differences do not impact the operation of a safety application, although they could impact its effectiveness – a safety application that focuses on types of crashes that are more prevalent for transit vehicles than for light vehicles has a greater opportunity to prevent crashes on transit vehicles. In the statement of work for this project, USDOT specified that this assessment should focus on the following crash scenarios:

- **Right-turn-in-front crash scenario**. This crash involves a vehicle passing a stopped transit vehicle on the left, intending to turn right after passing the transit vehicle. If the transit vehicle begins to accelerate while the vehicle is turning right in front of it, a crash can occur. This type of crash is uncommon with light vehicles, and there is no light vehicle safety application specifically targeting this type of crash. However, the blind spot warning plus lane change warning application targets crashes that share many characteristics with this type of crash.
- **Pedestrian versus turning bus crash scenario**. This type of crash involves a transit vehicle turning left or right and hitting a pedestrian, either because the transit driver did not notice the pedestrian or the pedestrian misjudged the bus path. There is no light vehicle safety application specifically targeting this type of crash.
- **Bus angle crash at intersection scenario**. This type of crash occurs when a bus enters an intersection on an intersecting course with a vehicle entering the intersection along one of the crossing approaches. This type of crash is addressed by the intersection movement assist safety application.
- **Left-turn head-on crash scenario**. This type of crash occurs when a vehicle traveling in the opposite direction to a transit vehicle turns left in front of the transit vehicle. This type of crash is addressed by the Intersection Movement Assist safety application of the left-turning vehicle.
- **Rear-end crash at bus stop scenario**. This type of crash occurs when a vehicle traveling behind a transit vehicle hits the rear of the transit vehicle while the transit vehicle is stopping or stopped at a bus stop. This type of crash is addressed by the forward collision warning safety application on the vehicle behind the transit vehicle.
- **Left-turn crash at light rail grade crossing scenario**. This type of crash occurs when a vehicle traveling beside and to the right of a light rail vehicle turns left in front of the light rail vehicle but does not clear the space in front of the light rail vehicle in time to avoid a crash. This type of crash could be addressed by the lane-change warning application on the left-turning vehicle.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **10**

3.1.3. Differences in DSRC Operation Characteristics

This category of differences refers to differences in how DSRC would operate with transit vehicles.

- **Line of sight to transit DSRC antenna**. The length and height of a transit vehicle could obstruct line-of-sight between that antenna and the antennae on nearby light vehicles, particularly vehicles close to the transit vehicle. Transit vehicles may need multiple DSRC antennae to communicate effectively with nearby vehicles.

- **Representing the position of a transit vehicle in a BSM**. The IEEE J2735 standard, which defines the BSM content, represents a vehicle position as the position of the vehicle, a vehicle heading, a vehicle length and width, and vehicle yaw rate. The implication is that the position and movement of a vehicle can be represented by a rectangle. This is true for non-articulate vehicles, but not true for articulated vehicles in some situations, like when turning. Figure 3-1 depicts the difference between a non-articulated vehicle (whose position is well-represented by a single rectangle) and an articulated vehicle (whose position requires two rectangles to represent accurately).
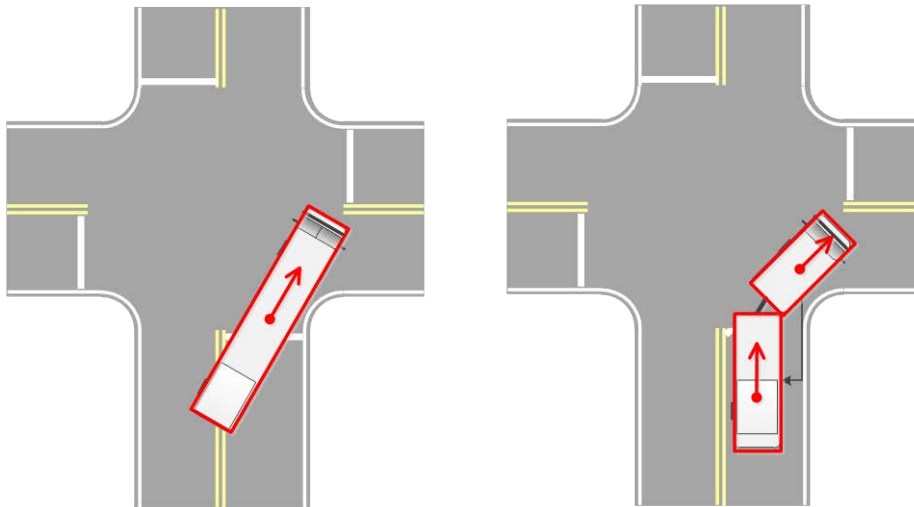
Figure 3-1. Representing the Position of a Transit Vehicle in a BSM

3.1.4. Summary of Differences that Could Impact Safety Applications

For each of the operational differences listed in the previous section, Table 3-1 indicates which of the safety applications could be impacted by those differences.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **11**

Table 3-1. Summary of Operational Differences Potentially Impacting Safety Applications

Operational Difference	EEBL	FCW	BSW+LCW	DNPW	IMA	CLW
Vehicle length			✓	✓	✓	✓
Blind spot size and location			✓			
Path tracking in curves						
Vehicle width	✓	✓	✓			
Vehicle height						
Line of sight obstructions						
Vehicle weight						
Vehicle acceleration rate				✓	✓	
Vehicle deceleration rate	✓	✓				
Frequent stops	✓		✓			
Well-defined future path					✓	
Vehicle data availability	✓	✓	✓	✓	✓	✓
DSRC antenna line of sight	✓	✓	✓	✓	✓	✓
Measuring vehicle position					✓	✓
BSM vehicle position	✓				✓	✓

More details on these factors will be described in the sections that individually address each safety application.

3.2. Applicability of the VSC2 Safety Application Framework for Transit[3]

This section reviews each of the critical system framework modules for the VSC2 safety applications, identifying modifications that might be needed to adapt that framework for transit vehicles.

- **VSC-A main.** No modifications identified.
- **CAN sensor data handler.** An interface would need to be developed to obtain data from data buses used on transit vehicles.
- **GPS sensor data handler.** The interface to the GPS sensor would not change. However, more than one GPS receiver may be required to capture position data for transit vehicles. Functionality to use multiple GPS sensors to track vehicle position might be integrated into the GPS sensor data handler.
- **Wireless message handler.** No modifications identified; the same message protocols, based on the IEEE 1609 standards, will be used for all DSRC communications. It is possible that changes to those standards will be needed to support transit safety applications, in which case updates to the wireless message handler would be required.
- **Security module.** No modifications identified; the same security management processes will apply to all DSRC messages.

---

[3] The information in this section is summarized from the VSC-A Final Report: Appendix B-1 Test Bed System Development.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **12**

- **Path history module.** The position of a transit vehicle may require a more complex representation than that of a light vehicle, which could affect the path history module.
- **Host vehicle path prediction module.** The position of a transit vehicle may require a more complex representation than that of a light vehicle, which could affect this module. Also, it might be advantageous to use route information in the path prediction module to better estimate future bus movements.
- **Target classification module.** The light vehicle target classification module divides vehicles traveling in the same direction into two categories: behind and ahead. Because of the length of a transit vehicle, it might be appropriate to include a "beside" category.
- **Threat arbitration.** Insufficient information is available about the VSC2 threat arbitration module to determine if modifications are likely to be required.
- **Driver vehicle interface notifier.** The VSC2 driver vehicle interface notifier restricts notification methods to visible and audible. Because transit drivers are trained, more complex notification methods can be used. For example, some existing transit safety systems use other types of notification (e.g., vibrating the driver's seat). This module may require modification to support other notification methods.
- **Engineering graphical user interface.** Some transit systems already include mobile data terminals with in-vehicle displays. It might be desirable to take advantage of existing display capabilities to support user interfaces on transit vehicles.
- **Data logging and visualization tool interface.** Some transit systems already include data logging systems. It might be desirable to take advantage of existing data logging systems on transit vehicles.
- **Error handler.** No modifications identified.
- **Scenario replicator.** Insufficient information is available about the VSC2 scenario replicator module to determine if modifications are likely to be required.

3.3. Review of General Factors that Impact Transit Safety Applications

The previous sections identified a number of factors that could impact applicability of at least one light vehicle safety applications for transit. This section provides a more detailed review of those factors that could impact many different light vehicle safety applications.

- **Line of sight to transit DSRC antenna.**[4] DSRC antennae are typically mounted on vehicle rooftops. Because of the height and length of a transit bus, line of sight between a DSRC antenna centrally mounted on a bus and a DSRC antenna mounted on a light vehicle could be blocked by the roof line of the transit bus. This will only occur when the vehicle is close to the transit vehicle—at greater distances, the line of sight will not be blocked. Transit vehicles could also block line of sight between vehicles ahead and behind it and between vehicles left and right of it. Because the line of sight is only blocked at close range, when the distance-related signal loss is low, DSRC communication between a transit and light vehicle is not likely to be disrupted.

  Tests conducted by VSC-A on the shadowing caused by a 45-foot trailer provide some indication of the signal that might be encountered. With a signal strength of 5 dBm, the

---

[4] This factor affects the design of DSRC antenna placement when used on transit vehicles, but does not directly impact safety applications

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **13**

packet error rate did increase at distances less than about 100 meters. At signal strength of 20 dBm and higher, the packet error rate remained small.

- **Measuring vehicle position and velocity.** For light vehicles, which are relatively short, the difference between the heading of the vehicle and the vehicle direction of travel is small. For transit vehicles, this difference can be important, particularly when the vehicle is cornering, as shown in Figure 3-2. With light vehicles, the vehicle heading can be accurately estimated from the vehicle direction of travel derived from GPS observations. With transit vehicles, the relationship between the vehicle heading and the vehicle direction of travel is more complex. The position of the vehicle is still accurately represented by the position of the vehicle center, the vehicle heading, and the vehicle width and length. Estimating the vehicle heading for a transit vehicle may require a more complex model than that used for a light vehicle.
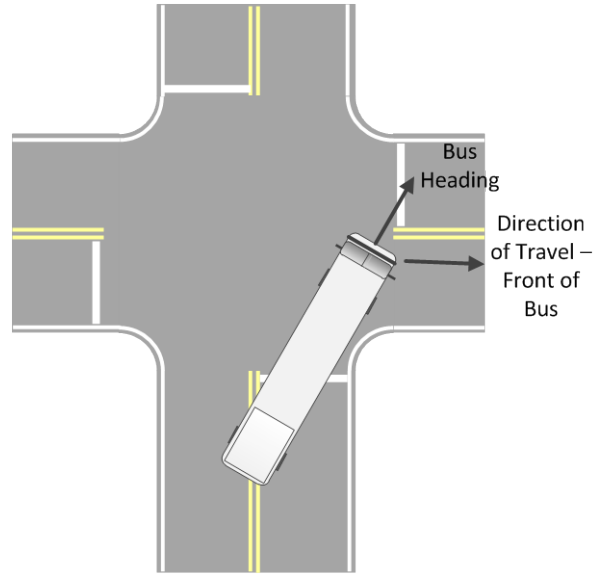
Figure 3-2. Difference Between Vehicle Heading and Direction of Travel for a Transit Bus

  The modules that compute vehicle position for light vehicles may require modification to function correctly for transit vehicles. Also, modules that identify conflicts between vehicle paths should be reviewed to ensure that algorithms used to identify those conflicts will work reliably for transit vehicles.

- **Representing the position of a transit vehicle in a BSM.** The BSM defines the position of a vehicle in terms of its position, heading, length, and width. This is sufficient for any vehicle that is roughly rectangular in shape, so long as the heading refers to the direction of the longitudinal axis? of the vehicle, not the direction of its velocity vector – including most transit vehicles. However, it may not be sufficient for articulated vehicles.

- **Access to In-vehicle Data.** With light vehicles, vehicle data needed to support connected vehicle operations (such as brake position, whether a turn signal is activated, etc.) is obtained by integrating with the CAN bus. This integration may require customization for different makes and models of vehicles. Similar customization would need to occur for acquiring in-vehicle data from a transit vehicle.

- **Target Classification.** The VSC2 safety applications use a target classification system that, for vehicles traveling in the same direction, classify other vehicles as either ahead or behind the host vehicle. Because of the length of transit buses, it may be appropriate to include a "beside" category in the target classification.

3.4. Review of Application-Specific Factors that Impact Transit Safety Applications

The following six sections describe the potential of the six light vehicle safety applications identified in Section 2.3 to be used for transit. The content of each of these sections is presented as four topics. The first topic gives a general description of the application and the second gives a general review of the types of modifications that could be required to adapt that type of

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **14**

application developed for light vehicles to transit. These first two topics are general in nature and would be applicable to any implementation of that application. The last two topics are specific to the VSC2 implementation of the application, giving a description of the VSC2 application and the specific modifications that would need to be made to that VSC2 application in order for that application to work for transit vehicles.

Note that each of these applications requires the interaction between (at least) two vehicles equipped with connected vehicle technologies. One vehicle, termed the host vehicle, includes an application that receives BSMs broadcast from other vehicles and determines whether to alert the driver to some hazard. The other vehicles, termed remote vehicles, broadcast BSMs, which could be periodic or event-driven BSMs.

3.4.1. Emergency Electronic Brake Light for Transit

Review of the Application and Its Use for Transit

The emergency electronic brake light (EEBL) application is intended to alert a driver that a preceding vehicle has braked hard and is decelerating rapidly. The alert is expected to decrease the driver's reaction time by focusing a distracted driver on the hazard and eliminating the time required to differentiate between a slowly and rapidly decelerating vehicle. This, in turn, will help the driver of the following vehicle to apply the brakes more quickly. If the brakes are applied quickly enough, the following vehicle will avoid a rear-end collision. If not, the quicker application of the brakes will lower the collision speed, reducing the consequences of the ensuing rear-end collision.

The EEBL application works as follows. When a connected vehicle (including a vehicle equipped with an EEBL application) brakes hard, an onboard application detects the hard braking and begins to broadcast an event-driven BSM that indicates the vehicle is braking hard. This remote vehicle continues to broadcast the hard-braking event-driven BSM as long as the vehicle continues to decelerate rapidly.

A nearby host vehicle equipped with the EEBL application receives the hard-braking BSM and assesses whether the rapidly decelerating remote vehicle is in a position ahead of the host vehicle such that there is a likelihood the host vehicle could collide with the remote vehicle. If so, the EEBL application issues an alert to the driver. Note that there may be vehicles between the remote vehicle and the host vehicle and the EEBL will still issue alerts based on the deceleration of the remote vehicle.

Figure 3-3. The EEBL Application

Assessment of Modifications Required to Apply this Application for Transit

Table 3-1 on page 12 identified six differences in transit vehicle operational characteristics that could impact this application. Three of these differences were addressed in the previous section under general factors that could impact transit safety applications. The other three are addressed below.

Vehicle Deceleration Rate. The vehicle deceleration rate for transit vehicles is typically lower than that for light vehicles. The deceleration rate at which an EEBL warning is issued may need to be lower for a transit vehicle than for light vehicles.

When a vehicle receives an EEBL message, it must determine whether a driver warning should be issued to help ensure the driver can decelerate in time to avoid a collision with the vehicle broadcasting the message. Part of this determination takes into consideration the deceleration

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **15**

rate of the vehicle and whether it can decelerate quickly enough to avoid rear-ending the vehicle in front of it. An EEBL application for transit should use a maximum deceleration rate appropriate for transit vehicles.

Because of the longer stopping distance for transit vehicles, an EEBL application for transit may need to consider lead vehicles that are further away as potential EEBL targets. Before applying a light vehicle EEBL application to transit, target classification modules should be reviewed to verify that the "look-ahead" distances in those modules are sufficient to support transit EEBL.

Finally, the value of EEBL broadcasts from transit vehicles may be less than for light vehicles. Because transit vehicle maximum deceleration rates are typically lower than for light vehicles, light vehicles are more likely to be able to stop before rear-ending a transit vehicle making an emergency stop. EEBL may also be less effective at preventing a transit vehicle from rear-ending a leading light vehicle, unless the transit vehicle maintains a long enough following distance to allow for the longer stopping distance of transit vehicles. To improve the performance of EEBL on a transit vehicle, a transit EEBL application could provide guidance to transit drivers on when their following distance is too close to avoid a rear-end collision if the leading vehicle stops suddenly.

Vehicle Width. A transit vehicle is wider than a light vehicle and may pull to the side of the road when stopping to pick up passengers. A key part of the VSC2 safety application framework is the target classification module, which classifies targets, in part, by their lateral position relative to a vehicle. A transit vehicle pulled to the side of the road to load passengers is likely to span target classifications (i.e., by both ahead and ahead right of a following vehicle). Target classification modules used for light vehicles should be reviewed to ensure that they work appropriately with wider transit vehicles.

Frequent Stops. A transit vehicle makes frequent stops at locations where other vehicles are unlikely to stop. Drivers of following vehicles, not expecting a vehicle to stop, might be less attentive to the possibility, increasing the likelihood of a crash when a transit vehicle stops, even if it does not decelerate rapidly. It might be appropriate to develop a transit vehicle safety application that addressed this scenario by broadcasting an alert that it was stopping unexpectedly. Because the current J2735 standard does not support an event code for an unexpected stop, this application would require a modification to the existing connected vehicle framework and is outside the scope of this document.[5]

Review of the VSC2 EEBL Application[6]

The VSC2 EEBL application monitors vehicle data to determine if the vehicle driver has initiated an emergency braking event. If so, the EEBL application requests that the wireless message handler broadcast an emergency braking event BSM.

The host vehicle tracks vehicles that are in the ahead left, ahead, and ahead right positions and activates the EEBL if a remote vehicle in those positions broadcasts an emergency braking event. If the distance from the host vehicle to the alerting remote vehicle is greater than a configurable threshold value, the event is ignored. If the speed of the host vehicle is below a configurable threshold value, the event is ignored. Otherwise, a threat level is calculated based on the positions and speeds of the host and remote vehicles. If the threat level exceeds a configurable threat level, the driver is alerted to the hazard.

Modifications Required to Apply VSC2 EEBL to Transit

In general, the VSC2 EEBL approach could be applied directly to a transit vehicle. A higher host-to-remote-vehicle distance filter and a lower host-vehicle speed threshold should be used to

---

[5] This crash scenario is also addressed by a forward collision warning application in the following vehicle.
[6] Based on descriptions provided in the VSC-A Final Report: Appendix B-1 Test Bed System Development.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **16**

accommodate the longer stopping distances of transit vehicles. Both of these thresholds are configurable in the VSC2 EEBL application. The threat level calculations for a transit vehicle should take into consideration the lower deceleration rates of transit vehicles. Limited information about how the EEBL threat level is calculated is available, so it is not clear whether the threat level calculations could be easily reconfigured for transit.

<u>Summary of Applicability of EEBL to Transit</u>

The application of EEBL to transit vehicles and, more specifically, the modification of the VSC2 approach to EEBL, are expected to be feasible. Some minor modifications may be required to accommodate the slower deceleration rates of transit vehicles. Target classification algorithms should be reviewed to confirm that the "look ahead" distance in those algorithms is sufficient to cover transit EEBL scenarios. Developers should consider enhancing EEBL for transit to warn transit drivers when they are following too closely to stop if the leading vehicle stops suddenly.

3.4.2. Forward Collision Warning for Transit

<u>Review of the Application and Its Use for Transit</u>

The FCW application is intended to warn a driver of an impending rear-end collision with a leading vehicle. The alert is expected to decrease the driver's reaction time by focusing the driver on the hazard. This will help the alerted driver to apply the brakes more quickly. If the brakes are applied quickly enough, the FCW could avoid a rear-end collision. If not, the quicker application of the brakes will lower the collision speed, reducing the consequences of the ensuing rear-end collision.

The FCW application works as follows. Every connected vehicle broadcasts BSMs that provide information about that vehicle's current position and speed and recent path history. Each host vehicle equipped with FCW receives these broadcasts and tracks the position, speed, and acceleration of nearby remote vehicles and determines if a forward collision with a nearby remote vehicle is likely. If so, the FCW alerts the driver to the hazard.

<u>Assessment of Modifications Required to Apply this Application for Transit</u>

Two areas were identified in which modifications to a light vehicle FCW application might be required to adapt it for use in transit.

Vehicle Width. A transit vehicle is wider than a light vehicle and the algorithms for determining whether a forward collision is likely must consider the additional width of a transit vehicle. In the VSC2 safety applications, this could impact both the target classification and the FCW-specific calculations needed to determine whether a warning is needed.

Vehicle Deceleration Rate. The vehicle deceleration rate for transit vehicles is typically lower than that for light vehicles. This means that a FCW application for transit will need to be calibrated for the lower deceleration rates of transit vehicles. The developers of the VSC2 safety applications would confirm whether this parameter could be easily adjusted in their implementation of the FCW application.

Because the stopping distance for a transit vehicle is longer than that for a light vehicle, the range over which the FCW application needs to "look ahead" is larger for a transit vehicle than for a light vehicle. Target classification algorithms built into transit FCW applications should be reviewed to verify that the "look ahead" distances are sufficient for FCW in transit.
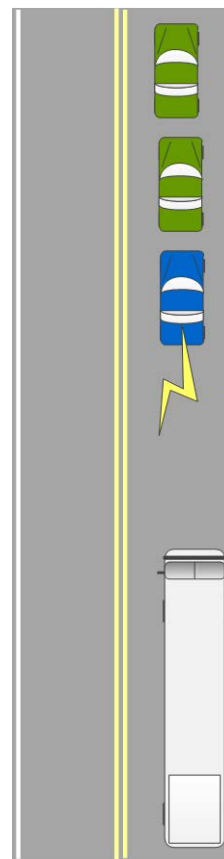
Figure 3-4. The FCW Application

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **17**

Review of the VSC2 FCW Application[7]

The VSC2 FCW application monitors nearby remote vehicles and identifies vehicles classified as being ahead of the remote vehicle. If the distance to the remote vehicle that is ahead of the host vehicle is greater than a configurable threshold, the vehicle is ignored. If the host vehicle's speed is below a configurable threshold, the FCW application ignores all vehicles. If the host vehicle is braking, the FCW application ignores all vehicles. Otherwise, the FCW application computes a collision avoidance range for each such remote vehicle and assigns a threat level based on the collision avoidance range. If the threat level exceeds a configurable threshold, the driver is alerted to the hazard.

Modifications Required to Apply VSC2 FCW to Transit

In general, the VSC2 FCW approach could be applied to a transit vehicle. A higher host-to-remote-vehicle-distance threshold and a lower host vehicle speed threshold should be used to accommodate the longer stopping distances of transit vehicles. Both of these thresholds are configurable in the VSC2 FCW application. The threat level calculations for a transit vehicle should take into consideration the lower deceleration rates of transit vehicles. Limited information about how the VSC2 FCW application computes this threat level is available, so it is not clear whether the threat level calculation could be easily reconfigured for transit.

Summary of Applicability of FCW to Transit

The application of FCW to transit vehicles and, more specifically, the modification of the VSC2 approach to FCW, are expected to be feasible. Some modifications may be required to accommodate the slower deceleration rates of transit vehicles, which could affect both the "look ahead" distance for target classification modules and the algorithms that determine whether an alert should be issued.

3.4.3. Blind Spot Warning plus Lane Change Warning for Transit

Review of the Application and Its Use for Transit

The blind spot warning plus lane change warning (BSW+LCW) application is intended to (a) inform a driver that a vehicle is in a blind-spot in an adjacent lane and (b) alert a driver if they initiate a lane change operation that is likely to result in a collision with a vehicle in an adjacent lane. The blind-spot information is expected to help prevent drivers from initiating a lane change when a vehicle is in their blind spot. The lane change alert is expected to help a driver abort a hazardous lane change before it results in a collision or, if a collision does occur, reduce the lateral collision speed.

The BSW+LCW application works as follows. The host vehicle monitors nearby remote vehicles that are broadcasting BSMs. If a remote vehicle is in the blind-spot of the host vehicle or soon will be, the host vehicle driver is informed of the presence of that vehicle. If the driver of the host vehicle activates a turn signal, the application determines if a remote vehicle is, or soon will be, in the host vehicle's blind spot on the side indicated by the turn signal and issues a warning.

Assessment of Modifications Required to Apply this Application for Transit

Several differences between transit and light vehicle operations were identified that could impact the performance of a BSW+LCW application.

---

[7] Based on descriptions provided in the VSC-A Final Report: Appendix B-1 Test Bed System Development.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **18**

Vehicle Length. Because a transit vehicle is longer than a light vehicle, the vehicle blind spots are larger and differently placed. A BSW+LCW application for light vehicles would need to be reconfigured to recognize the large size of the blind spot area. Also, the length of a transit bus makes it more likely both that a vehicle will be beside a bus attempting to change lanes and that a driver will overlook an adjacent vehicle.

Blind Spot Size and Location. This topic was addressed in the Vehicle Length segment above.

Frequent Stops. When a bus re-enters traffic after stopping to pick up passengers, it performs an operation that is, in many cases, equivalent to a lane change. This means that a transit bus has much higher exposure to lane change risks than a typical light vehicle.

When a bus is re-entering traffic after picking up passengers, it is also accelerating from a stop while adjacent traffic may be moving at speed. The dynamics of a re-entering traffic lane change are different than for a typical lane change. For example, a conflict point could exist between a transit bus and other vehicles well behind the transit bus because the other vehicle is moving faster than the accelerating bus.

Vehicle Width. Because a transit bus is wider than a light vehicle, there will usually be less lateral distance between a transit bus and adjacent vehicles. This means that the driver of a bus that is changing lanes has less time to react after being alerted that there is an adjacent vehicle.
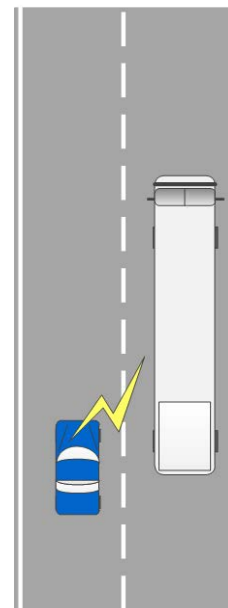
Figure 3-5. The BSW+LCW Application

Review of the VSC2 BSW+LCW Application[8]

The VSC2 BSW+LCW application monitors vehicles that are in the behind left or behind right positions. For each such vehicle, the application (a) determines if the vehicle is or will soon be within the host vehicle's blind-spot zone and (b) if so, issues a blind-spot warning. When a blind-spot warning is issued, the threat level is set to "inform" if the host vehicle turn signal is not activated or if the host vehicle's speed is below a configurable threshold. Otherwise, it is set to a higher threat level to generate a warning.

Modifications Required to Apply VSC2 BSW+LCW to Transit

The general approach used by the VSC2 BSW+LCW application for providing blind spot and lane change warnings would work for transit vehicles. However, insufficient information was available about the extent to which this application is configurable to determine if the application could be reconfigured for use on transit vehicles or if software modifications would be needed. In particular, the algorithm that determines if an adjacent vehicle was within the blind-spot zone would need to be modified to account for the different blind spot zone for transit buses. The VSC2 documentation did not indicate whether the blind spot location information was configurable.

When applied to transit, the host vehicle threshold speed for BSW+LCW warning activation should also be reviewed. The lane change warning system may be particularly useful for transit buses re-entering traffic after stopping to pick up passengers, when the bus will be operating at a low speed. Since this threshold is configurable on the VSC2 applications, this change would be easily accommodated.

---

[8] Based on descriptions provided in the VSC-A Final Report: Appendix B-1 Test Bed System Development.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **19**

If the VSC2 BSW+LCW approach is applied to transit and used when a transit vehicle re-enters traffic from a stop, the algorithm that determines if a vehicle will soon be in the blind-spot should be reviewed. The VSC2 BSW+LCW application seems to be designed for use at travel speeds when differences between vehicle speeds of the host and remote vehicles is small and when vehicle acceleration plays a relatively unimportant role. In the scenario when a bus is re-entering traffic after stopping to pick up passengers, the difference in travel speeds is much larger and the bus is accelerating. This complicates the algorithm for estimating whether a remote vehicle will soon be in the blind-spot. In fact, because of the long period of time before the bus reaches travel speed, there is a potential for a conflict even after the bus completed the lane change maneuver needed to re-enter traffic – a remote vehicle behind the bus could rear-end the bus after the bus re-enters traffic but is still accelerating up to speed. This algorithm should be reviewed before applying the VSC2 BSW+LCW approach to transit vehicles re-entering traffic after stopping for passengers.

Summary of Applicability of BSW+LCW to Transit

The VSC2 BSW+LCW approach would be applicable for transit vehicles if the blind-spot zone used in the BSW+LCW application can be reconfigured to reflect the blind-spot zone appropriate for transit vehicles. This would provide BSW and LCW when the transit bus was traveling at speed.

However, transit buses often perform lane change maneuvers re-entering traffic after stopping to pick up or drop off passengers. The VSC2 BSW+LCW application currently includes a minimum speed threshold, so would not provide lane change warnings for this type of lane change maneuver unless that speed threshold were set to 0. But, the algorithms used to determine if a vehicle will soon be in the host vehicle's blind spot should be reviewed before applying the VSC2 BSW+LCS application to a transit vehicle re-entering traffic from a stop.

3.4.4. Do Not Pass Warning for Transit

Review of the Application and Its Use for Transit

The do not pass warning (DNPW) application is intended to (a) inform a driver that the passing zone is occupied and a passing maneuver should not be attempted and (b) warn a driver if a passing maneuver is initiated while the passing zone is occupied. The information is expected to help prevent drivers from initiating a passing maneuver when there is a potential conflict with an oncoming vehicle. The warning is expected to help a driver safely abort a passing maneuver that has the potential to conflict with an oncoming vehicle.

The DNPW application works as follows. The host vehicle monitors remote vehicles to identify if a remote vehicle is in front of and in the same lane as the host vehicle. If there is no such vehicle, the DNPW remains inactive. Otherwise, the DNPW monitors BSMs from remote vehicles to determine if there are oncoming vehicles that might conflict with a passing maneuver. If so, the DNPW application provides the driver with information about the presence of a conflicting vehicle. If the driver of the host vehicle initiates a passing maneuver (e.g., activates the vehicle turn signal, begins to accelerate and change lanes), the DNPW application produces warnings if it determines that an oncoming vehicle could conflict with the passing maneuver.

Assessment of Modifications Required to Apply this Application for Transit

Several differences between transit and light vehicle operations were identified that could impact the performance of a DNPW application.

Vehicle Length. Because transit buses are longer than light vehicles, the passing distance is longer, which must be taken into consideration when computing the passing zone. This is addressed in greater detail in the next section on vehicle acceleration rate.

Vehicle Acceleration Rate. Transit buses typically have lower acceleration rates than light vehicles, so require more time to complete a passing maneuver. The DNPW application

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **20**

algorithm that computes the passing zone must take into consideration (a) the lower acceleration rate of transit buses as compared to light vehicles and (b) the longer length of transit buses.

Review of the VSC2 DNPW Application[9]

The VSC2 DNPW application works as follows. If the host vehicle's speed is below a configurable threshold, the DNPW application does not activate. If the host vehicle does not detect a remote vehicle ahead of it, the DNPW application does not activate. If the time gap between the host vehicle and the remote vehicle ahead of the host vehicle is above a configurable threshold, the DNPW application does not activate.

If the DNPW activates, it computes a passing zone required to pass the remote vehicle safely based on information about the host vehicle (i.e., speed, acceleration, and vehicle length) and the remote vehicle (i.e., distance to the remote vehicle, remote vehicle length, vehicle speed and acceleration). The DNPW estimates the future path of oncoming remote vehicles during the time required to pass the ahead remote vehicle, based on the distance to the oncoming remote vehicle and its length, speed, and acceleration. If this future path intersects with the passing zone, the DNPW takes one of the following actions:

- If the host vehicle left turn signal is off or the brake status is on, the DPNW sets the threat level to "inform" and issues DNPW information to the driver.
- If the host vehicle rate of closing on the ahead remote vehicle is below a configurable threshold, DNPW sets the threat level to "inform" and issues DNPW information to the driver.

Otherwise, the DNPW sets the threat level to "warning" and issues a DNPW alert to the driver.

Modifications Required to Apply VSC2 DNPW to Transit

The general approach used in the VSC2 DNPW application would apply to transit vehicles so long as the algorithm used to compute the passing zone could be adapted to the passing characteristics of a transit vehicle, particularly those relative to the lower acceleration rate and longer vehicle length that will result in longer passing zones. The passing zone calculation relies on vehicle information obtained from the CAN sensor data handler, so this calculation should adjust automatically to the vehicle data associated with a transit bus.

Summary of Applicability of DNPW to Transit

The VSC2 DNPW approach could be applied directly to a transit vehicle. The key element in the application is the computation of the passing zone, which depends on the host vehicle position, speed, length, and acceleration rate during the passing maneuver. In the VSC2 DNPW application, each of these is obtained from the CAN sensor data handler and should be configurable.

3.4.5.　Intersection Movement Assist (IMA) for Transit

Review of the IMA Application and Its Use for Transit

The intersection movement assist (IMA) application is intended to warn a driver if it is not safe to enter an intersection because of a high likelihood of a collision with another vehicle entering the intersection from the left or right. An IMA application activates as the vehicle approaches an intersection, or is always active if information is not available about whether the vehicle is approaching an intersection. Once active, it monitors the position and speed of nearby remote vehicles to identify vehicles on an intersecting path with the host vehicle and approaching from the left or right. If no such vehicles are identified, the IMA does nothing. Otherwise, the IMA application determines whether to inform the driver of the approaching vehicles or alert them,

---

[9] Based on descriptions provided in the VSC-A Final Report: Appendix B-1 Test Bed System Development.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **21**

depending on whether the host vehicle appears to be preparing to enter the intersection and whether the intersecting remote vehicles appear to be likely to enter the intersection.

Assessment of Modifications Required to Apply this Application for Transit

Several differences between transit and light vehicle operations were identified that could impact the performance of an IMA application.

Vehicle Length. Because a transit bus is longer than a typical light vehicle, it will take longer to clear the intersection if it enters it. This impacts the algorithm that estimates whether remote vehicles on intersecting paths are likely to collide with the host vehicle.

Vehicle Acceleration Rate. Because a transit bus accelerates more slowly than a typical light vehicle, it will take longer to clear the intersection if it enters it. This impacts the algorithm that estimates whether remote vehicles on intersecting paths are likely to collide with the host vehicle.

Well Defined Future Path. One of the challenges with the IMA application is determining whether the host vehicle will be entering the intersection. For example, it may be difficult to differentiate between a vehicle approaching the intersection to turn right (in which case a collision with a vehicle approaching the intersection from the right is not possible) and to proceed straight ahead. Because fixed route transit buses follow well-defined routes, a transit IMA application could integrate information about the bus route into the algorithm that determines whether the host vehicle will enter the intersection in a way that could collide with vehicles on intersecting approaches. This could help reduce false alerts, such as generating an alert for an intersecting vehicle from the right when the bus will be turning right.

Review of the VSC2 IMA Application[10]

The VSC2 IMA application becomes active when remote vehicles are identified as being in either the Intersecting Left or Intersecting Right positions. The VSC2 IMA estimates future paths for the host vehicle and all remote intersecting vehicles, then determines whether any of the remote intersecting vehicle future paths cross the future path of the host vehicle at about the same time as the host vehicle traverses it. The IMA application continues processing for each vehicle for which the crossing times are within configurable minimum and maximum cross-path values. Remote vehicles with crossing times outside those thresholds are ignored.

The IMA application next assigns a threat level to each remote vehicle that meets the crossing time criterion. The IMA then determines the intersection point and the distance of both the host and remote vehicle from that intersection point. Then, a threat level is assigned using the following approach:

- If the host vehicle's speed is above a configurable threshold:
  - If the remote vehicle's speed is above a configurable threshold:
    - If the distance from the host vehicle to the intersection point is less than a configurable minimum distance, a warning threat level is assigned to the remote vehicle.
    - If the distance from the host vehicle to the intersection point is less than a configurable maximum distance, an inform threat level is assigned to the remote vehicle.
    - Otherwise, the remote vehicle is ignored.
  - If the remote vehicle's speed is below a configurable threshold and does not have its brakes applied:

---

[10] Based on descriptions provided in the VSC-A Final Report: Appendix B-1 Test Bed System Development.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **22**

- If the distance from the host vehicle to the intersection point is less than a configurable minimum distance, an inform threat level is assigned to the remote vehicle.
- Otherwise, the remote vehicle is ignored.
  - o Otherwise, the remote vehicle is ignored.
- If the host vehicle's speed is below the configurable threshold:
  - o If the remote vehicle's speed is above a configurable threshold:
    - If the distance from the remote vehicle to the intersection point is less than a configurable minimum distance, a warning threat level is assigned to the remote vehicle.
    - If the distance from the remote vehicle to the intersection point is less than a configurable maximum distance, an inform threat level is assigned to the remote vehicle.
    - Otherwise, the remote vehicle is ignored.
- Otherwise, the remote vehicle is ignored.

If a threat level is assigned to at least one remote vehicle, the IMA application identifies the remote vehicle with the highest threat level and either informs the driver of that remote vehicle or generates a warning, depending on the threat level assigned.

Modifications Required to Apply VSC2 IMA to Transit

The general approach used in the VSC2 IMA would apply to transit vehicles. The following changes should be considered, with each of these changes being implemented via configuration parameters in the VSC2 IMA application.

- The minimum and maximum cross-path values should be larger for transit vehicles. Transit vehicles are longer than light vehicles, so the time period during which a collision could occur between vehicles on intersecting paths is longer.
- The host vehicle speed threshold should be lower for transit vehicles. Because transit vehicles have lower deceleration rates during hard braking, this speed threshold should be lower for transit vehicles than for light vehicles.

The other parameters—the minimum and maximum threshold distance for the host and remote vehicles and the speed threshold for the remote vehicle—should use similar values when this application is applied to transit vehicles as when applied to light vehicles.

Summary of Applicability of IMA to Transit

The VSC2 IMA approach could be applied directly to transit vehicles. Each of the parameters that would require adjustment to adapt the application for use on a transit vehicle is a configuration parameter of the VSC2 IMA application.

3.4.6. Control Loss Warning for Transit

Review of the Application and Its Use for Transit

The Control Loss Warning (CLW) application is intended to alert nearby vehicles when a vehicle is experiencing loss of control. The alert is expected to allow nearby drivers to identify that a nearby vehicle is out-of-control so the drivers can take evasive action, if needed, to avoid a collision with the out-of-control vehicle.

Each (remote) vehicle monitors its status to determine if it is out-of-control and, if it is out-of-control, broadcasts a loss-of-control warning message. Events that could trigger a loss-of-control warning message include activation of a vehicle's traction control, stability control, or anti-lock braking systems, as well as excessive yaw rates (i.e., because the vehicle is spinning) or vertical acceleration (i.e., because the vehicle is flipping).

When a host vehicle receives a loss-of-control warning message from a remote vehicle, it estimates the future paths of both the host and remote vehicles. If these future paths indicate a

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **23**

high likelihood of a collision, the application alerts the driver of the risk. If the future paths indicate very low likelihood of a collision, the application takes no action. Otherwise, the application informs the drivers of the out-of-control vehicle.

Assessment of Modifications Required to Apply this Application for Transit

Several differences between transit and light vehicle operations were identified that could impact the performance of a CLW application.

Vehicle Length. Operation of this application depends on estimating the likelihood of a collision due to crossing paths between the out-of-control remote vehicle and the host vehicle. This depends on whether the future paths of host and out-of-control vehicles cross and the timing of that crossing is such that the vehicle would collide while crossing. Because a transit bus is longer than a light vehicle, the time period during which crossing paths would result in a collision is larger for transit vehicles than for light vehicles.

Control Loss Identification. The types of the safety systems whose activation could be used to detect an out-of-control light vehicle (e.g., anti-lock brakes) are also common on transit buses and could be used similarly for a transit CLW application. The vehicle dynamics that would indicate an out-of-control vehicle (e.g., excessive yaw rates) may be different for transit vehicles, in which case a light vehicle CLW application would need to be calibrated differently to work for transit vehicles.

Review of the VSC2 CLW Application[11]

To support remote vehicle responsibilities for the CLW application, the CLW application monitors the anti-lock brake, traction control loss, and stability control systems. If one or more of those systems activate, a loss-of-control BSM is broadcast.

To support host vehicle responsibilities, the VSC2 CLW application monitors BSMs from all nearby remote vehicles to determine if a BSM indicates an out-of-control event is occurring. For each out-of-control remote vehicle, the VSC2 CLW application assigns a threat level based on the distance to the remote vehicle, the host vehicle speed, and whether the host vehicle brake is activated. (Other factors may be considered – the documentation is not clear on this point.) The VSC2 CLW identifies the out-of-control remote vehicle with the highest threat level and, depending on this threat level, issues a warning or provides the driver with information.

Modifications Required to Apply VSC2 CLW to Transit

The key to the CLW remote vehicle application is detection of the out-of-control condition. Because the VSC2 CLW application relies for this on the activation of vehicle safety systems, the presence of those systems is necessary for the CLW remote vehicle application. Fortunately, these systems are common on many new buses. For example, NHTSA estimates that 80 percent of new buses will be equipped with electronic stability control systems.[12] Transit-specific modifications may be required to obtain this activation information from transit data buses.

The key to the CLW host vehicle application is the threat assessment algorithm, and the available documentation provides little information on the algorithm used for the VSC2 CLW application. However, the only difference identified between transit and light vehicles that would impact the threat assessment is the longer length of transit vehicles. Because this feature is configurable in the VSC2 framework, it is likely that the VSC2 CLW threat assessment algorithm would provide reasonable threat assessment results for transit vehicles, after the vehicle configuration data was adjusted to reflect the longer length of transit vehicles.

---

[11] Based on descriptions provided in the VSC-A Final Report: Appendix B-1 Test Bed System Development.
[12] FMVSS No. 136, Electronic Stability Controls Systems on Heavy Vehicles, May 2012, NHTSA.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **24**

Summary of Applicability of CLW to Transit

The documentation of the VSC2 CLW application does not provide sufficient detail to determine whether the threat assessment algorithm would apply to transit vehicles. However, it is likely that changing configurable VSC2 vehicle data would allow the VSC2 CLW threat assessment algorithm to apply well to transit vehicles.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final   **25**

Chapter 4.   Conclusions

Based on data found in the *Vehicle Safety Communications Project Final Report*, the *Vehicle Safety Communications – Applications (VSC-A) Final Report*, expert opinion, and other sources, the conclusion reached by the study team is that there are no specific technical reasons that the basic framework of the existing Light Vehicle Safety Applications cannot be adapted to work on transit vehicles. As noted, there are specific issues that must be addressed in development and within the overall connected vehicle system; however, the barriers to successful implementation of safety applications for transit are minimal overall:

- The most challenging aspect of implementing DSRC-based safety applications on transit buses is the line-of-sight requirement for DSRC signals. Between the urban environments in which transit vehicles operate and the different vehicle configurations that will interfere with line of sight, overcoming this problem will require modified hardware platforms, most likely with several DSRC transmitter/receivers.
- The EEBL and FCW applications require minimal modification to work on transit vehicles.
  - The one adaptation may be the requirement to have front and back DSRC receiver/transmitters in order to successfully communicate with other vehicles. This is a hardware/underlying framework issue as opposed to an application issue, though.
- The most challenging aspect of adapting the applications is found in the Blind-Spot Warning concept. Current safety applications are not able to deal with a "beside" category that could stretch up to 40 ft, as opposed to the 10 ft normally accounted for.
  - This only impacts certain applications and certain transit safety scenarios. For example, the BSW+LCW application might require modification to account for the differences in size and location of the blind spot for light and transit vehicles.
  - The BSM dataset does contain length information, but the current implementation of the application uses a very limited definition of "beside" that is only suitable for light vehicles not towing trailers.

Overall, the potential to build from existing work rather than "re-invent the wheel" is very strong. Even though each manufacturer will design and implement its own transit safety applications, there is the potential for these manufacturers to benefit from the experiences of those that designed and implemented light vehicle safety applications.

There are some issues with DSRC and the BSM dataset that will need to be considered. For example, the height of the transit bus may impose line-of-sight restrictions that reduce the effectiveness of DSRC communication, and the BSM representation of a vehicle's position may not suffice for an articulated transit vehicle. These are identified within the report and are discussed, but their overall resolution is beyond the scope of this project.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | 26

Appendix A. DSRC and Transit Vehicle Applications

Introduction

From the main body of the report it is clear that DSRC limitations represent a concern for transit vehicles. The different physical configurations, the issue of line of sight, and the technical difficulties inherent in using wireless connections in high-traffic urban environments all present challenges that will need to be overcome in implementing connected vehicle technology for transit vehicles. In the course of developing the report, a large amount of information regarding DSRC performance on transit was developed. While not specifically the focus of the report, including it as an Appendix ensures that the information is retained.

DSRC provides low latency communications critical to enabling safety applications to:

1. Maintain real-time awareness of the surroundings of the host vehicle (HV) through accurate and rapid sensing, diagnosing, and information sharing between the HV and other remote vehicles (RVs);
2. Extend perception from local and transient to global and long-term, using prediction and preemptive response; and
3. Translate situational information to appropriate actions, including developing multiple and collaborative automatic vehicle safety control strategies.

The VSC-A project validated only for light vehicles and did not address transit vehicles. Transit vehicles differentiate from light vehicles in several aspects:

1. **Physical Characteristics**: Transit vehicles are typically longer, higher, wider and heavier than light vehicles. The larger size results in larger blind spot areas and serious blockage of line of sight (LOS) of neighboring vehicles and pedestrians, as well as the DSRC RF signals; the reduction is described mathematically by the term of shadow fading following a log normal distribution.
2. **Kinematic Characteristics**: Transit vehicles have lower magnitude of acceleration and deceleration and they move, change lanes and turn at lower speeds. Their trajectories are limited and nearly pre-determined when turning or passing through intersections. The situation is further exaggerated for those that are articulated, since each part may take a different path when turning, passing or changing lanes.
3. **Operational Characteristics**: A large number of transit vehicles operate in predefined routines and make frequent stops in designated or allocated areas, such as bus stops.

Application Framework

The VSC framework consists of the modular blocks of interface, positioning and security, core and safety applications, threat process and reporting, and data analysis. The interface modular block include the driver-vehicle interface (DVI), engineering graphical user interface (EGUI), DSRC radio, wireless message data handler and the sensor data handler. The wireless message data handler exchanges basic safety message (BSM) and other vehicle service data through DSRC radios. The sensor data handler deals with the data originated from the CAN bus, GPS units, onboard cameras, and radars. The core and safety application performs target classification, HV path prediction, and safety applications. Threat processing and reporting modular block realizes threat arbitration and verification and generates warning messages based upon priority. The security modular block achieves defined security message delivery, and the data analysis modular block completes data log and data investigation. When applied to transit vehicles, the re-purposed modular blocks are mainly the path prediction, core and safety application, threat arbitration, and prioritization.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | 27

1. The core and safety application can integrate into and accommodate advanced algorithms and processing cores, resulting in more accurate and confident warnings and predictions with heavy computation loads and large calculation latencies. These are all tolerable for transit vehicles, considering their low speed and larger available power supply.

2. In most safety applications, the path prediction core in a transit vehicle predicts not only the movements of the transit vehicle but also the behaviors of vehicles involved and in the vicinity**.**

3. Threat and prioritization processing can adopt a more sensitive and robust procedure to reduce the probability of a missed alarm.

4. The VSC framework does not integrate a driver behavior model, which is the observation of the trajectories and operations of an ordinary, functioning vehicle driven by a rational, sensible driver. Such a model can classify a driver's *safety driving assurance* into the categories of *conservative*, *normal*, *aggressive*, *reckless,* and *out of order* in real-time to further avoid collisions due to the driver's behaviors for whatever cause.

The sensor data handler, DVI, EGUI, core and safety applications, threat processing and reporting, data analysis, and security modular blocks are all programmable when applied to transit vehicles, and there is no hard-coded element that cannot transferred.

Basic Safety Message Factors

The BSM defines the over-the-air (OTA) message used to support all safety applications in current and the future, which was standardized in 2009 by the SAE J2735 Message Set Dictionary standard. This standard set BSM targets for the minimum message update rate and the inaccuracy tolerance of sensor data in order to support vehicle safety applications functionally. Currently, however, the two key parameters are still being investigated and need to be further researched.

Meanwhile, another goal of BSM is to deal with the collisions of the host vehicle (HV) from whole azimuth, including the same, inverse, and other directions and under diverse scenarios, such as roads, intersections and parking lots. For example, the collision case of "Vehicle(s) Not Making a Maneuver – Opposite Direction" is surveyed as one of the top five crashes. In such case, the BSM needs to develop path prediction and advanced vehicle dynamics models to help avoid a head-on collision. Another similar case is "Vehicle(s) Making a Maneuver – Opposite Direction."

The BSM fields are categorized into two main parts: Part I data includes critical vehicle state related to all safety applications; Part II data is for a specific application, either in a fixed rate or an even-driven mode.

Table A-1 and A-2 list the main fields of Part I and Part II data of BSM, respectively.

Table A-1. Part I Data Fields of BSM

Content	Usage
Message Count	To order packets and calculate packet error rate (PER)
Temporary ID	Vehicle identifier (4 bytes)
Latitude, Longitude and Elevation	Positioning (0.1 microdegree or 0.1 meter resolution)
Vehicle Size	Vehicle length and width
Time and Positional Accuracy	To interpret latitude and longitude
Transmission and Speed	Consists of speed, heading, steering wheel angle, acceleration and yaw rate
Brake Status	To convey status of stability control, brake boost and auxiliary brakes

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **28**

Table A-2. Key Part II Data Fields of BSM

Content	Usage

Event Flag	Unusual event including
	
	    1. Hard brake (e.g., a deceleration > 0.4g)
	
	    2. Hazard lights on
	
	    3. One or more cases of anti-lock brakes, stability control or traction control with duration > 100 ms

Path History	Records of recent vehicle movement
Path Prediction	Predict path and predication confidence to help identify in-lane and out of lane threats

BSMs are divided into two types: periodic BSM and event-driven BSM. For a periodic BSM, the information is broadcast at a rate of 10Hz and consists of a vehicle's positioning data, heading, speed, and other information. Event-driven BSM information containing an event, such as the hard brake, will be delivered to neighboring vehicles within a deadline defined by the safety application.

Technical Considerations

1. The fields of BSM for transit vehicles for all safety applications are the vehicle's present latitude, longitude, elevation, positional accuracy and associated time stamp; the vehicle's moving speed, heading, steering wheel angle and acceleration; the vehicle's hardness of braking and traction control activation status; and the vehicle's length and width—all components from Part I data.

2. Additionally, the vehicle's path history and path prediction, light usage, brake status, as well as environmental status—including weather conditions, temperature, and pressure, which are all from the Part II data—are included. For example, the imminent stop message can be included in the path prediction information, which is further broadcast to surrounding vehicles. The path prediction confidence level is regarded as high due to the routine operation characteristics of transit vehicles.

3. The IEEE 1609.4 standard (draft) divides the transmission period of 100ms into the control channel (CCH, Channel 178) interval and the service channel (SCH) interval, each taking up 50ms. BSMs are delivered through CCH only. Understandably, during the CCH interval, event-driven BSMs will be sent with a higher priority than periodic BSMs without adding on extra message buffering latency for time-critical, event-driven BSMs. However, there are two cases that will add waiting delay for event-driven BSMs:

   a. Case I: An additional latency is unavoidably created when an event-driven BSM occurs immediately after the periodic BSM starts to transmit. For example, if the periodic BSMs take a length of $N = 1000$ bytes and corresponding data rate is $R_b = 3Mbits/s$, it generates extra latency of $\tau = \dfrac{N}{R_b} = 2.7ms$.

   b. Case II: The most disruptive situation occurs when an event-driven BSM occurs when the transmission switches off into a SCH interval; this leads to a delay of up to 50ms, which is *not* acceptable for safety applications for transit vehicles.

To address this situation and offer always-on safety message broadcasting, one of the SCHs, Channel 172 in United States, has been suggested to broadcast BSM messages when safety applications are applied to transit vehicles. To further reduce the waiting delay for Case I, the periodic message can be segmented into several frames with a comparably smaller value for N .

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final   **29**

4. The IEEE 1609.2 security services standard defines two types of authenticating messages upon an elliptic curve digital signature algorithm (ECDSA), one with a key length of 224 bits and another of 256 bits. For a BSM, it requires a short validation time of a few seconds and the 224-bit key is adopted by considering the implementation complexity and real-time requirement. However, for safety applications for transit vehicles, it is suggested that the 256-bit key be adopted since the implementation complexity is tolerable.

Performance Limitations

There is no known limitation on performance that may affect the ability of light vehicle applications to be re-purposed for transit vehicles. The conclusion is supported by the following analyses:

1. GPS Positioning: The CAMP final report confirmed that in most testing scenarios GPS positioning accuracy, update rate, and availability are sufficient to support vehicle safety applications. Most GPS outages happened in high-density urban areas with durations less than 15s. When a GPS signal is lost or malfunctioning, vehicle positions can be estimated using recent information including travel speeds, headings, and yaw rates. The installation of GPS sensors on top of transit vehicles facilitates the reception of GPS signals from satellites, leading to enhanced GPS positioning, since GPS sensors at the height of transit vehicles are less likely to have their signals blocked. The length of transit vehicles makes it possible to use multiple GPS sensors precisely installed with known spacing on the top of transit vehicle. This would increase the diversity of GPS signal receivers to reduce GPS outages and enhance the GPS update rate if GPS sensors work asynchronously and account for positioning variations when integrating data.

2. Similarly, the heights and lengths of transit vehicles facilitate the installation and usage of DSRC radio, onboard cameras, and radars.

Line of Sight (LOS)

Line of sight and wireless communication are both factors impacting the success of transit safety applications.

In wireless communications, *path loss* is the metric used to measure the signal dissipation in the azimuth during propagation, which is dependent upon the distance between the transmitter and receiver, the signal central frequency, and propagation environments. Path loss is not dependent upon the absorption and conversion of a radiated signal during propagation. In free space where there are no reflectors at all, the path loss is inversely proportional to the square of distance between transmitter and receiver.

Mathematically, $PL \sim \dfrac{1}{r^2}$ where PL is the path loss and r is the distance between transmitter and

receiver. However, when considering the reflections from the ground, the path loss increases more

significantly with the distance than the free space scenario. This is expressed as $PL \sim \dfrac{1}{r^\alpha}$ where

$\alpha = 3 - 5$; here, α is called *path loss factor* and has a value greater than 2 for free space situations. For the path loss of the DSRC radios mounted on the tops of two transit vehicles, the height and length of transit vehicle can reduce, to a degree, the reflections from the ground, resulting in a smaller value of path loss factor. This implies the path loss between the two DSRC radios for transit vehicles is more close to free space path loss, increasing receiving signal strength.

When considering the path loss between two DSRC radios mounted on the tops of transit vehicles and light vehicles, the height of the transit vehicle will block the line of sight (LOS) between the two radios if the spacing of the two vehicles is too small, resulting in a non-LOS (NLOS) link. The signal can still reach the DSRC radios through refraction and multipath propagation. The estimated refraction fading is about 5-15dB under diverse scenarios. However, in most cases this happens when two vehicles are close to each other, causing a small path loss. When the space between two vehicles is increased, NLOS will become

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | 30

LOS, resulting in greater signal strength. In summary, the path loss between two DSRC radios of a transit vehicle and a light vehicle will experience a fluctuation of between 10 dB and 20dB. The radio link should be sufficient in most situations if the radiation power of DSRC radio is greater than 20dBm.

Another issue is that the transit vehicle will block and generate shadow fading to the following light vehicle within certain distances. The shadow fading is estimated to be between 10 dB and 20dB. A solution to address this issue is to have the transit vehicle relay the RF signal.

The large metal frame of a transit vehicle will impact the receiving and radiation patterns of the antennas of DSRC radios. In general, it will boost the gains of the antennas but distort both the radiation pattern and the RF signal polarization. The antennas are suggested to be mounted at a distance of 2-3 cm above the roof of a transit vehicle.

To reduce the likelihood of NLOS links and to attain diversity gains, it may be possible that an antenna can be installed on both the front and the rear of the transit vehicle. This will require field testing.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | 31

Appendix B. Assessment of the Applicability of Light Vehicle Applications to Transit Scenarios

Introduction

The challenge in adapting existing Light Vehicle Safety Applications to transit vehicles lies less in the different standards they use for their internal system and more in the four dimensions of the vehicle. While the standard height, width, and length are obvious elements, the movement of the vehicle through time is a function of its mass and velocity. In short, this is a fancy way of saying that a transit vehicle is slower to pick up speed and slower to come to a halt. These elements of physics affect how the transit vehicle interacts with other traffic and the roadway itself.

Current implementations of the DSRC Message Set do not implement the length subset making an assumption that all vehicles of standard length. This presents a challenge for longer transit vehicles. For the Safety Pilot Transit Retrofit Package, the current solution is to use a Vehicle Awareness Device on the front and the back of the vehicle. While this is a marginally effective stop-gap measure it does not address the long-term needs of transit vehicles.

A key question at this point is what methodology to use in proceeding: linked devices or revised messaging. Based on the study team's current understanding our focus will be on the leveraging of linked devices as opposed to assuming the entire connected vehicle universe will adapt to a new implantation of messaging including length. The study team will note where the key differences in adapting the applications

A second key question is which vehicle is affected by the application modification. Looking at the "right turn in front" crash scenario the most effective solution is to provide a warning to both the Light Vehicle driver and the transit vehicle driver. This is beyond the scope of this effort. All warnings will be given to the transit driver.

Another factor beyond the scope of this effort is the incorporation of a known map into application functionality. There are strong indications that using a known map improves GPS accuracy substantially; however there are also privacy implications that must be considered. For the purpose of transit vehicles, the assumption has been made that, where required, the use of a known map will be incorporated as transit vehicles do not have the same privacy requirements as light vehicles.

Finally the job of a transit vehicle driver is more involved than that of a light vehicle driver. Transit vehicle drivers already need to monitor different systems, passengers, and radio communications in addition to just driving. Keeping this in mind all inputs to the driver are simple warnings and are limited. Preventing driver overload and habituation are key to long term success.

Applicability of Light Vehicle Safety Applications to Scenarios

The following Light Vehicle Safety Applications were identified as having characteristics that could make them useful as a basis for a Transit Vehicle Safety Application.

Emergency Electronic Brake Lights (EEBL). This application warns nearby drivers when a vehicle stops abruptly. A host vehicle is behind a remote vehicle when the driver of the remote vehicle brakes hard. The remote vehicle broadcasts an event-driven BSM identifying that it is rapidly decelerating. The host vehicle considers factors such as the distance to the remote vehicle and the relative speeds of the host and remote vehicles and issues a warning if there is a likelihood that the host vehicle will rear end the remote vehicle.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **32**

Forward Collision Warning (FCW). This application warns a driver of an impending rear-end collision with a vehicle ahead in traffic. A host vehicle is behind a remote vehicle and approaching it such that there is a likelihood that the host vehicle will rear-end the remote vehicle. This could be because the remote vehicle is stopped or because the remote vehicle is decelerating rapidly. The host vehicle issues a warning.

Blind Spot Warning and Lane Change Warning (BSW+LCW). This application warns a driver attempting to change lanes that a lane change is unsafe because a vehicle is present in the driver's blind spot. The driver of a host vehicle activates a turn signal prior to changing lanes and there is a remote vehicle beside the host vehicle or in the host vehicle's blind spot. The host vehicle issues a warning.

Do Not Pass Warning (DNPW). This application monitors the position and speed of vehicles ahead (traveling both in the same and opposing directions) and warns the driver if there is a risk that a passing maneuver could result in a crash with an oncoming vehicle.

Intersection Movement Assist (IMA). This application warns a driver when it is unsafe to enter an intersection because of the likelihood of a crash with another vehicle entering the intersection from a crossing direction. A host vehicle either approaches the intersection at a speed indicating it will enter the intersection without stopping or a host vehicle is stopped on an intersection approach and begins to accelerate into the intersection. A remote vehicle is approaching the intersection from one of the crossing directions and also appears likely to enter the intersection. The host vehicle issues a warning.

Control Loss Warning (CLW). This application warns nearby drivers when a vehicle is out of control. The driver of a remote vehicle loses control of the vehicle (e.g., as indicated by extreme yaw rates) and broadcasts an event-driven BSM identifying that the vehicle is out of control. A host vehicle receives the message and issues a warning if the out-of-control vehicle is likely to affect the host vehicle.

Cooperative Intersection Collision Avoidance System – Violations (CICAS-V). This application warns drivers that they are in danger of violating a traffic signal. The traffic signal must be equipped with connected vehicle technologies and be broadcasting signal phase and timing (SPaT) information over DSRC. In one scenario, a host vehicle is approaching the intersection with the signal phase either being red or going to be red before the host vehicle clears the intersection given its current position and speed. In another scenario, the host vehicle is at the intersection, the signal is red, and the host vehicle begins to move forward as if to enter the intersection. In both cases, a warning is issued to the driver of the host vehicle.

Cooperative Intersection Collision Avoidance System – Signalized Left-Turn Assist (CICAS-SLTA). This application warns a driver when it is unsafe to initiate a left turn at a signalized intersection because of the likelihood of a crash with another vehicle entering the intersection from the opposite direction. A host vehicle is preparing to turn left at a signalized intersection during a permissive left-turn phase (as indicated by either a left-turn signal or presence in a left-turn only lane). The host vehicle makes movements that indicate it is initiating the left turn, either by starting to move forward while previously stopped or by approaching the stop bar at a speed that indicates the host vehicle will not stop. A remote vehicle is approaching the intersection from the opposite direction with a position and speed that indicates a crash is likely if the host vehicle continues the initiated left-turn action. The host vehicle issues a warning to its driver.

Curve Speed Warning (CSW). This application warns drivers if they are approaching a curve at a potentially unsafe speed. Roadside equipment (not necessarily adjacent to the curve) broadcasts information about the location of curves with reduced speed limits and the speed limits at those locations. A host vehicle receives this information and monitors the vehicle's position to determine if it is approaching a CSW curve. If so, and if the vehicle's speed is higher than the curve speed limit, then a warning is issued to the driver as he or she nears the curve.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **33**

Table B-1. Applicability Matrix

	Emergency Electronic Brake Lights (EEBL)	Forward Collision Warning (FCW)	Blind Spot + Lane Change Warning (BSW+LCW)	Do Not Pass Warning (DNPW)	Intersection Movement Assist (IMA)	Control Loss Warning (CLW)	Cooperative Intersection Collision Avoidance System – Violations (CICAS-V)	Curve Speed Warning (CSW)
1. Right-Turn-in-Front Crash	X	X	X	X				
2. Pedestrian vs. Turning Bus Crash								
3. Bus Angle Crash at Intersection					X		X	
4. Left-Turn Head-On Crash		X			X		X	
5. Rear-End Crash at Bus Stop	X	X						
6. Left-Turn Crash at Light Rail Grade Crossing								

Stakeholder Review Process

Stakeholder feedback was obtained on these applications and their applicability to transit via a Webinar and follow up telephone interviews with selected stakeholders. The goals of the Webinar were to:

- Ensure a common understanding of the scenarios and applications.
- Understand why the scenarios are important to transit operations.
- Discuss the safety applications, their likely effectiveness, and the feasibility of adapting them to transit.

The results of this Webinar are summarized in the next section.

Overall Comments from Stakeholder Group

There were a number of comments from the Stakeholders that indicated there are additional functions that should be considered within these types of Scenarios.

- Warnings to Passengers
  - Several Stakeholders commented that an audible warning to passengers inside the bus would be of value.
  - For collisions impacting a bus from behind an audible warning in front of the bus to warn passengers using the bike racks was suggested.
- Visual warnings to other drivers
  - For vehicles about to collide with a bus from behind a flashing light was suggested to potentially avert the accident.
- Extensive Human Interface Engineering required
  - Stakeholders noted that transit drivers already work with a number of systems in addition to needing to watch traffic and be aware of passengers.
  - A great deal of care should be taken in adding to the cognitive burden the drivers already face.
  - Warnings must allow the driver to react; a warning such as "side collision" is useless unless it includes the side of the vehicle that will be impacted.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **34**

- This may create challenges in developing the warning mechanism as the real estate on the driver's console is already limited.

Scenarios

Right-Turn-In-Front Crash Prevention Application

The key goal is to warn a transit driver when a vehicle may be turning right in front of a transit vehicle as the transit vehicle starts from a bus stop located in front of an intersection. In reviewing the requirements for an application to address this scenario, the following elements were identified:

- Initialization
  - A bus stop is placed with an intersection just upstream.
    - The bus stop is a known location.
      - □ Using GPS and a known map, the bus can identify that it is at one of these locations.
      - □ The intersection allows a right hand turn.
        - – The term "intersection" should be taken to mean any place where a vehicle can make a legal right-hand turn from the travel lane; this would include into a parking lot.
      - □ There are two lanes of traffic.
        - – This can be a different directions or the same direction, but a single lane with no way to pass would not be affected.
  - The application becomes active when the vehicle starts up.
  - The application monitors to determine if it is at one of the known locations.
- Active Mode
  - The application enters active ,mode based on location via the known map.
    - The application will assume that this means the bus is in passenger mode.
    - Given the limitation that the bus must slow down compared to traffic, this should prevent false alarms.
  - A transit vehicle drops off or picks up passengers at a bus stop with the above characteristics:
    - If the bus does not slow the application is not triggered.
      - □ The bus not slowing down substantially presumes that the vehicle is simply traveling through and will move as normal traffic.
    - If the bus does not stop and open the doors, depending on bus speed relative to traffic around it, the application may not trigger.
  - When in active mode, the application is reviewing BSMs received from vehicles in the area.
  - If there is no vehicle passing the transit vehicle from behind, the application does not provide a warning.
- Trigger Warning
  - Step 1: The transit vehicle releases the brakes and begins to accelerate.
  - Step 2: A vehicle begins to pass the transit vehicle from behind.
    - Vehicle is accelerating enough to pass transit vehicle.
    - Vehicle is changing lanes/turning.
- Warning
  - Alerts the driver that a vehicle is coming up beside.
  - Warns the driver the vehicle is beginning to turn and tells the driver to brake.

Will utilize four existing Light Vehicle Safety Applications:

- Emergency Electronic Brake Lights (EEBL)
  - Identifies when the brakes are applied, but also can be leveraged to identify when the brakes are released.
- Forward Collision Warning (FCW)
  - Identifies when vehicles in front of the transit vehicle are a risk.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **35**

- Blind Spot Warning+Lane Change Warning (BSW+LCW)
  - Key Application
    - Identifies lane change.
- *Do Not Pass Warning (DNPW)*
  - Not relevant to the transit vehicle, but could be used to broadcast a warning to a light vehicle.

Pedestrian vs. Turning Bus Crash Scenario

The key goal is to warn a transit driver when a pedestrian is crossing the street as the bus is making a left- or right-hand turn. This scenario represents a greater challenge as the pedestrians are not equipped with Safety Awareness Devices, limiting the ability of connected vehicle technology to detect them. It is more likely that utilization of vehicle-to-infrastructure (V2I) warnings will be effective to inform the driver of the risk as opposed to the actuality. Key factors are as follows:

- Initialization
  - Vehicle
    - The application becomes active when the vehicle starts up.
    - The application monitors to determine if a warning is being broadcast.
  - Intersection
    - The intersection is equipped with a roadside unit that broadcasts Signal Phase and Timing (SPaT).
    - SPaT details include phases for the crosswalk.
- Active Mode
  - The vehicle approaches an intersection equipped with SPaT.
- Trigger Warning
  - The transit vehicle releases the brakes and begins to accelerate.
  - The transit vehicle begins to turn.
  - SPaT broadcasts indicate a "Walk" signal for pedestrians in the direction of the turn.
- Warning
  - Alerts the driver that the "Walk" signal is active.

Because this application is V2I-based as opposed to vehicle-to-vehicle-based (V2V) the applications listed in the SOW are not relevant; however SPaT is an application being developed and can be leveraged for this purpose. Without some sort of active sensing technology, however, this application will not be able to address pedestrians crossing against the signal or prevent false alarms when no pedestrian is present at the crosswalk/intersection.

Bus Angle Crash at Intersection Scenario

The key goal is to warn transit drivers when they are approaching an intersection where a vehicle from a cross street is coming through the intersection and may impact the transit vehicle. This application would also function when a vehicle is pulling out of a parking lot or other side street areas. Note that due to urban canyons and range of DSRC, this application may need to be bolstered with V2I; however, the current write up is based on V2V. Key factors are as follows:

- Initialization
  - The application becomes active when the vehicle starts up.
- Active Mode
  - This application will remain active while the vehicle is in use.
  - If combined with a known map, the application will not be active when in an area where there are no turn points (HOT Lane as an example).
    - Note that if not combined with a known map, then the application will run continuously, which should not be a problem, but may lead to false alarms.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **36**

- Trigger Warning
  - The transit vehicle approaches an intersection/turn point.
  - A vehicle's projected trajectory and speed indicates that the vehicle will enter the intersection (or "intersect" with the bus if from a turn point) while the transit vehicle is passing through/by.
    - Requires line of sight to the approaching vehicle or assistance from infrastructure
- Warning
  - Warns the driver of the impending collision and indicates they should brake.

Will utilize one existing Light Vehicle Safety Application:

- Intersection Movement Assist
  - Identifies vehicle trajectories, speed, and collision potential.

Left-Turn Head-On Crash Scenario

The key goal is to warn a transit driver that a vehicle is turning in front of them from the opposite lane. This may occur at an intersection or at any point in the road where a left turn against oncoming traffic can be made. Once again, line of sight for the DSCR signal plays a key role in the efficacy of the application. Key factors are as follows:

- Initialization
  - The application becomes active when the vehicle starts up.
- Active Mode
  - This application will remain active while the vehicle is in use.
  - If combined with a known map, the application will not be active when in an area where there are no turn points (such as a freeway).
- Trigger Warning
  - A vehicle begins to turn left in front of the transit vehicle.
    - Ideally the turn signal indicator is on, but this is not assumed.
    - Vehicle begins to accelerate and turn.
  - Transit vehicle's speed and the turning vehicle's speed and trajectory indicate a possible collision.
- Warning
  - Warns the transit driver of the impending collision and indicates the driver should brake.

Will utilize two existing Light Vehicle Safety Applications:

- Forward Collision Warning (FCW)
  - Identifies when vehicles in front of the transit vehicle are a risk.
- CICAS V
  - Identifies turns and trajectories.

Rear-End Crash at Bus Stop Scenario

Key goal is to provide a Transit driver a vehicle is rapidly approaching from behind and may not be able to stop in time. This scenario does not assume warning the light vehicle driver. Key factors are as follows:

- Initialization
  - The transit vehicle is at a bus stop.
    - The stop is a known location.
      - Using GPS and a known map, the bus can identify that it is at one of these locations.
  - The application becomes active when the vehicle starts up.
  - The application monitors to determine if it is at one of the known locations.
- Active Mode

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **37**

- A transit vehicle drops off or picks up passengers at a bus stop.
- If the bus does not stop, the application is not triggered.
- If the bus does not open the doors, the application is not triggered.
  - □ The bus not opening the door presumes that the vehicle is simply traveling through and will move as normal in traffic.
  - o The application enters active mode with a combination of location and doors opening.
  - o When in active mode, the application is reviewing BSMs received from vehicles in the area.
- Trigger Warning
  - o The transit vehicle activates the brakes at a bus stop.
  - o A vehicle approaches from behind.
    - Vehicle's speed is increasing or unchanged.
    - Vehicle is not applying brakes.
    - Vehicle is in the same lane at the transit vehicle.
- Warning
  - o Alerts the transit driver that a vehicle is approaching from behind.
  - o Warns the driver of the impending collision.
  - o Some thought may be given to whether a warning should be broadcast at the front of the transit vehicle (for instance if someone is getting a bike off the bike rack).

Will utilize two existing Light Vehicle Safety Applications:

- Emergency Electronic Brake Lights (EEBL)
  - o Identifies when the brakes are applied, but also can be leveraged to identify when the brakes are released.
- Forward Collision Warning (FCW)
  - o May be able to be leveraged to broadcast a warning in front from the light vehicle.

Left-Turn Crash at a Light Rail Grade Crossing Scenario

The key goal is to warn a transit driver that the planned turn at a light-rail crossing is likely to result in an accident. There are two options here: equip every light-rail vehicle with DSRC, or use infrastructure to broadcast the warning. While there are positive elements to both options, the implementation of DSRC on light vehicles raises the risk of false alarms for both transit and light vehicles in scenarios where light rail tracks run alongside roads. GPS accuracy on light vehicles remains a challenge in some cases, and that could create situations in which a vehicle is perceived to be a risk. As the technology improves this can be mitigated, but at this point an infrastructure based solution is envisioned. Key factors are as follows:

- Initialization
  - o A light-rail crossing is equipped with a roadside unit.
    - The crossing is a known location.
      - □ Using GPS and a known map, the bus can identify that it is at one of these locations.
  - o The application becomes active when the vehicle starts up.
  - o The application monitors to determine if it is at one of the known locations.
  - o The roadside unit is integrated into the signal crossing safety systems and can detect an approaching light-rail vehicle.
- Active Mode
  - o The transit vehicle approaches the light-rail crossing.
  - o If there is no light rail vehicle in range the application does not provide a warning.
- Trigger Warning
  - o The transit vehicle releases the brakes and begins to accelerate.
  - o A light-rail vehicle is approaching the intersection.
- Warning

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **38**

- o Alerts the driver that a light-rail vehicle is approaching.
- o Warns the driver to brake.

Because this application is V2I-based as opposed to V2V-based, the applications listed in the SOW are not relevant; however SPaT is an application being developed and can be leveraged for this purpose.

Collisions at a Bus Transfer Station or Bus Maintenance Depot

The large number of vehicles moving in and out of transfer stations and depots creates a risk for minor impacts due to vehicles in the blind spot, multiple distractions from curbside, and the need to remain on schedule. By using Light Vehicle Safety Applications, it may be possible to provide valuable warnings to transit drivers preventing near misses and minor collisions. This application can be partially based off the "right turn in front" scenario as the incidents frequently involve a Left Turn in Front element, where a bus pulls out of the bay into the stream of traffic in front of another bus approaching from behind. For the purpose of this scenario the driver leaving the bay is the departing driver and the driver approaching from behind is the approaching driver. Key factors are as follows:

- Initialization
  - o A bus approaches a transfer station or depot.
    - The station or depot is a known location.
      - □ Using GPS and a known map, the bus can identify that it is at one of these locations.
      - □ There are multiple lanes of traffic and/or a large area where buses can travel.
        - – If the transfer station or depot does not allow vehicles to pass each other, then there is no requirement for this application.
  - o The application becomes active when the vehicle starts up.
  - o The application monitors to determine if it is at one of the known locations.
- Active Mode
  - o The application enters active mode based on location via the known map.
  - o When in active mode the application is reviewing BSMs received from vehicles in the area.
  - o If there is no vehicles whose paths will intersect that of the transit vehicle, the application does not provide a warning,
- Trigger Warning
  - o Step 1: Transit vehicle begins to exit the bay after dropping off passengers or receiving service.
  - o Step 2: The application determines whether another transit vehicle is approaching on a possible collision path.
- Warning
  - o Alerts the departing driver that a transit vehicle is coming up alongside.
  - o Warns the approaching driver a transit vehicle is beginning to pull out into traffic and tells the driver to brake.

Will utilize four existing Light Vehicle Safety Applications:

- Emergency Electronic Brake Lights (EEBL)
  - o Identifies when the brakes are applied, but also can be leveraged to identify when the brakes are released.
- Forward Collision Warning (FCW)
  - o Identifies when vehicles in front of the transit vehicle are a risk.
- Blind Spot Warning+Lane Change Warning (BSW+LCW)
  - o Key Application
    - Identifies lane change.
    - Identifies vehicles in the blind spot.
    - Identifies potential collisions.
- Do Not Pass Warning (DNPW)
  - o Warns other transit vehicles that this vehicle is moving and not to pass.

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office

Assessment of the Use of Light Vehicle Safety Applications for Transit – Final | **39**

U.S. Department of Transportation