Transit Vehicle-to-Infrastructure (V2I) Assessment Study

Project Report

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16. Abstract

The United States Department of Transportation (USDOT) is engaged in assessing applications that realize the full potential of connected vehicles, travelers, and infrastructure to enhance current operational practices and transform future surface transportation systems management. This effort, known as the Connected Vehicle Program, is a collaborative initiative spanning the Intelligent Transportation Systems Joint Program Office (ITS JPO), Federal Highway Administration (FHWA), Federal Transit Administration (FTA), Federal Motor Carrier Safety Administration (FMCSA), Federal Railroad Administration (FRA) and National Highway Traffic Safety Administration (NHTSA). At its foundation is a communications network that supports vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and vehicle or infrastructure-to-device (X2D) communications. Onboard equipment (OBE) units consist of connected vehicle equipment installed in the vehicle capable of broadcasting and receiving wireless messages. Roadside units (RSU) consist of roadside equipment capable of broadcasting and receiving wireless messages from vehicles.

With its unique operational behaviors, vehicle characteristics, institutional assets, and mission to serve the public, the transit community holds a unique set of opportunities to support V2I applications that benefit all road users in general, and transit riders in particular.

The overall scope of this Transit Connected Vehicle V2I Assessment Study is to: (i) to perform a thorough cross-cutting exploration of transit unique V2I needs (such as data and communications needs), opportunities (where transit can contribute, for example, to the data environments) and constraints (such as ownership of and accessibility to certain infrastructures), and then (ii) define and prioritize selected transit V2I application bundles, and develop operational descriptions. This report, as a final project report, documents the thought process and approaches used in this study, as well as key findings derived from these research activities.

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Table of Contents

List of Tables

List of Figures

Executive Summary

The Intelligent Transportation Systems (ITS) Joint Program Office (JPO) is undergoing connected vehicle research in order to improve the safety, mobility, and environmental outcomes of the U.S. surface transportation system. The Transit Connected Vehicle Safety program participated in the Model Deployment in Ann Arbor, Michigan with a set of five connected vehicle applications that were known as the Transit Retrofit Package (TRP). This Transit V2I Assessment Study aimed to identify what, if any, additional V2I applications the ITS JPO and Federal Transit Administration (FTA) Office of Research, Demonstration, and Innovation should pursue development for the next stages of pilot deployments.

This document serves to summarize the entire body of work conducted under the Transit V2I Assessment Study. Chapter 2 provides background on the Transit V2I Safety program and collision statistics from the 2010 National Transit Database (NTD). Chapter 3 summarizes the Literature Review that was conducted for this study. Chapter 4 discusses the stakeholder engagement process. Chapter 5 outlines the application prioritization process. Chapter 6 provides brief descriptions of the selected applications. Chapter 7 discusses infrastructure needs for the different proposed applications. Lastly, Chapter 8 discusses conclusions and next steps for the Transit V2I Safety research program.

1 Introduction

1.1 Connected Vehicle Research

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

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

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

1.2 The Transit V2I Research Program

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

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

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

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

Objectives: Use V2I technology:

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

A successful Transit V2I Program will lead to the more rapid and cost-effective deployment of interoperable technologies and applications that improve transit safety and enhance mobility for transit vehicles. The Transit V2I Program will act to promote the highest levels of collaboration and cooperation in the research and development of V2I applications for connected vehicles. The Transit V2I Program positions the federal government to take on an appropriate and influential role as a technology steward for a continually evolving integrated transportation system.

1.3 Document Overview

The purpose of this report is to summarize the process and outcomes of the Transit V2I Assessment Study. It also serves to build consensus among transit user groups and stakeholders concerning the applications discussed herein. Finally, this report should act as a guideline moving forward with research and development of any part of the Transit V2I Program.

This project report includes the following chapters:

- **Chapter 1** provides the scope and introduction to the Transit V2I Program, and an overview of the document.
- **Chapter 2** includes an overview of transit collisions and the role of the Transit V2I Program to mitigate these collisions. Included are statistics of motor bus collisions, injuries, and fatalities from the 2010 National Transit Database (NTD).
- **Chapter 3** provides a summary of the literature review conducted as part of this project. The review focused on three main areas of research: connected vehicle core research, multi-modal connected vehicle research, and transit-focused ITS and connected vehicle research.
- **Chapter 4** describes the stakeholder engagement process used to identify a set of potential applications for prioritization. This chapter also includes the individuals that participated in the three stakeholder engagement events. Lastly, this chapter includes an overview of near term Transit V2I applications that were considered by the USDOT.
- **Chapter 5** outlines the application prioritization process used to narrow the focus from twelve potential applications to four applications for concept development (operational concepts) and then the selection of two of these applications for development and testing.
- **Chapter 6** provides brief descriptions of the four applications selected for concept development.
- **Chapter 7** discusses infrastructure needs for the twelve potential applications.
- **Chapter 8** discusses conclusions reached, as well as next steps for the Transit V2I research program.
- **Appendix A** provides a list of acronyms used in this report.
- **Appendix B** provides a list of documents reviewed for the Literature Review.

2 Background

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

2.1 Transit Collisions Summary

In 2013, the Transit V2I Program completed a report entitled *Analysis of Collisions Involving Transit Vehicles and Applicability of Connected Vehicle Solutions* [1]. The report included a thorough analysis of transit collision characteristics. The report assisted the Transit V2I Program in determining whether and the extent to which connected vehicles could effectively reduce the number and severity of collisions that involve transit vehicles. The study analyzed transit collision datasets from the National Transit Database (NTD), which is the FTA's primary national database for statistics related to the transit industry. NTD data is used extensively by the transit community to derive values for transit performance measures and the NTD is the sole source of standardized and comprehensive data for use by all constituencies of the transit industry.

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

Table 2-1: NTD Transit Collisions Reported from 2005 through 2010 *(Source: NTD)*

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

Table 2-2: NTD Transit-Related Injuries Reported from 2005 through 2010 *(Source: NTD)*

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

Table 2-3: NTD Transit-Related Fatalities Reported from 2005 through 2010 *(Source: NTD)*

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

Table 2-4 breaks down 2010 NTD collisions by the object hit. Objects defined by the NTD include: motor vehicles, persons, fixed objects, rail vehicles, and 'other'. As shown in this table, in 2010 motor buses had 2,684 (83.2%) of collisions with motor vehicles, 451 (13.9%) with a person, 80 (2.4%) with a fixed object, and 10 (0.3%) with 'other'.

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

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

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

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

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

2.2 Transit Retrofit Package

In 2011, the USDOT JPO launched Transit Safety Retrofit Package (TRP) research and development activities with two primary goals in mind:

- First, to support participation of transit vehicles in the Model Deployment Phase of the Safety Pilot as a means to test overall compatibility and interoperability of transit vehicles with other light and heavy vehicles; and
- Second, to support future transit V2V and V2I Research and Development activities.

In January 2012, the USDOT awarded a contract to the Battelle team for TRP development, testing and support for transit participation in the Safety Pilot Model Deployment in Ann Arbor, Michigan. In its initial roll-out, the TRP was preloaded with the following basic safety applications (Battelle, 2012 [2]):

- **Curve Speed Warning (CSW).** CSW aids drivers in negotiating curves at appropriate speeds. This application will use information communicated from roadside beacons located ahead of approaching curves. The communicated information from roadside beacons would include curve location, curve speed limits, curvature, bank, and road surface condition. The device would determine, using other vehicle information, such as speed and acceleration whether the driver needs to be alerted. This application requires the ability to receive a message from the roadside unit (RSU) and is an example of Vehicle-to-Infrastructure / Infrastructure-to-Vehicle (V2I / I2V) technology.
- **Emergency Electronic Brake Light (EEBL).** The EEBL application enables a host vehicle to broadcast a self-generated emergency brake event to surrounding remote vehicles. Upon receiving such event information, the remote vehicle determines the relevance of the event and provides a warning to the driver if appropriate. This application

is an example of Vehicle-to-Vehicle (V2V) technology, and is particularly useful when the driver's line of sight is obstructed by other vehicles or bad weather conditions (e.g., fog, heavy rain).

- **Forward Collision Warning (FCW).** The FCW application is intended to warn the driver of the host vehicle in case of an impending rear-end collision with a remote vehicle ahead in traffic in the same lane and direction of travel. FCW is intended to help drivers in avoiding or mitigating rear-end vehicle collisions in the forward path of travel using Vehicle-to-Vehicle (V2V) technology.

Following the initial roll-out, the TRP was enhanced by incorporating two transit-specific safety applications:

- Pedestrian in Signalized Crosswalk Warning – PCW (V2I)
- Vehicle Turning Right in Front of Bus Warning – VTRW (V2V)

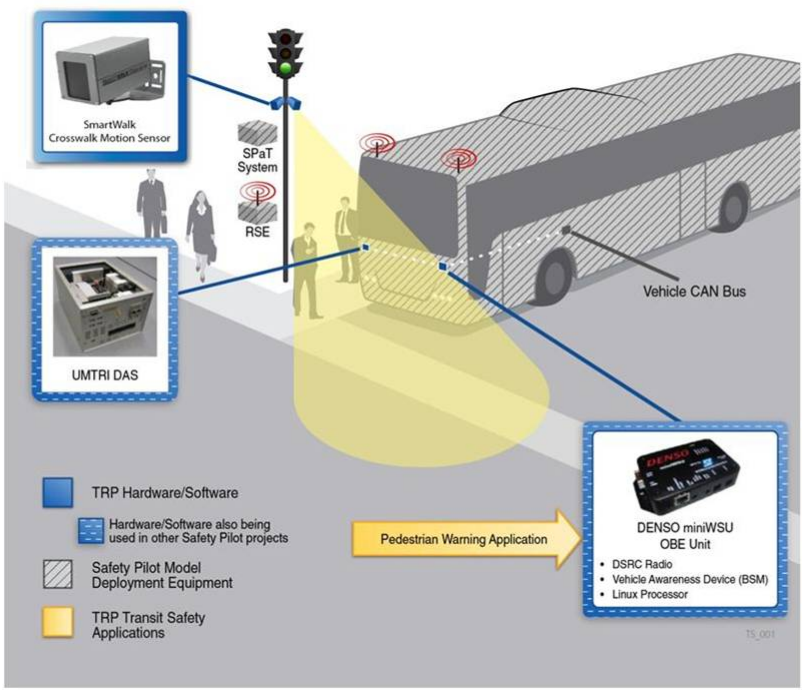

Figure 2-1: Pedestrian in Signalized Crosswalk Warning *(Source: USDOT, 2012)*

Pedestrian in Signalized Crosswalk Warning – PCW

This V2I application is intended to mitigate the problem of transit vehicles hitting pedestrians while the transit vehicle is making either a right or left hand turn at a signalized intersection. This problem occurs when transit vehicles, turning at a signalized intersection, fail to recognize pedestrians' presence in the roadway for a variety of reasons. For example, during evening hours or inclement weather, pedestrians may be difficult for transit drivers to see, especially when pedestrians are wearing dark clothing. Another situation is when pedestrians are crossing the street at a speed in conjunction with the turning speed of the transit vehicle. This creates a situation where the pedestrian can remain obscured from the driver's view for a period of time by the column in the transit vehicle that supports the windshield. A final example is when a pedestrian is obscured by oncoming vehicles. When these vehicles pass, and the transit vehicle begins turning, the transit vehicle driver may not see the pedestrian.

Vehicle Turning Right in Front of Bus Warning – VTRW

This V2V application is intended to mitigate the problem of crashes between transit vehicles and other vehicles (remote vehicles) occurring when the remote vehicle turns right in front of a transit vehicle as it leaves a bus stop. This situation occurs when a bus stop is located prior to an intersection and the transit vehicle is stopped in the right lane. A remote vehicle traveling behind the transit vehicle—and planning to turn right at the intersection—is unsure of the transit vehicle's dwell time. As a result, the remote vehicle passes the transit vehicle on the left. After passing the transit vehicle, the remote vehicle immediately makes a right hand turn in front of the transit vehicle. If the transit vehicle is pulling away from the bus stop at the same time the remote vehicle is turning right at the intersection, there is potential for a collision.

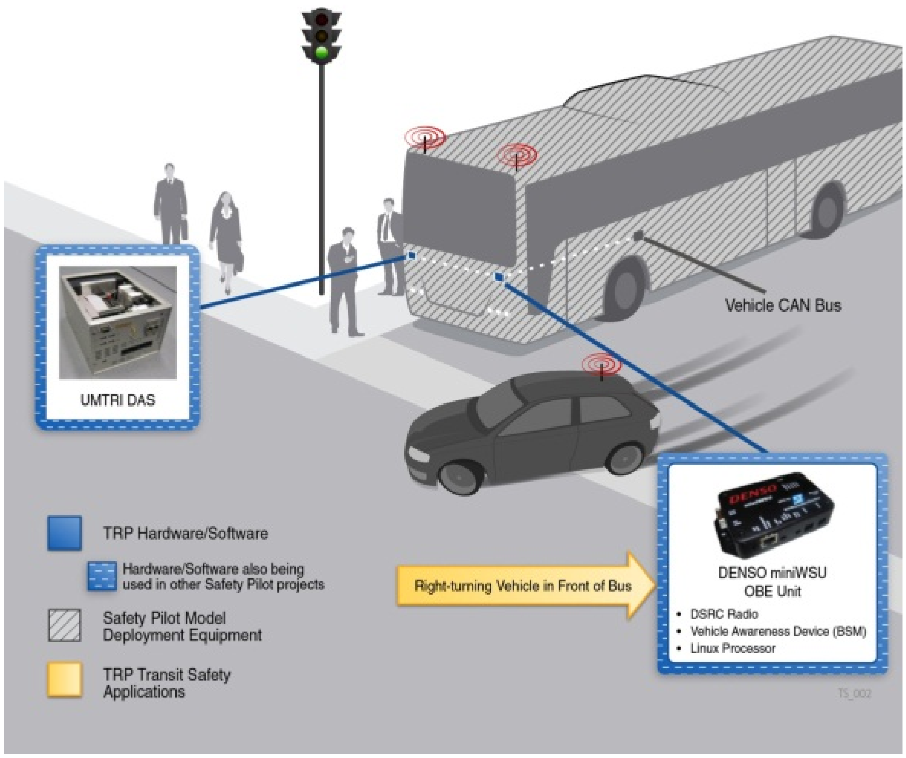

Figure 2-2: Vehicle Turning Right in Front of Bus Warning *(Source: USDOT, 2012)*

The assessment of TRP performance and user acceptance used in the Safety Pilot Model Deployment, developed by an independent evaluation team led by Volpe, the National Transportation Systems Center, is available at the National Transit Library (JPO-14-175, February 2014).

This field test utilized two rounds of operational use, with the second round coming after revisions to the application were made based on data analysis and feedback from the bus drivers using the system. The TRP project report is available at the National Transportation Library (FHWA-JPO-14-142).

3 Literature Review

3.1 Connected Vehicle Research

The scope of connected vehicle research encompasses different vehicle platforms and applications areas. For the purpose of this Transit V2I Assessment Study literature review activity, the research team identified and focused its search and review on three categories of literature: connected vehicle core research, multi-modal connected vehicle research, and transit-focused ITS and connected vehicle research. A complete list of documents reviewed can be found in Appendix B.

Connected Vehicle Core Research

This category mainly includes research that establishes the framework and/or defines the boundary of the connected vehicle environment. Examples include *Connected Vehicle Core System Concept of Operations (ConOps)* (USDOT, 2011) [A.1], *AASHTO Connected Vehicle Infrastructure Deployment Analysis* (USDOT, 2011) [A.4], and the *National ITS Architecture* (USDOT, 2015) [A.7].

Multi-modal Connected Vehicle Research

This category consists of literature from multi-modal connected vehicle research that is not transit specific. This literature is included in the review because its research outcomes may shed light on possible transit adaptation, such as the *Smart Roadside ConOps* (USDOT, 2012) [B.6] developed for commercial vehicles. The category also includes literature from intermodal research efforts in which transit plays a substantial role, such as the Applications for the Environment: Real-Time Information Synthesis (AERIS) Programs related research.

Transit-focused ITS and Connected Vehicle Research

This category focuses on general ITS and connected vehicle research that is transit-oriented and produces outcomes with direct transit implications. Examples of literature in the category include *Transit Safety Retrofit Package ConOps* (USDOT, 2012) [C.5] and *Transit Vehicle Collision Characteristics for Connected Vehicle Applications Research* (USDOT, 2013) [C.4].

Figure 3-1 illustrates these three literature categories and their relationships. The full list of documents reviewed as part of this task is provided at the end of this report in Appendix B. The Noblis Team recognizes that there is some literature with scopes across multiple categories. For instance, the *Assessment of the Use of Light Vehicle Safety Applications for Transit* (USDOT, 2012) [C.10] report discussed light vehicle safety applications and explored their respective transit applicability. It could be both a "Multi-modal Connected Vehicle Research", as well as a "Transit-focused ITS Transit and Connected Vehicle Research." For the purpose of this study, this report is categorized as the latter, as the Noblis Team reviewed this document primarily from the transit perspective.

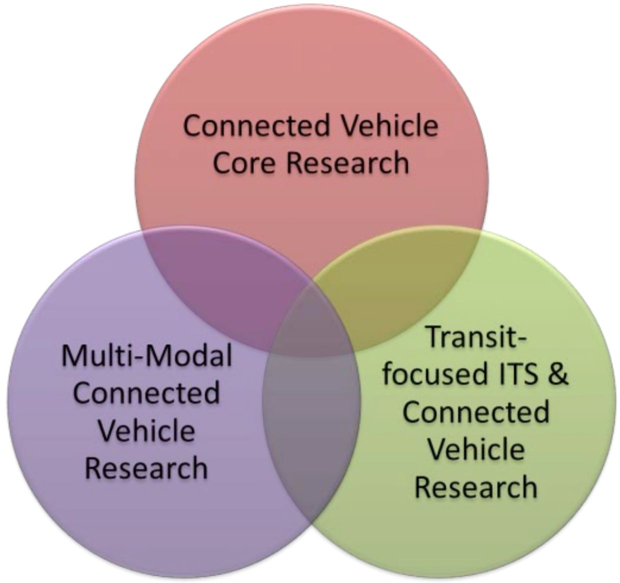

Figure 3-1: Literature Categories

3.2 Observations

In addition to delivering a technical memorandum summarizing the literature review results, the research team also provided the following observations and recommendations for sharing and consideration in the planning and execution of follow up project activities.

Observation #1: Detailed analysis of transit bus collisions by Noblis using 2010 NTD indicated the need for safety applications in regards to transit vehicle conflicts with: **pedestrians at intersections or near bus stops**, **other motor vehicles near bus stops**, and **other motor vehicles at intersections** (especially red-light violation, angle and left-turn head-on crashes). Some applications currently under development and testing for light vehicles, both V2I and V2V, such as Red-Light Violation Warning (RLVW) under V2I, and Left Turn Assist (LTA) and Intersection Movement Assist (IMA) under V2V may directly correspond to meeting those safety concerns.

Recommendation: More proactively and selectively participate in certain safety R&D efforts, but only focus on applications that align with transit strategic priorities, such as RLVW, LTA, and IMA. In addition, the concept of Pedestrian Mobility, an application in the Multi-Modal Intelligent Traffic Signal Systems (MMITSS) mobility application bundle, may shed some light on how V2I capability may be leveraged to mitigate collisions involving transit vehicles and pedestrians.

Observation #2: Generally, there was a lack of research and literature pertaining to connected vehicle safety applications developed for demand response transit service. It is unclear whether this is because the work being done for light vehicles is generally comprehensive enough and applicable to the demand response vehicles or if there is a gap in the existing safety research in regards to demand response vehicles.

Recommendations - Incorporate demand response service in safety discussions during stakeholder meetings/webinars and determine whether unique V2I needs and opportunities exist for demand response services.

Observation #3: Many of the ITS Transit technologies that have transferability to the Connected Vehicle program have a mobility focus, rather than a safety focus. For instance, the Integrated Dynamic Transit Operations (IDTO) and the Enabling Advanced Traveler Information Services (Enable ATIS) Dynamic Mobility Applications (DMA) bundles are intended to empower travelers by providing real-time traveler information and tools to facilitate a more positive travel experience. The Transit Signal Priority (TSP) application of the Multimodal Intelligent Traffic Signal System (MITSS) bundle, which was mentioned most frequently in the literature reviewed for this report, is also a mobility-focused application.

Recommendation- Stakeholders will be more familiar with these ITS technologies, which may lead them to brainstorm more mobility ideas than safety ideas. It may be pertinent to point out some of the existing connected vehicle applications ahead of time in order to steer the group away from focusing too heavily on mobility.

Observation #4: While not specifically transit, motorcoach vehicles that are utilized by some transit agencies for commuter express routes could have similar operational challenges as experienced by inter-city transit bus service providers. Motorcoach vehicles are regulated by the Federal Motor Carrier Safety Administration (FMCSA) and are generally not included with transit research.

Recommendation- Coordination with FMCSA may be necessary in order to ensure that any transit-related needs for connected vehicles are being met for the motorcoach vehicles. Literature relating to FMCSA connected vehicle activities may need to be examined at a later date.

4 Stakeholder Participation & Brainstorming of Candidate Applications

In addition to the literature review and the 2010 NTD Collision Analysis report, the USDOT wanted to ensure that any Transit V2I applications it may pursue after the TRP were vetted through stakeholders and used that group to help brainstorm concepts for potential applications based on their practical experiences. Stakeholder input was gathered through their participation in at least one of three meetings (one in-person and two webinar meetings) hosted by USDOT representatives, which are described below in Section 4.2.

4.1 Goals of Stakeholder Participation

The goals of stakeholder participation were as follows:

- Define the vision and goals for the Transit V2I program.
- Identify critical Transit V2I concepts.
- Identify challenges that could be faced in meeting the Transit V2I vision.
- Provide input into USDOT prioritization process.

4.2 Meetings

4.2.1 Face-to-Face

The face-to-face meeting was held on July 9, 2013 in Washington, D.C. The meeting was a full day at the Noblis site office.

4.2.1.1 Discussion

The meeting was facilitated by Carol Schweiger (TranSystems) and included an introduction and connected vehicle overview by Steven Mortensen (FTA). Visions were developed for Safety, Mobility, and Environment (presented in Section 4.2.2). Participants were then asked to brainstorm critical concepts, challenges to implementation, and potential solutions to those challenges.

Participants identified key safety-related considerations, as follows:

- There are two types of crashes: preventable (operator error) and non-preventable.
- Using infrastructure monitoring (smart intersection) to develop shared situational awareness.
- Of the eight light vehicle V2I safety applications being researched by FHWA, they found those that addressed intersection crashes, spot weather and curve speeds to be the most applicable to transit.

- Connected vehicle technologies could be applied to yard activities to reduce the number of clipped mirrors and maximize yard space utilization.
- Use of "temporary" infrastructure could help transit vehicles maneuver more safely in temporary situations, such as work zones, where lanes are narrowed or there is compromised sight distance.
- It is imperative to ensure that the alerts received by the driver are not distracting and are helpful with preventing crashes.
- Incentives should be developed to encourage drivers to rely on their own skills primarily and only secondarily on the alerts.

Participants identified key mobility-related considerations, as follows:

- A richer interaction between infrastructure and vehicles could lead to an adaptive transit signal priority, rather than a simple yes or no to a priority request. Passenger loads could be used as an input to determine priority instead of simply using schedule adherence.
- Being able to associate a passenger with a vehicle could provide benefits including protected scheduled connections and en-route information that provides status updates and possible itinerary changes based on O-D and information about trip times (akin to dynamic routing in personal vehicles based on traffic data).
- Dynamic scheduling for transit operations.
- Temporary infrastructure broadcasting information for incidents, construction and special events (e.g., "smart" barricades or detours).

Participants identified key environment-related considerations, as follows:

- Using transit vehicles as environmental probes, capturing data on environmental conditions and passing that information back to the Traffic Management Center (TMC) via infrastructure. Deploying this now could allow for "before" measurements to be taken so that benefits of future policies could be better quantified.
- Use of topographical information combined with congestion data to provide more environmentally friendly routing for transit (and freight) vehicles. Similar to factors already taken into account in freight rail.
- Existing performance measures will need to adapt based on changes in fuel choices.
- Guidance to light vehicles for peripheral parking and transit connections should be provided.

Participants identified three areas of challenges: internal, technology, and federal-level.

- Internal Challenges:
  - Articulating the return-on-investment/value to those in charge of funding and investment decisions is difficult because of risk exposure with technologies that are unproven.
  - Every new investment involves negotiations with unionized employees, which can slow deployment or can make it not worth the investment.
  - Questions about connected vehicle deployment's effect on insurance is a major sticking point.
  - Many agencies do not have enough (or properly trained) staff to manage large procurements, which can lead to issues with contractors later on.

  - Benefits from using technology are not often visible until operations staff makes a change to vehicle schedules or staffing.
  - Maintaining these devices is difficult because they need to be monitored and repaired/rebooted in the field and Connected Vehicle (CV) equipment “ownership” issues may lead to conflicts.
  - Better planning and needs assessments are needed from the outset.

- Technology Challenges:
  - Most agencies have insufficient computing power to manage large databases and manipulate those large datasets for analysis.
  - Vendor-related challenges such as limited choices, vendor lock-in, and buying functionality which those agencies do not need.
  - The procurement process has a much longer lifecycle than the pace of technological innovation.
  - Need to manage both the physical security of the deployed technologies, as well as the information (communications & stored data).
  - Some municipal information technology (IT) departments treat connected infrastructure technologies the same as desktop PCs, which leads to firewall and interoperability problems.

- Federal-level Challenges:
  - Funding from piecemeal federal and state grants leads to incomplete or unlinked systems.
  - Different requirements between FTA and FHWA (e.g. Buy America) can lead to issues with multi-modal projects.
  - Each transit agency tends to view itself as unique, which makes it more difficult for “off the shelf” solution development and lengthens procurement time because of need to meet the written specifications. (Agencies present acknowledged that they are more similar than different, but feel there is a place for federal guidance to make that push on a national scale.)
  - Lack of federal guidance on focusing on optimizing for the entire transportation system vs. individual/vehicle optimization.

4.2.1.2 Participants

- Jeff Becker, Regional Transportation District (RTD), Denver
- Jan Black, Ann Arbor Transportation Authority (AATA)
- Ron Boenau, FTA
- James Dreisbach-Towle, San Diego Association of Governments (SANDAG)
- Bruce Edwards, Fairfax County
- Mike Haddad, Charlotte Area Transit System (CATS)
- Amy Jacobi, Noblis
- David Krulewitch, New York City Transit
- Gabriel Lopez-Bernal, TranSystems
- Steven Mortensen, FTA
- Raymond Mui, Alexandria DASH
- Carol Schweiger, TranSystems
- Nazy Sobhi – USDOT/Volpe Center

- John Toone, King County Metro
- Gwo-Wei Torng, Noblis
- Christie Wegener, Fairfax County
- Steve Yaffe, Arlington Transit (ART)

4.2.2 Webinar #1

Webinar #1 was conducted on August 12, 2013 for two hours. The meeting was facilitated by Carol Schweiger. This meeting was used as a follow on to the July face-to-face meeting, sharing the vision statements generated during the previous meeting with a larger group of transit stakeholders.

4.2.2.1 Discussion

Carol Schweiger and Steven Mortensen presented an abridged version of the introduction and background materials presented at the July meeting.

Carol Schweiger presented the V2I vision statements that were developed at the face-to-face stakeholder meeting in July (provided below). There was no objection from the group to the vision statements presented.

- **Safety Vision**: Use V2I technology to prevent, reduce or mitigate personal injury and loss of property
- **Mobility Vision**: Use V2I technology to:
  - Maximize the number of person trips and access to transportation
  - Optimize the effectiveness and efficiency of public transportation operations
  - Improve traveler decision-making and access to transportation information
- **Environmental Vision**: Use V2I technology to:
  - Reduce transportations environmental impacts and maximize the benefits
  - Quantify the transportation environmental impacts and benefits

Participants identified the additional key safety-related considerations, as follows:

- User safety at bus stops and stations (in addition to vehicle safety)
- Environmental hazards at stops/shelters
- Monitoring the securement of passengers in wheelchairs
- Data mining position data from transit vehicles to provide beacon information as a supplement to V2I/V2V messages
- Smartphone “Here I Am” for pedestrians
- Reiterated the need for a bike/pedestrian warning - Stops that are not on the curb (such as streetcars) have issues with doors opening into cyclists

Participants identified the additional key mobility-related considerations, as follows:

- Communication of approaching bus information for ADA (Americans with Disabilities Act) passengers
- Bike slot availability information available in advance to cyclists that transfer to transit vehicles, which could be similarly applied to wheelchair spots
- Utilizing V2I as a means for improved wayfinding, particularly at large transfer stations and bus hubs

- Fare payment information more easily available to customers, particularly those with disabilities
- Use of V2I to help reduce the occurrence of bus bunching
- Use of sensing at bus stops to alert agency to an atypical surge of passengers at a stop which could cause bunching and overcrowding of vehicles
- Spot weather information provided to passengers that may affect their choice of transfer location

Participants identified the additional key environment-related considerations, as follows:

- Approach assist for “green” approaches to intersections based on vehicle characteristics
- Variable pricing to incentivize transit use
- Free transit parking on “spare the air” days
- Improved information sharing between transit agencies and TMCs

4.2.2.2 Participants

- Stephen Abbanat, Metropolitan Transportation Commission (MTC)
- Greg Davis, USDOT FHWA
- Jim Davis, King County DOT
- James Dreisbach-Towle, San Diego Association of Governments (SANDAG)
- Barry Einsing, Cisco Systems
- Brendon Hemily, Consultant/ITS America
- Amy Jacobi, Noblis
- Doug Jamison, Central Florida Regional Transportation Authority (LYNX)
- TJ Khan, Suburban Bus Division (Pace)
- Greg Larson, California DOT (Caltrans)
- Gabriel Lopez-Bernal, TranSystems
- Bradley Mizuno, California DOT (Caltrans)
- Steven Mortensen, USDOT FTA
- Siva Narla, Institute of Transportation Engineers (ITE)
- Lou Sanders, American Public Transportation Association (APTA)
- Reuben Sarkar, US Department of Energy
- Carol Schwieger, TranSystems
- Nazy Sobhi, USDOT Volpe Center
- Sonja Sun, California DOT (Caltrans)
- Ken Thompson, Easter Seals Project Action (ESPA)
- John Toone, King County DOT Metro Transit Division (King County Metro)
- Derek Toups, Metropolitan Transportation Commission (MTC)
- Chris Zeilinger, Community Transportation Association of America (CTAA)

4.2.3 Webinar #2

This final webinar was held on October 9, 2013 for one hour. Nazy Sobhi from the USDOT provided an introduction, an overview of the two previous stakeholder meetings, and the purpose for webinar #2. Webinar #2 was facilitated by Carol Schweiger (TranSystems) and Gwo-Wei Torng (Noblis). This meeting was used to solicit stakeholder input on the prioritization of application concepts developed based on the discussions from the July and August stakeholder meetings.

4.2.3.1 Discussion

Carol Schweiger reviewed and led the discussion on each of the 12 transit V2I applications as described below, in Section 4.3. A summary of these 12 applications was distributed to all webinar participants in advance for review along with Figure 4-1. The 12 applications include nine (9) safety-oriented applications, two (2) mobility-oriented applications, and one (1) application related to “portable” roadside equipment.

Figure 4-1: Transit V2I Applications *(Source: USDOT, 2015)*

Webinar participants raised a few questions/comments in the “Chat” windows during the discussion of candidate transit V2I applications. These questions/comments were responded to by Carol Schweiger and/or Gwo-Wei Torng (GWT) of Noblis as appropriate. These include:

- On one hand, safety warnings/alerts shall not interfere/distract/overload transit drivers. On the other hand, these warnings/alerts shall also not infuse a false sense of safety so that transit drivers pay less attention on traffic than they would otherwise do.
- Is rail grade-crossing considered in the angle crash applications? [GWT responded that USDOT is planning a study that focuses specifically on light rail grade-crossing safety issues.]
- 3D application requires the ability to recognize/distinguish spatial configurations in both at-grade, and overpass/underpass situations.
- Is transit vehicle crossing-over adjacent bike path when approaching/leaving a bus stop (or turning right) considered as a use case in the transit crossing warning application?

[GWT responded that this particular scenario may be more suited for the transit stop/station pedestrian safety application.]

The remainder of the webinar was the prioritization exercise, discussed in detail in Section 5.2.

4.2.3.2 Participants

- Jeff Becker, Denver Regional Transportation District (RTD)
- Jan Black, Ann Arbor Transportation Authority (AATA)
- Patrick Chan, Consensus Systems Technologies Corporation (ConSysTec)
- David Crout, Tri-County Transportation District of Oregon (TriMet)
- James Dreisbach-Towle, San Diego Association of Governments (SANDAG)
- Ravi Gundimeda, Dallas Area Rapid Transit (DART)
- Brendon Hemily, Consultant / ITS America
- Amy Jacobi, Noblis
- Doug Jamison, Central Florida Regional Transportation Authority (LYNX)
- TJ Khan, Suburban Bus Division (Pace)
- Gabriel Lopez-Bernal, TranSystems
- Lou Sanders, American Public Transportation Association (APTA)
- Carol Schweiger, TranSystems
- Nazy Sobhi, USDOT Volpe Center
- Sonja Sun, California DOT (Caltrans)
- Gwo-Wei Torng, Noblis
- Steve Yaffe, Arlington Transit (ART)
- Chris Zeilinger, Community Transportation Association of America (CTAA)

4.3 Transit V2I Program Near-Term Applications

Through the brainstorming process during the face-to-face meeting and first webinar, the Transit V2I Program identified twelve near term candidate applications that have the potential to maximize safety, mobility, and environmental benefits. The applications are depicted in Figure 4-1 and summarized below. Red icons indicate applications with the potential to impact safety, blue icons are related to mobility and the environment, and orange icons are crosscutting applications. The names of some of the applications have been updated since the prioritization process. The bolded names in the text below are the official application names. When the name of an application has been changed, the former name used in the prioritization process (discussed in Section 5), has also been identified.

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

that assists drivers in avoiding crashes at intersections by alerting the vehicle driver that a stop sign violation is predicted to occur. An equipped vehicle approaching an equipped intersection receives messages about the intersection geometry and if necessary, position correction information. The driver is issued an alert if the vehicle processing platform determines that, given current operating conditions, the driver is predicted to violate the stop sign.

- **Left-Turn Assist (Left-turn Head-on Crashes at Intersections with Permissive Left-turn Phase).** The Left Turn Assist (LTA) application provides information to drivers performing unprotected left turns to judge the gaps in oncoming traffic and to warn them when it is unsafe to perform a left turn on a permissive green light. While this application may be supported using V2V communications where vehicles exchange information about their location, speed, trajectories, and other vehicles at the intersection, it may also leverage V2I communications such as SPaT, intersection map data, and infrastructure based vehicle and pedestrian detectors. The purpose of the application is to provide information to support the driver's decision making process regarding when it is unsafe to make a left turn at an intersection (i.e., gap rejection), but not make the decision for the driver. In other words, the LTA application does not tell the driver when it is safe to proceed, but assists with rejecting gaps that are unsafe.
- **Stop Sign Gap Assist.** The Stop Sign Gap Assist (SSGA) application provides the vehicle operator with timely, relevant information regarding unsafe traffic gaps at a stop-controlled intersection. The SSGA safety application is intended to improve safety at two-way stop controlled intersections where only the minor road has posted stop signs. This application includes both onboard (for equipped vehicles) and roadside signage warning systems (for non-equipped vehicles). The purpose of the application is to provide information to support the driver's decision making process regarding when it is unsafe to proceed through the intersection (i.e., gap rejection), but not make the decision for the driver. In other words, the SSGA application does not tell the driver when it is safe to proceed, but assists with rejecting gaps that are unsafe.
- **Spot Weather Information Warning** *(formerly Spot Weather Safety)***.** The Spot Weather Information Warning (SWIW) application is intended to improve safety in areas subject to repeated and localized adverse or inclement weather events, which may include relatively high-elevation or low-elevation areas that are more prone to reduced visibility, adverse surface conditions due to rain, snow, ice, and/or flooding, and high winds. This will be achieved through the integration of both vehicle-based and infrastructure-based technologies as well as backhaul networks to weather and TMCs, including onboard and roadside signage warning systems, to make drivers approaching an area with adverse weather conditions aware of the need to reduce speed or divert to safely navigate through or avoid the adverse weather impact area. This is not an application that is intended to provide the driver with weather information at every geographic location, but rather provide real time weather information at areas that are prone to adverse weather events, such as low-lying flood zones and bridges with high winds which may impose restrictions on high-profile vehicles. In this way, the SWIW application will help to increase driver awareness of the severity of hazardous weather conditions, reducing the risk potential for conflicts and crashes.
- **Transit Bus - Pedestrian/Cyclist Crossing Warning** *(formerly Transit Vehicle-Pedestrian/Cyclist Crossing Warning)***.** This application provides alerts to transit bus drivers of a pedestrian's or cyclist's presence while they are crossing the roadway at intersections and midblock crossings, using V2I wireless communications. When a pedestrian or cyclist is detected via the infrastructure, an RSU would send a message to nearby buses that a pedestrian or cyclist is in or may be entering the roadway. The application would provide alerts to bus drivers for all bus movements (left, right, and straight) at infrastructure-equipped

signalized and non-signalized intersections and at midblock crossings when imminent conflicts with pedestrians and bicyclists are possible.

- **3D Intersection Mapping for Collision Avoidance and Situational Awareness.** This 3D Mapping application enables an RSU to rapidly recognize/update intersection configurations in 3D (latitude, longitude and elevation), including fixed objects such as signal cabinets and light poles. This 3D intersection configuration information embedded in the RSU will support V2I safety applications to mitigate single vehicle crashes.
- **Transit Bus Stop Pedestrian Safety** *(formerly Transit Stop/Station Pedestrian Safety)***.** The application, using V2I wireless communications, would provide alerts to pedestrians, via infrastructure (e.g., electronic signage with audible warnings), at major bus stops (e.g., those equipped with bus shelters serving multiple bus routes) indicating a transit bus' intention of pulling into or out of a bus stop. In certain situations and locations, the application may also alert pedestrians of motor vehicles in the vicinity of the bus stop, specifically alerting passengers alighting buses at the stop to address potential collisions of pedestrians with motor vehicles, whose sight are blocked by the bus.
- **Reduced Speed Zone Warning** *(formerly Transit Speed Zone Safety)***.** The Reduced Speed Zone Warning (RSZW) safety application features the concept of reduced speed zone where a reduction in transit approaching speed is required and/or advised, such as entrance to work zones, school zones, and roadway configuration alteration (e.g., lane closures, lane shifts). This will be achieved through the integration of both vehicle-based and infrastructure-based technologies, including onboard and roadside signage warning systems.
- **Transit Vehicle and Center Data Exchange.** Modern transit buses are equipped to collect/process data on transit vehicles (such as engine health monitoring) as well as the surrounding environment such as external facing digital cameras. This Transit Vehicle and Center Data Exchange application allows the authorized entities (such as traffic management centers, fire and emergency medical services [EMS], and Transit Management Centers) see what is happening at a location such as non-recurring congestion due to a crash or disabled vehicle by pinging an infrastructure point to request the next transit vehicle or vehicles passing the point to provide a snapshot of requested information, such as a short video. The bus could then capture a geo-referenced visual and upload at the next access point.
- **Transit Traveler Information Infrastructure** *(formerly Traveler-Oriented Integrated Infrastructure Information)***.** The Transit Traveler Information Infrastructure application allows transit vehicles and travelers to be connected to nearby infrastructure, such as a smart intersection, smart bus stop, and smart parking. For example, transit vehicles would communicate with transit stops to provide travelers information on approaching vehicles, such as passenger loads, available disability seating, bicycle rack availability, fare information, etc. The application would support dynamic trip planning at transit stops.
- **Portable Infrastructure.** This transit V2I application features the concept of portable infrastructure such as portable RSUs and signage which may be used to handle special events (i.e., surging demand) at strategic locations, such as bus depots and light rail platforms to perform dynamic information collection/dissemination such as added buses or routes or assist transit vehicle maneuvers and detours.

5 Application Prioritization

After the twelve applications were identified through stakeholder participation, the literature review, and the collision analysis, the applications needed to be prioritized in order to determine which would be pursued by USDOT. Stakeholders and USDOT program managers participated in prioritization exercises in order to determine which applications best aligned with both industry needs and USDOT strategic goals. As noted in Section 4.3, some of the applications were renamed after the prioritization process. All Applications described below will be identified by the original names that were used during this approach.

5.1 Prioritization Approach

The Transit V2I team developed two methods described below for identifying and ranking applications. After some internal discussion, the Transit V2I team decided to use a combination of Method #1 and Method #2 with multiple rounds of voting for the purpose of conducting this stakeholder prioritization exercise through a webinar (Webinar #2).

> **Method #1: Identifying Preferred Applications.** Stakeholders select a handful of applications (number to be specified by USDOT representative) out of a field of twelve initial applications. This does not show ordinal preference for any application over another. This question will show if there are any applications that are *not* a priority for any of the stakeholders. This process can be repeated multiple times, including changing the number of applications the stakeholders are allowed to select.

> **Method #2: Ranking Applications.** Stakeholders rank applications based on their view of the order in which applications should be moved forward for near-term research and development. This can be done in two ways: Stakeholders can be forced to rank all applications, or they can be allowed to not rank applications that they think are not worth further consideration.

The Team ultimately decided that the overall prioritization would be carried out in two rounds: the “Selection” Round (i.e., Round 1), followed by the “Prioritization” Round (i.e., Round 2). For the “Selection” Round, the Team would use Method #1 – Identifying Preferred Applications and requested that each participating organization identify up to five among the pool of twelve transit V2I applications for further discussion. Upon reviewing the “Selection” Round results, the USDOT representative would determine which applications were to advance to the next round, and which applications would be eliminated from further consideration.

In the “Prioritization” Round, each participating organization would rank the remaining applications advancing from the “Selection” Round. For the “Prioritization” Round, the Team used Method #2 – *Ranking Applications* and prompted each participating organization to rank their top five transit V2I applications in the order of 1 through 5 (descending order with 1 being the highest priority) from the reduced pool of applications.

The Team used an online survey tool to conduct the webinar prioritization with the stakeholders due to the availability of multiple question types and ability to direct the way participants ranked applications.

5.2 Stakeholder Prioritization

5.2.1 Selection Round (Round 1)

To execute the Round 1 survey, the Team posted a link in the WebEx "Chat" window during Webinar #2 (see 4.2.3). The link took participants to the survey that allowed each organization (one survey response per organization) to select its top five priorities for the applications. The Team presented the Round 1 results, as shown in Table 5-1, to all participants after all non-USDOT participants submitted input. Upon reviewing the first round voting outcomes, the USDOT representative made the decision to eliminate the bottom three applications which received one vote each. As a result, nine applications moved forward to the next round.

Table 5-1: Summary of Round 1 Voting Results

Round 1 Transit V2I Application	# of Participants Selected as Top 5 Choices	% of Participants selecting application in their Top 5	Note
Red Light Violation Warning	9	75.0%	Advance to Round 2
Transit Vehicle - Pedestrian/Cyclist Crossing Warning	9	75.0%	Advance to Round 2
Transit Vehicle and Center Data Exchange	8	66.7%	Advance to Round 2
Transit Stop/Station Pedestrian Safety	7	58.3%	Advance to Round 2
Traveler-Oriented Integrated Infrastructure Information	7	58.3%	Advance to Round 2
Stop Sign Violation Warning	6	50%	Advance to Round 2
3D Intersection Mapping for Collision Avoidance and Situational Awareness	4	33.3%	Advance to Round 2
Left-Turn Assist	3	25%	Advance to Round 2
Stop Sign Gap Assist	2	16.7%	Advance to Round 2
~~Spot Weather Safety~~	~~1~~	~~8.3%~~	~~*Eliminated*~~
~~Transit Speed Zone Safety~~	~~1~~	~~8.3%~~	~~*Eliminated*~~
~~Portable Infrastructure~~	~~1~~	~~8.3%~~	~~*Eliminated*~~

5.2.2 Prioritization Round (Round 2)

For the second round, the Team posted a different link in the WebEx "Chat" window for Webinar #2, which took participants to the Round 2 survey. The survey prompted each organization to rank its top priorities for the applications. Each organization was encouraged to rank up to five applications.

In Table 5-2, the number of votes reflects the total number of participants who selected that particular application as their highest priority (#1 Priority) through their fifth most important priority (#5 Priority). To obtain an aggregated indication of stakeholder priorities, the Team converted the distribution of votes into a composite score with respect to each candidate transit V2I application. The composite score for each application is defined as follows:

Composite Score = 5 x (# of 1st priority votes) + 4 x (# of 2nd priority votes) + 3 x (# of 3rd priority votes) + 2 x (# of 4th priority votes) + 1 x (# of 5th priority votes)

Figure 5-1 displays the composite scores by candidate transit V2I application.

Table 5-2: Summary of Round 2 Voting Results

Round 2 Transit V2I Application	#1 Priority Pick	#2 Priority Pick	#3 Priority Pick	#4 Priority Pick	#5 Priority Pick
Transit Vehicle - Pedestrian/Cyclist Crossing Warning	3	4	3	1	0
Transit Stop/Station Pedestrian Safety	4	2	1	0	1
Red Light Violation Warning	3	0	2	3	3
Transit Vehicle and Center Data Exchange	2	1	3	0	2
Traveler-Oriented Integrated Infrastructure Information	0	1	2	3	0
Left-Turn Assist	0	2	0	2	0
Stop Sign Violation Warning	0	1	0	2	2
3D Intersection Mapping for Collision Avoidance and Situational Awareness	0	1	0	0	3
Stop Sign Gap Assist	0	0	1	1	1

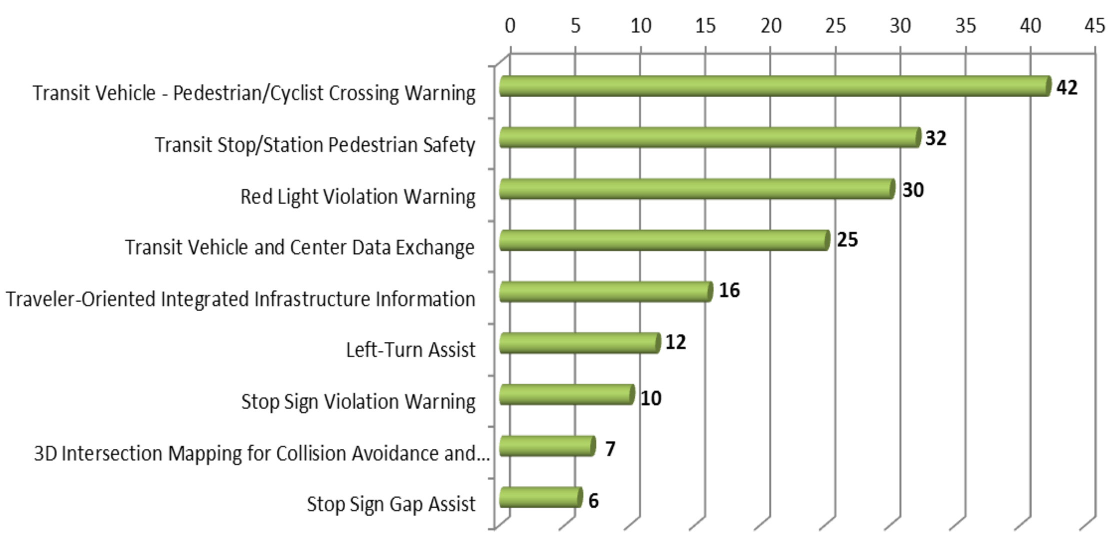

Figure 5-1: Composite Priority Score of Transit V2I Applications *(Source: USDOT, 2013)*

5.3 USDOT Prioritization

To discuss and select transit V2I applications for near-term prototype development and testing, the Transit V2I team convened a meeting on November 5, 2013 with a few key staff members from FTA, ITS JPO and FHWA.

The Transit V2I team focused the meeting discussion specifically on the top six applications as prioritized by the stakeholders (Figure 5-1). Meeting participants discussed the merits of each application based on its justification for selection and past/concurrent research activities, and opportunities for collaboration. Table 5-3 summarizes the consensus on the following course of action.

Table 5-3: Near-Term Transit V2I Applications - Recommended Course of Action

Action #	Transit V2I Application	Recommended Actions
1	*Transit Vehicle – Pedestrian/Cyclist Crossing Warning*	• Leverage/expand existing TRP functionality to include 1) all bus movements at intersection (left, right, straight), 2) all pedestrian crosswalks in intersection; 3) mid-block crossings; 4) cyclists on crosswalks, and 5) signalized and non-signalized intersections and mid-block crossings
2	*Transit Stop/Station Pedestrian Safety*	• Conduct new research
3	*Red Light Violation Warning*	Collaborate with existing research through one of the following three options: • Transit begins to participate in full capacity in current FHWA/RLVW research efforts • Transit reviews/modifies existing FHWA/RLVW ConOps and requirements designed for light vehicles and conducts its own prototype development and testing • Pursue as a V2V application by leveraging the IMA research. IMA is a V2V application where alerts are given to drivers as they begin to accelerate from rest into, or across, another road, to help the driver avoid crashes with crossing traffic.
4	*Transit Vehicle and Center Data Exchange*	Defer this application for future ICM research. No further action was recommended during the prioritization meeting.
5	*Traveler-Oriented Integrated Infrastructure Information*	A similar application is being developed in the Interactive Transit Station Information System (ITSIS) project sponsored by FTA. No further action was recommended during the prioritization meeting.
6	*Left-Turn Assist*	Initiate discussion and explore feasibility to collaborate with light vehicle LTA research. LTA is a V2V application where alerts are given to the driver as they attempt an unprotected left turn across traffic, to help them avoid crashes with opposite direction traffic.

5.4 Final Selections

FTA and the ITS JPO staff agreed to pursue the development and testing of operational concepts and prototypes for the first two transit V2I applications (Actions 1 and 2). It was decided that Intersection Movement Assist and Left-Turn Assist V2V applications would best address angle and left turn collisions at intersections (signalized and non-signalized). The development and testing of these V2V applications for transit may be pursued in the future.

Later in the process, FTA staff made the decision to also develop additional operational descriptions for two mobility applications: Transit Vehicle and Center Data Exchange and Transit Traveler Information Infrastructure (formerly Traveler-Oriented Integrated Infrastructure Information) (Actions 4 and 5).

6 Selected Applications

As described in Section 5, the prioritization process resulted in four applications being selected for further definition and/or development: Transit Bus - Pedestrian / Cyclist Crossing Safety Application; Transit Bus Stop Pedestrian Safety Application; Transit Vehicle and Center Data Exchange Application; and the Transit Traveler Information Infrastructure Application. As a result, an operational description was written for each of the four final applications and are published by the USDOT and available on the National Transit Library. Brief descriptions of the applications are included below.

6.1 Transit Bus – Pedestrian/Cyclist Crossing Safety Application

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

- Motor bus approaching a signalized intersection, traveling straight. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. Infrastructure sends a warning to the driver of a motor bus to alert them of a pedestrian in the roadway.
- Motor bus approaching a signalized intersection where it will be turning. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. Infrastructure sends a warning to the driver of a motor bus to alert them of a pedestrian in the roadway, potentially in the vehicle's path.
- Motor bus approaching an unsignalized intersection where it will be traveling straight. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. Infrastructure sends a warning to the driver of a motor bus to alert them of a pedestrian in the roadway, potentially in the vehicle's path.
- Motor bus approaching an unsignalized intersection where it will be turning. Pedestrian detection infrastructure detects the presence of a pedestrian in a crosswalk that the motor bus will be crossing. Infrastructure sends a warning to the driver of a motor bus to alert them of a pedestrian in the roadway, potentially in the vehicle's path.
- Motor bus traveling towards a mid-block pedestrian crossing. Pedestrian detection infrastructure detects the presence of a pedestrian in the crosswalk that the motor bus will be crossing. Infrastructure sends a warning to the driver of a motor bus to alert them of a pedestrian in the roadway, potentially in the vehicle's path.

The focus of this application is on safety for pedestrians and cyclists at crosswalks at signalized and unsignalized intersections, and mid-block crossings. While this application sounds similar to the Pedestrian Crossing Safety application in the TRP during the Safety Pilot Model Deployment, the intention is that this application builds upon the lessons learned and expands its application beyond TRP functionality of reducing conflicts while turning at signalized intersections.

This application will provide alerts to drivers for any of the four crosswalks (at a standard intersection). Additionally, it is intended to be able to be deployed at unsignalized intersections and mid-block crossings where pedestrians may be at risk.

This application's alert algorithm is intended to be more sophisticated than the TRP. The intention is that the pedestrian detectors for this field test would be able to better pinpoint the locations of pedestrians, with the algorithms only alerting drivers when collisions are imminent.

The Transit Bus-Pedestrian/Cyclist Crossing Safety Application Operational Concept is available at the National Transportation Library (FHWA-JPO-14-129).

6.2 Transit Bus Stop Pedestrian Safety Application

This application is intended to reduce the number of collisions between pedestrians and transit vehicles as the vehicles approach and depart transit stops, as well as improve the safety of alighting passengers who may be blocked from the line of sight of passenger vehicles by the transit vehicle.

The Transit Bus Stop Pedestrian Safety application will alert nearby pedestrians indicating the transit vehicle's intention of pulling into or out of a transit stop. The application allows messages to be sent from transit vehicles to instrumented transit stops that in turn provide audible or visual alerts to pedestrians in the vicinity of a transit stop. This application also intends to prevent conflicts with pedestrians, including alighting passengers, and surrounding motor vehicles whose drivers may not be able to see crossing pedestrians due to line of sight obstruction by the transit vehicle. This application differs from other transit applications because it not only provides alerts to the transit vehicle driver that there are passengers at the stop, but also alerts pedestrians to the approach or departure of the transit vehicle, so they can move themselves from harm's way. The Operational Concept discusses the following scenarios:

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

warn the driver via the Driver-Vehicle Interface (DVI) of a potential collision between the pedestrian and motor bus.

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

The Transit Bus Stop Pedestrian Safety Application Operational Concept is available at the National Transportation Library (FHWA-JPO-14-174).

6.3 Transit Vehicle and Center Data Exchange Application

The Transit Vehicle and Center Data Exchange application will allow for advanced communications and data transfer between a transit vehicle and centers (e.g., transit management/dispatch center, transit maintenance yard, traffic management center, and emergency management center). These communications will allow authorized personnel to utilize transit buses as remote, mobile infrastructure, capable of gathering and transmitting data regarding the transit vehicle and its surroundings to the data center and other connected vehicles. The application allows Traffic Management Centers (TMC), Emergency Management Centers (EMC), and Transit Dispatch Centers to obtain and disseminate transit vehicle data by “pinging” an infrastructure point to request the next transit vehicle or vehicles passing the point to provide a snapshot of requested information. In addition, a transit bus could simply transmit vehicle data each time a bus is within range of an RSU. Similarly, the application seeks to facilitate the communication necessary to support previously defined transit mobility applications, particularly those defined by the Integrated Dynamic Transit Operations (IDTO) bundle of applications. IDTO calls for advanced communications between the transit vehicles and a transportation management coordination center (TMCC) to develop mobility-oriented applications.

This application is designed to account for multiple Transit Vehicle and Center Data Exchange scenarios. The Operational Concept discusses the following three scenarios:

- Motor Bus Transmits Data to Support Mobility Applications and Real-Time Trip Planning. This scenario describes the transfer of real-time transit data to the TMC to support with the deployment of other mobility applications and with trip planning.
- Motor Bus Approaching Non-recurring Congestion due to an Incident or Collision. This scenario describes how a motor bus may serve as a mobile data collection unit (i.e., vehicle probe) for the TMC when a non-recurring event disrupts the flow of transit and traffic along connected corridors.
- Emergency Situation aboard or within Vicinity of Motor Bus. This scenario describes how a motor bus may serve as a mobile data collection unit for the TMC when an emergency situation aboard or within the immediate vicinity of a motor bus has prompted the driver to engage the emergency covert alarm.

The scenarios were developed to account primarily for their effects on mobility. For this particular application, corollary benefits may also include safety benefits gleaned from enhanced communication and coordination between transit service providers and regional or arterial TMCs.

The Transit Vehicle and Center Data Exchange Operational Concept is available at the National Transportation Library (FHWA-JPO-14-196).

6.4 Transit Traveler Information Infrastructure Application

The Transit Traveler Information Infrastructure application connects transit vehicles and travelers to nearby infrastructure, such as a smart bus stop, smart intersection and smart parking. For example, connected transit vehicles would communicate wirelessly with transit stop infrastructure to provide travelers with information regarding available transportation services and approaching vehicles, such as passenger loads, availability of priority seating for persons with disabilities, bicycle rack availability, and fare information, among other data. Through connected infrastructure, this information would be transmitted to transit management centers and disseminated to travelers through the Transportation Information Center (TIC) applications. A key component of the application is the ability to support dynamic trip planning at transit stops. The Operational Concept discusses the following scenarios:

- V2I (and I2V) traveler information and dynamic trip planning at bus stops for travelers *without* personal information devices. This scenario describes the provision of traveler information, including dynamic trip planning, at transit stops. The scenario assumes that the traveler does not have access to a personal information device (e.g., mobile device). Connected transit vehicles communicate mobility data with RSU and connected transit stop/stations using DSRC. This data is provided to the Transit Management Center and processed by the TIC which disseminates information to travelers through mobility-specific planning applications and through Public Information Devices.
- V2I (and I2V) traveler information and dynamic trip planning at bus stops for travelers with personal information devices. This scenario describes the provision of information to travelers with personal information devices. The device provides the capability for travelers to receive real-time information at the transit stop location (V2I) and en-route through Vehicle-to-Infrastructure-to-Pedestrian (V2I2P) and Pedestrian-to-Infrastructure-to-Vehicle (P2I2V) communications. V2I communication through an RSU, may serve as a physical gateway for the traveler to access multi-modal travel planning applications hosted within the TIC. The personal information device may also be used to communicate wirelessly with connected vehicle OBE (e.g., to request a transit stop or pay a fare).

The scenarios were developed in order to provide useful travel information for travelers with and without personal information devices. The benefits of this application would be extended for all travelers. Improved information availability and connectivity would assist and promote transit travel.

The Transit Traveler Information Infrastructure Mobility Application Operational Concept is available at the National Transportation Library (FHWA-JPO-15-212).

7 Infrastructure Needs

The basic relevant elements of a connected vehicle system include vehicle and infrastructure computing and communications equipment. The compliment of equipment to be located at the roadside includes the RSU, which will prepare and transmit messages to vehicles and receive messages from vehicles for the purpose of supporting the V2I applications. The RSU[1] is a device that contains multiple radio sets for localized communication over 5.9 GHz DSRC, an integrated GPS receiver for positioning and UTC time, and an Ethernet interface. Additionally, the RSU may interface with a traffic signal controller where appropriate, and to the backhaul communications network necessary to support the applications, and support such functions as data security, encryption, buffering, and message processing. OBE includes computing and communications devices installed in the vehicle. Using these definitions as a starting point, prior iterations of this transit-oriented V2I study refined and broadened the definitions of "V" (vehicle) and "I" (infrastructure) to include the following components:

- **"V"** – transit revenue fleet (motor bus, demand response, light rail, etc.), support service fleet (field supervisor vehicle, transit police vehicle, etc.) and transit passengers and personnel (both on- and off-board transit vehicles).
- **"I"** – infrastructure/facilities owned by transit agencies (including transit centers, signage, bus stops/shelters, pedestrian detectors, ticket vending machines, maintenance yards, dispatching garages, etc.) and other infrastructures/facilities (such as traffic signals and signs, roadside sensors, dynamic message signs, etc.). Parking lots/garages for intermodal transfers are also considered.

Occasionally, a third classification, "P" (personal) is used to capture the potential inclusion of Vehicle to Everything - V2X applications which include personal devices.

The Transit V2I Assessment Study team identified roadway/wayside equipment assets, as well as transit vehicle assets, in a technical memorandum entitled, "Overview of Transit Vehicle and Roadway Infrastructure Assets in Candidate Transit V2I Applications". A summary of the infrastructure components that would likely be needed by each of the twelve candidate applications is summarized in Table 7-1. All of the nine safety applications require a connected vehicle RSU, with eight of those also utilizing ITS roadway equipment. The safety applications also require environmental conditions monitoring equipment, dynamic signage, pedestrian detection equipment, and TMC communications capabilities, depending on the needs of each application.

The three remaining applications require TMC communications capabilities. They could use connected vehicle RSUs with DSRC to communicate with the TMC, though other communications media could also be used. The two mobility applications require additional ITS roadside equipment beyond the connected vehicle RSU.

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[1] The USDOT specification for the RSU version 4 is available at http://www.its.dot.gov/testbed/PDF/USDOT_RSUSpecification4%200_Final.pdf

Table 7-1: Summary of Infrastructure Components to Support Candidate Transit V2I Applications

Application	ITS Roadway Equipment	Connected Vehicle RSU	Environmental Conditions Monitoring Equipment	Dynamic Signage	Pedestrian/Cyclist Detection	TMC Communications Capability
Red Light Violation Warning (RLVW)	X	X				
Stop Sign Violation Warning (SSVW)	X	X				
Left Turn Assist (LTA)	X	X				
Stop Sign Gap Assist (SSGA)	X	X		X		
Spot Weather Information Warning (SWIW)	X	X	X	X		X
Transit Bus - Pedestrian/Cyclist Crossing Warning	X	X			X	
3D Mapping for Collision Avoidance and Situation Awareness		X				
Transit Bus Stop Pedestrian Safety	X	X		X	X	
Reduced Speed Zone Warning (RSZW)	X	X		X		
Transit Vehicle and Center Data Exchange	X	X (potentially)				X
Transit Traveler Information Infrastructure	X	X (potentially)				X
Portable Infrastructure		X (potentially)		X		X

8 Conclusions & Recommended Next Steps

In 2013, the USDOT launched this Transit V2I Assessment Study to shape the direction and priority for future transit V2I research and development activities. Because public transportation generally operates on roadways managed by entities other than transit agencies, much of the roadway signal control functions and associated infrastructure fall outside of the authority of transit providers. The ownership of the existing infrastructure brings an added layer of complexity to transit agencies in planning and deploying transit V2I applications.

The study accomplished this goal by structuring the research in two major components:

- Stakeholder Brainstorming and Needs/Opportunities Identification: Perform a thorough, cross-cutting exploration of unique transit V2I needs (such as data and communications needs), opportunities (where transit can contribute, for example, to the data environments) and constraints (such as ownership of and accessibility to certain infrastructure types).
- Prioritization of Transit V2I Applications and Operational Descriptions: Define and prioritize selected transit V2I applications, and develop detailed operational descriptions for near-term research and development targets.

The remainder of this section summarizes the key findings drawn from this study, and recommends areas for future research and development activities.

8.1 Conclusions

This study utilizes three major sources of input to assess transit V2I research needs and to determine the near-term priorities for transit V2I applications:

- Literature Review (see Section 3)
- Direct Stakeholder Input (see Sections 4 and 5)
- USDOT Priorities (see Section 5)

Transit V2I Safety Application Prototypes

Based on the results from the Study, it is the intent of the USDOT to pursue the following two transit V2I safety applications for prototype development and testing: 1) Transit Bus – Pedestrian/Bicycle Crossing Safety Application and 2) Transit Bus Stop Pedestrian Safety Application. These applications are restated briefly below. It should be noted that additional transit safety applications may be selected for prototype development and testing, subject to funding availability.

Transit Bus - Pedestrian / Bicycle Crossing Safety Application: This application would provide alerts to transit bus drivers of a pedestrian's or cyclist's presence while they are crossing the roadway at intersections and midblock, using V2I wireless communications. When a pedestrian or cyclist is detected via the infrastructure, an RSU would send a message to nearby buses that a pedestrian or cyclist is in or may be entering the roadway. This application would build upon the TRP PCW, by providing alerts to bus drivers for all bus movements (left, right, and straight) in infrastructure-equipped signalized and non-signalized intersections and at midblock crossings when imminent conflicts with pedestrians and bicyclists are present. A new pedestrian warning message will need to be developed, one that does not rely on a SPaT transmission.

Transit Bus Stop Pedestrian Safety Application: Three safety scenarios at bus stops include: 1) the infrastructure alerts pedestrians of approaching and/or alerts transit bus drivers of pedestrians at bus stops, 2) the infrastructure alerts pedestrians of departing transit buses and/or alerts transit bus drivers of pedestrians at bus stops, and 3) the infrastructure alerts passengers alighting from buses about approaching motor vehicles. This application, using V2I wireless communications, would provide alerts to pedestrians, via infrastructure (e.g., electronic signage with audible warnings), at major bus stops (e.g., those equipped with bus shelters, likely serving multiple bus routes) indicating a transit bus' intention of pulling into or out of a bus stop. The application may also alert pedestrians of motor vehicles in the vicinity of the bus stop, including alerting passengers alighting buses at the stop to address potential collisions of pedestrians with motor vehicles, whose sight are blocked by the bus. A new pedestrian warning message will need to be developed for this application.

Transit V2I Mobility Application Prototypes

Based on the results from the study, the USDOT may also pursue the following two transit V2I mobility applications for prototype development and testing: 1) Transit Vehicle and Center Data Exchange Application and 2) Transit Traveler Information Infrastructure Application.

Transit Vehicle and Center Data Exchange Application: This application allows for remote access to transit vehicle information and equipment in order to enable more efficient and effective assessment of the transit vehicle and the traffic environment it is operating in. This could enhance the capabilities of applications in the IDTO bundle. Additionally, it could improve timely and appropriate responses to incidents on the roadway and the transit vehicle when the TMC or EMC has access to visual information from the exterior/interior vehicle cameras in near real-time.

Transit Traveler Information Infrastructure Application: This application enhances and complements the capabilities of the applications in the IDTO bundle, making them more accessible to those with and without smartphone access. This application connects transit vehicles and travelers to nearby infrastructure, such as a smart bus stop, smart intersection and smart parking. Connected transit vehicles would communicate wirelessly with transit stop infrastructure, communicating key mobility information such as: schedule adherence, vehicle position/heading, travel speed, passenger loads, priority seating availability for persons with disabilities, bicycle rack availability, connection protection status, and fare information, among other data.

8.2 Recommended Next Steps

In addition to further prototype development and testing of transit connected vehicle safety applications, the USDOT may consider five (5) follow up activities discussed in the following sections related to transit V2I research.

8.2.1 Transit Vehicle Driver Vehicle Interface (DVI) Human Factors Analysis

For any onboard transit vehicle safety systems that require interaction with vehicle drivers, there are two important factors that collectively determine driver/agency acceptance, and ultimately affect the systems' user adoption and scale of impact.

- Application reliability and accuracy [i.e., system performance], and
- Driver vehicle interface [i.e., human factors], including visual, audio, and tactile (if any) alert messages for the drivers and the frequency, density and timing of those alerts.

According to Federal Highway Administration (2013) [4], **human factors research deals with human physical, perceptual, and cognitive abilities and characteristics and how they affect our interactions with tools, machines, and surroundings.** The interactions between the driver and the vehicle occurs through operation of controls, reading onboard and traffic control displays, interpreting visual (light) and audio (e.g., horn) cues from other road users, and observing all other environmental situations. For safety systems onboard transit vehicles that require driver interactions, understanding of human factors is particularly important. This importance is largely driven by the more complex and demanding driving conditions facing transit vehicle drivers (e.g., vehicle size, interaction with passengers, frequent stop/go, and other onboard equipment, such as fare boxes).

While the USDOT recognizes that DVI was not a major focus during TRP development in the Safety Pilot Model Deployment, preliminary anecdotal feedback from drivers indicated that the TRP would have been even more beneficial to and valued by the drivers if more focus had been put on DVI. Some examples of driver feedback related to human factors includes:

> ".. *[TRP] makes you turn your head in the wrong direction.*"

> *"Gave you advance warning. You knew which crosswalk to pay the most attention to."*

> *"[Dislike] volume of the beep"*

> "…. *I usually found it a little overwhelming because I was never close to rear ending a vehicle [regarding forward collision warning] but the system made it feel that way"*

> *"It was distracting; I was paying attention to the device instead of the immediate danger"*

> *"…I am concerned that bus passengers who can see and hear the warnings might think I am driving poorly"*

Key Human Factors for Transit Connected Vehicle Safety Systems and Drivers:

- Driver Information Needs Assessment
- An Effective Safety System Interface
- Integration with Other Driving Control and Information Systems/Workload Issue
- Driver Distraction Challenge

The research team recommends a thorough study of human factors related to transit vehicle drivers. The study will obtain and analyze data on transit driver performance, acceptance and behavior in response to various onboard safety system design parameters through a variety of driver vehicle interfaces.

Beginning in October 2014, the National Highway Traffic Safety Administration (NHTSA) with assistance from the FTA began a relevant study on Human Factors for Connected Vehicles (HFCV) Modal and Application Gaps Research. The goal of the project is to explore research and knowledge gaps associated with driver-vehicle interface needs for various modes of travel, including transit and use that information to further refine current HFCV Design Principles. While not specifically transit, this project will have crossover and relevance to a recommended Transit Vehicle Driver Vehicle Interface (DVI) Human Factors Analysis.

8.2.2 Transit Connected Vehicle Safety Research Strategic Plan

Built upon the outcomes from this study, **the research team recommends developing/updating a Transit Connected Vehicle Safety Research Strategic Plan**, integrating V2I, V2V and V2P, that define the strategic direction and priority of future transit safety research, and align with the 2015 – 2019 ITS Strategic Plan (recently released), FTA ITS Research Plan 2010 – 2014, as well as the overall V2I research vision, mission and goals.

This Research Strategic Plan may include the following:

- **Introduction**. Provides background on the transit connected vehicle research and how it supports the ITS Strategic Plan. It should present a picture of the changing landscape of transportation network and services through connectivity and automation.
- **Vision, Mission, and Values**. States the vision, mission, and values of the Transit Connected Vehicle Research Program.
- **Strategic Goals and Objectives**. Describes the strategic plan for the transit connected vehicle research. It should define the strategic goals and sets objectives and anticipated outcomes for each goal.
- **Research Activities**. Prescribes research actions/activities, such as studies, development/testing, demonstration, evaluation, deployment support and workforce development, and defines dependencies between these activities, that support the strategic goals and objectives.
- **Benefits and Conclusion**. Describes potential benefits and measurable impacts of transit connected vehicle safety research.

8.2.3 Light Rail Safety Exploratory Research

At the direction of the USDOT, this Transit V2I Assessment Study focused primarily on V2I applications related to transit buses. Nevertheless, the literature review found that light rail collisions make up 4.3% of all transit collisions, and yet account for 10.9% of all fatalities. Most of these injuries and fatalities are due to pedestrian collisions. Further analysis shows that 55% of light rail collisions with motor vehicles occurred when the motor vehicle is going straight at grade crossings, and 43% occurred when the motor vehicle is turning left, as shown in Figure 8-1.

The research team recommends exploratory research on connected vehicle safety for light rail safety. The main objective of this project would be to explore the technical and institutional feasibility of vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-pedestrian (V2P) applications to enhance safety of light rail systems, both at-grade in mixed-flow traffic, and at light rail grade crossings where rail intersects with other traffic, including light, commercial, and transit vehicles, and pedestrian/bicycle traffic. A key output of this project is a set of operational descriptions for multiple light rail safety applications, prioritized by the stakeholders, for USDOT consideration for further prototype development and testing.

The project may conduct research on the following areas:

- Research on Existing Rail Grade Crossing Safety Systems and Communication Capabilities
- Research on Potential Light Rail Vehicle (LRV) to Roadway Vehicle (V2V), LRV to Infrastructure (V2I) and LRV to Pedestrian (V2P) Safety Applications
- Research on Institutional Issues and Potential Barriers
- Preliminary Light Rail Safety Application Assessment

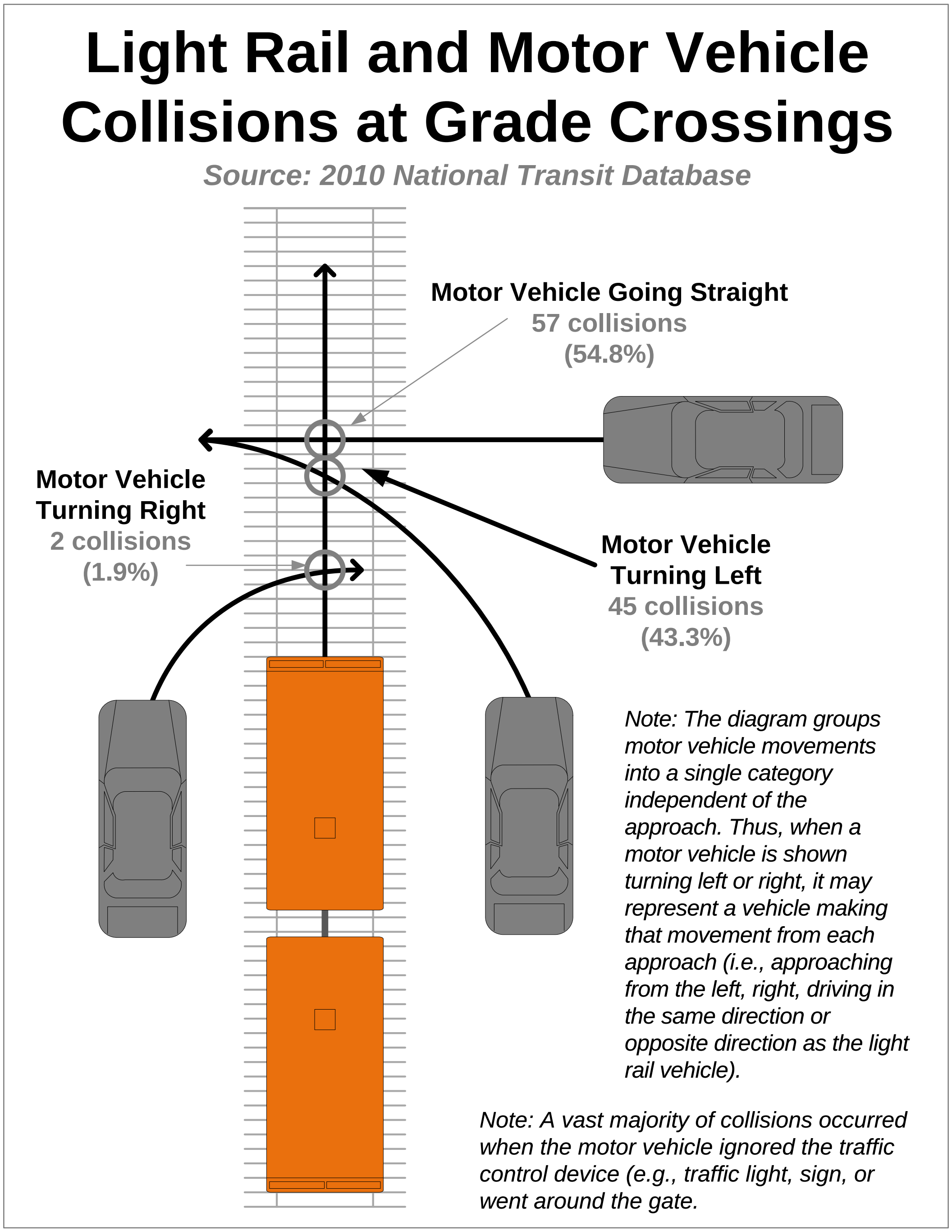

Figure 8-1: Diagram of Light Rail - Motor Vehicle Collisions, based on 2010 NTD data *(Source: USDOT, 2013)*

8.2.4 Transit Connected Vehicle Infrastructure Footprint Assessment

During the exploration of infrastructure needs as a part of this study (see Chapter 7), it became apparent that a more comprehensive assessment of field infrastructure footprint in support of transit connected vehicle environment would be beneficial. This recommended research is expected to provide transit decision makers useful tools and knowledge resources to determine strategic paths, incremental steps and actions that are most appropriate and feasible for their respective jurisdictions. The assessment will address, at a minimum, the following areas:

- Analysis of potential transit connected vehicle infrastructure needs and priorities
- Description of a preliminary transit connected vehicle footprint
- Development of a phased and coordinated transit connected vehicle infrastructure deployment plan

Research questions regarding infrastructure footprint may include:

- How can the transit industry redefine and articulate needs within and beyond the transit community regarding future infrastructure to meet the objectives candidate transit V2I applications?
- What gaps exist between the state of the industry today and the candidate V2I applications?
- Do alternate technologies or infrastructure exist that could facilitate the objectives of the candidate applications?

8.2.5 Transit V2I Deployment Guidance Project

There remains a lack of guidance for the transit community in regards to Vehicle-to-Infrastructure (V2I) technology, paths toward deployment and infrastructure preparations. The FHWA is in the process of finalizing the *2015 FHWA Vehicle to Infrastructure Deployment Guidance and Products Report* (USDOT, 2015) which will serve as a guidance resource to assist both the USDOT as well as transportation system owners and operators prepare to deploy V2I technologies. The document provides a very clear and descriptive overview of V2I guidance, much of it important to Transit V2I deployments, however since the FHWA report is cross modal, and represents multiple modes of travel, not just transit there is a need to create a document that corresponds directly with transit.

The research teams recommends that the USDOT undertake a Transit V2I Guidance project which would review and assess the current FHWA report from a transit perspective. This project would approach V2I deployment from the viewpoint of the transit community (e.g., transit agencies and transit operators) and produce a transit V2I guidance document. This document would expand on transit related gaps in the FHWA report as well as provide a deployment resource that the transit community could use without having to sort through material that is not related to transit. The report should assess, at a minimum the following areas; deployment needs specific to transit agencies, transit specific evaluations and infrastructure needs.

9 References

1. Noblis, Inc., *Analysis of Collisions Involving Transit Vehicles and Applicability of Connected Vehicle Solutions,* prepared for the ITS JPO under Contract No. DTFH61-11-D-00018, November 2013. http://ntl.bts.gov/lib/38000/38000/38051/fhwa-jpo-13-116.pdf
2. Battelle Memorial Institute, *Transit Safety Retrofit Package Development – Final Report*, prepared for the Federal Highway Administration under Contract No. DTFH61-12-C-00007, July 30, 2014. http://ntl.bts.gov/lib/54000/54500/54592/FHWA-JPO-14-142_v1.pdf
3. John A. Volpe National Transportation Systems Center, Independent Evaluation of the Transit Retrofit Package Safety Applications, prepared for the ITS JPO under Contract No. DOT-VNTSC-FTA-15-01, February 2015. http://ntl.bts.gov/lib/54000/54800/54839/FHWA-JPO-14-175_v1.pdf
4. Federal Highway Administration (FHWA), Signalized Intersections Informational Guide, 2nd Edition, 2013. http://safety.fhwa.dot.gov/intersection/signalized/13027/fhwasa13027.pdf
5. Noblis, Inc., *Transit Bus-Pedestrian/Cyclist Crossing Safety Application: Operational Concept*, prepared for the ITS JPO under Contract No. DTFH61-11-D-00018, June 2014. http://ntl.bts.gov/lib/54000/54000/54075/14-129.pdf
6. Noblis, Inc., *Transit Bus Stop Pedestrian Safety Application: Operational Concept*, prepared for the ITS JPO under Contract No. DTFH61-11-D-00018, December 2014. http://ntl.bts.gov/lib/54000/54400/54483/FHWA-JPO-14-174_v1.pdf
7. Noblis, Inc., *Transit Vehicle and Center Data Exchange: Operational Concept,* prepared for the ITS JPO under Contract No. DTFH61-11-D-00018, March 2015. http://ntl.bts.gov/lib/55000/55000/55046/FHWA-JPO-14-196_v1.pdf
8. Noblis, Inc., *Transit Traveler Information Infrastructure Mobility Application: Operational Concept,* prepared for the ITS JPO under Contract No. DTFH61-11-D-00018, June 2015. http://ntl.bts.gov/lib/55000/55100/55145/FHWA-JPO-15-212_v1.pdf

APPENDIX A. List of Acronyms

Acronym	Meaning
AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ATIS	Advanced Traveler Information Systems
BRT	Bus Rapid Transit
CSW	Curve Speed Warning
DMA	Dynamic Mobility Applications
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications
DVI	Driver-Vehicle Interface
EEBL	Emergency Electronic Brake Lights
EMS	Emergency Medical Services
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FTA	Federal Transit Administration
GPS	Global Positioning System
I2V	Infrastructure-to-Vehicle
ICM	Integrated Corridor Management
IDTO	Integrated Dynamic Transit Operations
IMA	Intersection Movement Assist
ITS	Intelligent Transportation Systems
ITSIS	Interactive Transit Station Information System
JPO	Joint Program Office
LRV	Light Rail Vehicle
LTA	Left Turn Assist
MMITSS	Multi-Modal Intelligent Traffic Signal System
NHTSA	National Highway Traffic Safety Administration
NTD	National Transit Database
OBE	On-Board Equipment
O-D	Origin - Destination
PCW	Pedestrian Crossing Warning
RLVW	Red Light Violation Warning
P2I2V	Pedestrian-to-Infrastructure-to-Vehicle
RSE	Roadside Equipment
RSU	Roadside Unit
SSGA	Stop Sign Gap Assist
SSVW	Stop Sign Violation Warning
SWIW	Spot Weather Information Warning
TMC	Transportation Management Center
TRP	Transit Retrofit Package
TSP	Transit Signal Priority
USDOT	U.S. Department of Transportation

Acronym	Meaning
V2I	Vehicle-to-Infrastructure
V2I2P	Vehicle-to-Infrastructure-to-Pedestrian
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VTRW	Vehicle Turning Right in Front of Bus Warning
X2D	Vehicle or Infrastructure-to-Device

APPENDIX B. Literature Review Documents

Table B-A: Connected Vehicle Core Research

ID	Literature Title	Author	Source/Publication	Year
A.1	Connected Vehicle Core System Concept of Operations	Core System Engineering Team	USDOT www.its.dot.gov/docs/CoreSystemConOpsRevE2.pdf	2011
A.2	eSafety 4th Communications Working Group Meeting Minutes and Materials, September 7, 2006	eSafety Communications Working Group	eSafety	2006
A.3	Signal Phase and Timing (SPaT) ConOps (Draft)	Battelle	USDOT http://www.iteris.com/cvria/html/applications/app67.html	2011
A.4	AASHTO Connected Vehicle Infrastructure Deployment Analysis	Christopher J. Hill, Ph.D., J. Kyle Garrett	USDOT ntl.bts.gov/lib/43000/43500/43514/FHWA-JPO-11-090_AASHTO_CV_Deploy_Analysis_final_report.pdf	2011
A.5	Mapping Technology Assessment for Connected Vehicle Highway Network Applications – Task 3 Mapping Technology Final Interim Report	Booz Allen Hamilton	USDOT	2012
A.6	Vehicle Positioning Trade Study for ITS Applications Final Report	ARINC Inc.	USDOT http://ntl.bts.gov/lib/42000/42600/42673/FHWA-JPO-12-064_FinalPKG_508.pdf	2012
A.7	National ITS Architecture	USDOT	USDOT http://www.iteris.com/itsarch/	2015

Table B-B: Multi-modal Connected Vehicle Research

ID	Literature Title	Author	Source/Publication	Year
B.1	Accelerated V2I Concept of Operations	Battelle	USDOT http://ntl.bts.gov/lib/48000/48500/48523/272C82A5.pdf	2012
B.2	V2I Non- Accelerated Concept of Operations	Battelle	USDOT	2012

ID	Literature Title	Author	Source/Publication	Year
B.3	Eco-Lanes - Operational Concept	Noblis	USDOT http://ntl.bts.gov/lib/51000/51700/51774/114.pdf	2013
B.4	Low Emissions Zones - Operational Concept	Noblis	USDOT http://ntl.bts.gov/lib/52000/52700/52755/FINAL_Low_Emissions_Zones_ConOps_01-2014.pdf	2013
B.5	Eco-Signal Operations - Operational Concept	Noblis	USDOT http://ntl.bts.gov/lib/51000/51400/51429/FINAL_Eco-Signal_Operations_ConOps_01-2014.pdf	2012
B.6	Smart Roadside Concept of Operations	Science Applications International Corporation (SAIC)	USDOT http://ntl.bts.gov/lib/54000/54800/54830/SRI_ConOps_5-22-12_FINAL.pdf	2012
B.7	Connected Vehicle Safety Applications for Highway Rail Intersections – Concept of Operations	Volpe	USDOT	2012
B.8	Interoperability Issues for Commercial Vehicle Safety Applications	UMTRI	USDOT http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2012/811674.pdf	2012
B.9	CICAS-V Project Reports	CAMP	USDOT ntl.bts.gov/lib/38000/38600/38631/CICAS-V_Final_Report_Rev_4-21-2010_v2_wAppendix_List__FHWA-JPO-10-068_.asd.pdf	2008
B.10	CICAS-SSA Project Reports (5 reports)	University of Minnesota	USDOT www.its.dot.gov/research_docs/pdf/cicas_tech_doc1-5.pdf	2010
B.11	CICAS-LTAP Project Report	California PATH	USDOT www.path.berkeley.edu/PATH/Publications/PDF/PRR/2010/PRR-2010-20.pdf	2010

Table B-C: Transit-focused ITS and Connected Vehicle Research

ID	Literature Title	Author	Source/Publication	Year
C.1	Vehicle-Infrastructure Integration: Applications for Public Transit	Michael Baltes, et. al.	Transportation Research Board 87th Annual Meeting trid.trb.org/view/2008/C/847684	2008

ID	Literature Title	Author	Source/Publication	Year
C.2	Prioritizing Transit in a Connected Vehicle World	Peter Koonce, P.E.	ITE Journal www.ite.org/transitpriority/JB12LA18.pdf	2012
C.3	Transit Connected Vehicle Concept of Operations	Booz Allen Hamilton	USDOT	2012
C.4	Transit Vehicle Collision Characteristics for Connected Vehicle Applications Research	Noblis	USDOT http://ntl.bts.gov/lib/38000/38000/38051/fhwa-jpo-13-116.pdf	2013
C.5	Transit Safety Retrofit Package (TRP) Concept of Operations	Battelle	USDOT http://ntl.bts.gov/lib/54000/54000/54069/14-117.pdf	2012
C.6	Report on Assessment of Relevant Prior and Ongoing Research for the Concept Development and Needs Identification for Integrated Dynamic Transit Operations	Science Applications International Corporation (SAIC)	USDOT	2012
C.7	The Development and Testing of An Interactive Transit Station Information System Using Connected Vehicle Technologies (Proposal)	California PATH		2013
C.8	Development and Testing of Priority Control System in Connected Vehicle Environment	Ding, Jun; He, Qing; Head, Larry; Saleem, Faisal; Wu, Wei	TRB 92nd Annual Meeting Compendium of Papers trid.trb.org/view.aspx?id=1241792	2013
C.9	Coordination of Connected Vehicle and Transit Signal Priority in Transit Evacuations	Yi Wen, Li Zhang, Zhitong Huang	TRB 91st Annual Meeting Compendium of Papers	2012
C.10	Assessment of the Use of Light Vehicle Safety Applications for Transit – Final Report	Science Applications International Corporation (SAIC)	USDOT http://ntl.bts.gov/lib/50000/50600/50618/90B74F17.pdf	2012

ID	Literature Title	Author	Source/Publication	Year
C.11	Multi-Modal Intelligent Traffic Signal System Assessment of Relevant Prior and Ongoing Research	University of Arizona	USDOT cts.virginia.edu/PFS_MMITSS02_Task2.1.pdf	2012
C.12	National ITS Architecture	USDOT	USDOT http://www.iteris.com/itsarch/	2015

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