Texas A&M Transportation Institute

Automated and Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, and Pedestrian Safety: Phase II Technical Report

Technical Report 0-6875-01-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

in cooperation with the
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16. Abstract

Crashes involving transit vehicles, bicyclists, and pedestrians are a concern in Texas, especially in urban areas. This research explored the potential of automated and connected vehicle (AV/CV) technology to reduce or eliminate these crashes. The project objectives focused on identifying safety concerns related to the interaction of transit vehicles, bicyclists, and pedestrians, and targeting AV/CV technologies to mitigate or eliminate those concerns. In Phase II, concept applications were identified, along with public- and private-sector partners. A concept of operations (ConOps) Plan for designing, testing, piloting, demonstrating, and deploying candidate applications through an AV/CV test bed to improve transit, bicycle, and pedestrian safety was developed.

Phase II focused on improving safety at signalized intersections, which represents complex space for buses, bicyclists, and pedestrians. Research activities included identifying use cases and alert scenarios for buses and pedestrians interacting at intersections, developing the system requirements, and developing the test plan, test scenarios, and test procedures for the proof-of-concept tests. Researchers conducted a preliminary test of possible alert methods and messages. A proof-of-concept test was conducted at a new state-of-the-art smart intersection at The Texas A&M University System's RELLIS Campus.

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AUTOMATED AND CONNECTED VEHICLE (AV/CV) TEST BED TO IMPROVE TRANSIT, BICYCLE, AND PEDESTRIAN SAFETY: PHASE II TECHNICAL REPORT

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object this report.

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I. INTRODUCTION

BACKGROUND, PROJECT OBJECTIVES, AND ACTIVITIES

Public transit vehicles, bicyclists, and pedestrians share roads in urban, suburban, and rural areas. Crashes involving transit vehicles, bicyclists, and pedestrians are a concern in Texas, especially in urban areas. The 2013 National Transit Database reported 657 incidents, 836 injuries, and 6 fatalities involving transit vehicles, bicyclists, and pedestrians in Texas. In addition to injuries and the tragic loss of life, these incidents have financial consequences. A 2017 pedestrian fatality in Seattle involving a bus making a right turn at an intersection resulted in a $7.7 million settlement.

This research explored the potential of automated and connected vehicle (AV/CV) technology to reduce or eliminate these crashes. The project objectives focused on identifying safety concerns related to the interaction of transit vehicles, bicyclists, and pedestrians, and targeting AV/CV technologies to mitigate or eliminate those concerns. In Phase I, concept applications were identified, along with possible public- and private-sector partners. A concept of operations (ConOps) plan for designing, testing, piloting, demonstrating, and deploying candidate applications through an AV/CV test bed to improve transit, bicycle, and pedestrian safety was developed. It included the overall vision and goals for the test bed and described the operational scenarios — the who, what, why, where, when, and how — for the near-term candidate applications. The applications focus on smart buses, smart intersections, smart bicycles and pedestrians, and smart bike racks on buses.

In Phase I, the research team conducted 25 meetings and 4 workshops with diverse stakeholder groups to gain insight into safety issues and concerns, as well as ideas on possible technologies to address these problems. The research team also reviewed AV/CV case studies of related technologies and examined federal, state, and local legislation and policies related to AV/CV, bicyclist, and pedestrians. A pilot of a camera and sensor-based collision-avoidance system was conducted on one Texas A&M University bus. The pilot was monitored, and the results were used to assist in developing the ConOps plan. Roundtable forums were held with stakeholders and technology firms to review the near-term applications and to identify possible partnerships.

The Phase I activities were documented in the 2016 Automated and Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, and Pedestrian Safety: Technical Report. The activities conducted in Phase II — focusing on enhancing safety at signalized intersections, which represent complex shared space for buses, bicyclists, and pedestrians — are summarized in this report.

The smart intersection and the smartphone app included in the Phase I ConOps plan were developed and piloted in Phase II. Researchers first identified the use cases and alert scenarios for the smart intersection. The use cases include the location and action of bases and pedestrians for the different scenarios focusing on right turning, left turning, and through buses. Researchers next developed the system requirements, including the system configuration, system detection, system alerts, bus-route information, connected-bus information, and data-logging information.

Researchers conducted a preliminary test on the Texas A&M University campus of possible pedestrian alert methods and surveyed pedestrians at three intersections in Houston to obtain additional information on preferred alert messages and methods. Researchers also conducted three focus groups in Houston with individuals using wheelchairs, individuals with visual impairments, and individuals with hearing loss to gain further insights into alert methods and messages for disabled pedestrians.

Researchers developed the test plan, test scenarios, and test procedures for the use cases. An audio alert message ("caution bus turning" in English and Spanish) and a visual method (a supplemental bus sign above the pedestrian signal) were used in the pilot. A beta android smartphone app was also developed and tested.

TTI installed a state-of-the-art smart intersection at The Texas A&M University System's RELLIS Campus to pilot test the system. The smart intersection was developed through a public-private partnership. TTI resources covered construction of the intersection and some equipment. Econolite® donated most of the traffic signal control and detection equipment, including two signal cabinets. This TxDOT project provided the first use of the smart intersection, with proof-of-concept tests conducted on seven of the use cases and the audible warning, the supplemental bus sign, and the beta smartphone app.

The project concluded with a roundtable forum on October 23, 2018. Representatives from TxDOT, transit agencies, Metropolitan Planning Organizations (MPOs), and other groups participated in the roundtable forum. The roundtable forum included a project update and a proof-of-concept demonstration of the smart intersection and smartphone app at the RELLIS Campus. Participants discussed and voiced support for moving forward with possible Phase III deployment projects.

ORGANIZATION OF REPORT

This report is organized into eight sections. Following this introduction in Section I, Section II summarizes recent pilots, demonstrations, and research projects using AV/CV technologies to improve transit, bicyclist, and pedestrian safety. Section III presents the use cases and alert scenarios for the smart intersection application. Section IV outlines the system requirements for the smart intersection. Section V describes a preliminary pilot test undertaken on the Texas A&M University campus and intercept surveys and focus groups conducted in Houston to gain input from pedestrians on potential technologies, methods, and messages to use in alerting pedestrians and bicyclists of turning buses at intersections. Section VI presents the test plan, test scenarios, test procedures, and the results of the smart intersection and smartphone app proof-of-concept tests conducted at the RELLIS Campus. Section VII summarizes the October 23, 2018 Roundtable Forum in College Station, Texas. The report concludes with a discussion of possible Phase III deployment projects in Section VIII.

II. REVIEW OF TRANSIT, BICYCLE, AND PEDESTRIAN AV/CV TECHNOLOGY DEMONSTRATIONS AND RESEARCH

This section examines demonstrations, pilots, projects, and research activities in Texas, the United States, and internationally focusing on reducing conflicts and improving safety among buses, bicyclists, and pedestrians. Six case studies of different transit, bicycle, and pedestrian AV/CV applications were examined in Phase I of this project. The case studies included bus-based collision warning systems, technology to assist with bus lane keeping, low-speed automated shuttles, and a smartphone app to improve pedestrian safety. Information on these case studies, as well as other research and demonstration projects, was presented in the Phase I final report.

These case studies, as well as new pilots, demonstrations, and research projects were monitored during Phase II. This section summarizes recent projects focusing on bus-based collision warning systems, low-speed autonomous shuttles, and smartphone apps for pedestrian and bicyclists. Research projects exploring different AV/CV technologies to improve, transit, bicyclist, and pedestrian safety are also presented.

BUS-BASED COLLISION-WARNING SYSTEMS

Bus-based warning systems are one approach to reducing crashes involving buses, pedestrians, and bicyclists. In Phase I, researchers examined the CycleEye® sensor-alert system tested in the United Kingdom and the Transit Safety Retrofit Package (TRP) developed by Battelle and tested on buses at the University of Michigan in Ann Arbor.

Demonstrations and tests of other technologies in Cleveland, Ohio; Portland, Oregon; and other cities were also examined. A pilot of the Rosco Mobileye Shield+™ collision-avoidance system on one Texas A&M University bus was conducted and evaluated. Researchers continued to monitor tests, pilots, and demonstrations of bus-based collision-warning systems during Phase II. Information on pilots and tests of the Mobileye system, the Clever Devices Turn Warning™ System, the Protran Safe Turn Alert 2.0 system, and the enhance TRP are highlighted in this section.

SUMMARY OF MOBILEYE PILOTS

The Rosco Mobileye Shield+™ collision-avoidance system uses cameras, sensors, and algorithms to monitor pedestrians and bicyclists in the path of a moving bus. It measures distance and relative speeds of the bus and bicyclists/pedestrians to calculate the risk of a collision. As illustrated in Figure 1, the system includes pedestrian displays located to the right, center, and left of the bus driver. Displays provide two types of warnings. A yellow light is illuminated when a bicyclist or pedestrian is detected near the right, center, or left of the bus. The yellow light indicates that the bus driver should exercise additional caution until confirming that the danger of a collision has passed. A flashing red light is illuminated with a beeping sound when a collision with a bicyclist or pedestrian is predicted by the system, alerting the driver to stop to avoid a crash.

As part of Phase I, TTI partnered with TxDOT, Texas A&M University Transportation Services, and the technology firms Mobileye and Roscoe to pilot the Mobileye Shield+™ collision-warning system on one Texas A&M bus. TTI purchased the system, Texas A&M Transportation Services provided the bus, and the TxDOT project funding supported the assessment of the pilot. The Phase I final report documents the operation of the Mobileye Shield+ ™ and the pilot. The system continues to operate in regular service on bus 120.

Source: Texas A&M Transportation Institute.

Figure 1. Rosco Mobileye Shield+™ Display on Texas A&M University Bus.

Researcher monitored additional pilots of the Mobileye Shield+™ system in the United States during Phase II. A few of these pilots are summarized in this section.

Florida Advanced Driver Assistance Systems Pilot

As a part of the Florida Automated Vehicles Initiative, the Florida Department of Transportation (FDOT) tested advanced-driver-assistance systems in the Tampa Bay area (FDOT District Seven) from 2014 to 2016. The pilot assessment involved 100 vehicles. Half of them were equipped with a telematics system GEOTAB only (as a control group); the other half were mounted with GEOTAB and the Mobileye's Advanced Driver Assistance System. GEOTAB tracks vehicle movement and collects data to measure Mobileye's safety enhancement. Tested vehicles included sedans, light trucks, buses, and vans from FDOT's District Seven and four transit agencies, including the Hillsborough Area Regional Transit, Tampa Bay Area Regional Transit Agency, Pasco County Public Transportation, and the Pinellas Suncoast Transit Authority.

The two-year pilot project included three tasks. These tasks were developing the experimental design, conducting the field assessment, and analyzing the data. The initial assessment indicated that the system was successful in reducing the number of crashes. One limitation of the system noted in the assessment was that the system focuses on heights 36 inches above the ground and, therefore, may not sense a small child.

New York City Transit Pilot

In coordination with the New York City's Vision Zero plan, the Metropolitan Transportation Authority's (MTA's) New York City Transit (NYCT) is testing the Clever Devices pedestrian-turn-warning system and the Mobileye Shield+ collision-warning system on buses. NYCT began a 60-day pilot program in October 2015 and installed the Clever Devices system on four buses and the Mobileye system on two buses.

The Turn Warning™ system produced by Clever Devises automatically detects when a bus is turning and sends an audio announcement to alert pedestrians. System features include the ability to provide announcements on both sides of a bus or just in the direction of the turn, to adjust the volume of the announcement by the time of day, and to geofence the announcement to disable or adjust the audio levels based on location. Warning lights can be added to provide increased awareness of turning buses. The system can also be configured to audibly remind drivers to check for the presence of pedestrians. Additionally, Turn Warning™ can be integrated with third-party systems, including collision-warning systems.

In 2016, NYCT reported that the Clever Devices system functioned as designed on the four buses and that the proof-of-concept of the Mobileye Shield+ system functioned as planned on the two buses. The report on the proof-of-concept test noted that the Mobileye Shield+ algorithm was adjusted for better object recognition and response under low and dim lighting conditions.

The 60-day pilot led to full pilots of both systems in 2016. The pilot was still ongoing as of February 2018, with the expansion of the Clever Devices pedestrian-turn-warning system to 257 buses and the collision-warning system to 114 buses in the fleet. The NYCT plans to install the technologies on additional buses by late 2018.

Washington State Demonstration Pilot

The University of Washington Smart Transportation Applications and Research Laboratory (STAR Lab) and the Washington State Transit Insurance Pool (WSTIP) conducted a pilot of the Mobileye Shield+ system in 2016 on three buses from King County Metro Transit in Seattle, Washington, and 35 transit buses provided by WSTIP members. The 7 WSTIP members participating in the pilot included the following transit agencies.

- Ben Franklin Transit, Richland.
- Community Transit, Everett.
- C-Tran, Vancouver.
- InterCity Transit, Olympia.
- Kitsap Transit, Bremerton.

- Pierce Transit, Tacoma.
- Spokane Transit, Spokane.

The project was funded by WSTIP; the Transportation Research Board's IDEA Program; Alliant Insurance Services, Inc.; Government Entities Mutual, Inc.; Pacific Northwest Transportation Consortium; and Munich Reinsurance America Inc.

In addition to Mobileye Shield+, a telematics system was installed to capture and transmit data and video for use in assisting the Shield+ system. Data collection occurred from April 2016 to June 2016. No collisions with bicyclists or pedestrians were recorded on the Shield+ equipped buses during that period, while 10 incidents occurred on other buses. After the data collection period, drivers received a survey about their experience with the technology. Out of the 277 respondents, 37 percent reported that the system was helpful, while 63 percent suggested the system was distracting.

Pierce Transit Pilot

Pierce Transit participated in the Washington State demonstration project. In January 2017, the Federal Transit Administration's Collision Avoidance and Mitigation Safety Research and Demonstration Project awarded Pierce Transit a $1.6 million grant to implement an additional pilot of the Mobileye Shield+ system.

Combining the federal grants with $500,000 from Pierce Transit; $100,000 each from the Munich Reinsurance America, Inc. and WSTIP; and in-kind contributions, Pierce Transit secured $2.9 million to equip 176 buses with the Generation 2 Shield+ collision avoidance warning system and 30 buses with a Pedestrian Avoidance Safety System. Pierce Transit is conducting a year-long pilot and evaluation project throughout 2018.

Virginia Department of Rail and Public Transportation Pilot

The Virginia Department of Rail and Public Transportation (DRPT) announced a statewide cooperative procurement of the Mobileye Shield+ Driver Assistance System (DAS) for all public transportation providers in the state in December 2017. Funding sources include a Statewide Transit Demonstration Grant and the Commonwealth Transportation Board's Innovation and Technology Transportation Fund.

DRPT budgeted $450,000 for a DAS pilot program, to support 10 public transportation providers in equipping a total of 50 buses with DAS. The Hopper, a downtown circular operated by the Great Lynchburg Transit Company, is projected to be the first bus service to be equipped with DAS.

Miami-Dade Department of Transportation and Public Works Pilot

The Miami-Dade Department of Transportation and Public Works (DTPW) — in partnership with FDOT, Florida International University, and Rosco — initiated a pilot in December 2017 to test the Mobileye Shield+ system on 10 buses. The buses operate on high volume routes in busy travel corridors. The pilot focuses on providing support to bus operators driving in these conditions. DTPW is developing an evaluation plan based on an analysis of current DTPW and national safety statistics. DTPW also plans to conduct a cost-benefit analysis to measure initial and recurrent technology costs as compared to the estimated reduction in pedestrian crashes using the tested technology.

Dallas Area Rapid Transit (DART)

DART initiated a pilot of the Mobileye Shield+ system on seven buses in June 2018. The buses operate on both fixed-route and demand-responsive service. Approximately 25 bus operators have been trained in the use of the system. The pilot is anticipated to run for several months, with assessments of the system and operator feedback.

PROTRAN SAFE TURN ALERT 2.0

The Protran Safe Turn Alert (STA) system was one of the technologies piloted by TriMet in Portland, Oregon, and the Maryland Transit Administration (MTA) as described in the Phase I report. The STA 2.0 is a passive-warning system that alerts pedestrians and bicyclists a bus is turning. An audible warning message is automatically played when a bus makes a right or left turn.

The trigger for the alert system can be set to either proximity sensors mounted near the pitman arm or by the bus turn signals. The warning message can be played on both sides of the bus or only on the side of the direction of the turn. Multiple recordable messages can be used, including messages in different languages. The message volume automatically adjusts to outside ambient noise and can be further adjusted by location and time of day. An option for using flashing LED lights on the bus during turns is also available. Another option is the Protran Blindspot Awareness system that provides audible and visual warnings to the bus operator when an object is detected in the blind spot of the bus.

The Protran STA system has been installed on buses operated by the MTA and the Southeastern Pennsylvania Transportation Authority, as well as other systems.

GREATER CLEVELAND REGIONAL TRANSIT AUTHORITY AND BATTELLE-ENHANCED TRANSIT SAFETY RETROFIT PACKAGE

The Greater Cleveland Regional Transit Authority (GCRTA) is partnering with Battelle to test a system using infrared cameras, dedicated short range communications (DSRC) radio, and GPS to provide alerts to bus operators when pedestrians are present in an intersection crosswalk. The system also notifies the bus operator when another connected vehicle is turning in front of the bus. The system builds on the TRP demonstration conducted by Battelle at the University of Michigan in 2013, documented in the Phase I report.

The GCRTA project uses DSRC radios for vehicle-to-vehicle and vehicle-to-infrastructure, GPS to track the movement of buses, and forward-looking, infrared cameras to detect pedestrians. The infrared cameras provide additional precision from the system used in the earlier demonstration.

The system is operating on 24 buses at three intersections in Cleveland during the demonstration. Battelle is collecting and analyzing data during the demonstration and will be developing an evaluation report.

LOW-SPEED AUTONOMOUS SHUTTLES

The Phase I report summarized the automated road transport systems (ARTS) projects being piloted in Europe as a part of the European Commission (EC)-funded CityMobil2 program. The ARTS vehicles were not autonomous. Rather, they were fully automated public transport vehicles controlled by a centralized fleet management system that also controlled the vehicle's interaction with the infrastructure and with other road users. An operator, who could take control if needed, was also onboard the vehicles. The five demonstration sites included three large-scale pilots in La Rochelle and the West Lausanne Region of France and in Milan, Italy. Two small-scale pilots were conducted in Oristano, Sardinia, and Vantaa, Finland.

Since the Phase I report, low-speed autonomous shuttles have been tested, piloted, and demonstrated in over 20 cities in the United States. These activities range from short pilots of a few days to longer, multi-year demonstrations. Examples of pilots and demonstrations in Minneapolis and St. Paul, Minnesota; Arlington, Texas; Las Vegas, Nevada; San Ramon, California, the University of Michigan in Ann Arbor, and Texas A&M University and downtown Bryan in Texas are highlighted in this section. Driverless shuttles have also been or are being piloted and deployed in Tampa Bay, Florida; Denver, Colorado; and other cities.

Pilots are also being conducted in Europe. Other pilots and demonstrations are being conducted and considered in Texas, including on the Texas Southern University campus, in Austin, and in other cities. Capital Metro, in partnership with the City of Austin and RATP Dev USA, initiated a limited test of driverless shuttles in downtown Austin in the summer of 2018. No passengers were allowed on the shuttles during an initial two-week test, but a year-long pilot is expected to begin later in 2018.

The autonomous shuttles are of interest to this project, since they should reduce or eliminate crashes with bicyclists and pedestrians. How the autonomous shuttles interact with other road users is being examined in the pilots and demonstrations.

Minnesota Department of Transportation (MnDOT) Autonomous Bus Pilot Program

The MnDOT Autonomous Bus Pilot Program represents one of the more comprehensive testing and demonstrations of low-speed-shuttle vehicles. MnDOT authorized testing and demonstrations of AVs on MnDOT roads in February 2017. Based on that authorization, MnDOT initiated this pilot program.

The following goals guided the pilot.

- Identify the challenges of operating AV technologies in snow and ice, and test potential solutions.
- Identify the challenges and strategies of having third parties safely operate AVs on the MnDOT transportation system.
- Identify infrastructure gaps and solutions to safely operate AVs on the MnDOT transportation system.
- Prepare transit for improving mobility services through AVs.
- Increase Minnesota's influence and visibility on advancing CAVs.

- Enhance partnerships between government and industry to advance CAVs in Minnesota.
- Provide opportunities for public demonstrations of AVs and obtain public feedback.

In addition to MnDOT, the pilot partners included the Colorado Department of Transportation (CDOT), EasyMile, First Transit, and 3M. MnDOT provided project management, funding support, use of the MnROAD test facility, and media and public outreach. CDOT provided financial support to the project. EasyMile provided the automated shuttle bus, operations, and maintenance troubleshooting, and coordinated with MnDOT on delivery and operation of the shuttle. First Transit operated the automated shuttle bus for all the demonstrations and provided staff trained on the technical aspects of operations and maintenance. 3M coordinated with EasyMile for delivery of the vehicle to the 3M campus for the custom vehicle wrap, provided CV technology, and supported the demonstrations. In addition, WSB and AECOM served as the project consultants, coordinating weekly meetings, overseeing the demonstrations, and completing the project report.

The pilot included the following activities.

- The EasyMile shuttle was tested in December 2017 and January 2018 under winter weather conditions at MnDOT's MnROAD test track northwest of the Minneapolis-St. Paul metropolitan area. Tours and demonstrations were provided during the testing.
- Public demonstrations of the automated shuttle were provided January 24–28 in conjunction with the community activities preceding Super Bowl LII in downtown Minneapolis.
- Additional demonstrations were held at 3M in St. Paul, the city of Rochester, the University of Minnesota in Minneapolis, Hennepin County, and the City of Bismarck, North Dakota.

Tests were conducted on an almost 1-mile segment of the 2.5-mile low-volume loop at the MnROAD facility. A climate-controlled storage building was also provided for the vehicle. The preprogrammed route for the stakeholder demonstrations included four stops. The EasyMile EZ10 model was used for the project. The EZ10 is a driverless electric bus with capacity for six seated and six standing passengers. The seating can also be rearranged to accommodate 15 passengers.

The EZ10 has no steering wheel or brake pedal. It navigates autonomously based on preprogrammed routes determined using GPS and LiDAR. The EZ10 has a maximum operating speed of 25 miles per hour (mph), but typically operates in the 12–15 mph range. Speeds during the MnROADs testing ranged from 2 to 11 mph. For the test, the EZ10 was equipped with four-wheel drive, winter tires, and an interior heater.

A number of scenarios were tested following the demonstration plan. Snowmaking machines were used to produce desired snow and ice conditions at the appropriate times. Digital recording of the scenarios were produced along with a summary log. Overall, the EZ10 performed well in periods of clear weather and bare pavements. The vehicle also performed well after a light, one-inch snow, with temperatures in the low 30s (degrees Fahrenheit), and calm winds. However, sensor-activated slowdowns and emergency stops did occur when blowing snow was detected. Sensor activated slowdowns and emergency stops occurred more often in conditions involving falling and blowing snow and loose snow on the track. The vehicle also performed well at night in foggy and misty rain/snow conditions.

The EZ10 also responded by stopping in response to the placement of work zone barrels at various locations to mimic roadway obstructions. The EZ10 responded appropriately by slowing and/or stopping when other vehicles, pedestrians, and bicyclists were introduced on the test track. Other tests examined road-salt spray, snow accumulating in the sensor housings, wheel-wander accuracy, and vehicle-battery performance.

Nine tours for stakeholder groups were provided over five days at the MnROAD facility, with a total of 238 stakeholders attending. The tours included briefings by the project staff, rides in the EZ10, and a question/answer period after the rides.

The demonstration in downtown Minneapolis prior to the Super Bowl was held along a short segment of the Nicollet Mall, which was closed to all traffic. The Minneapolis Public Library, which is owned by Hennepin County, served as the staging area. Permits from the City of Minneapolis and Hennepin County were required for the demonstration. A total of 1,279 riders participated in the three-day event. The overall response from riders to the demonstration and the potential for driverless vehicles was positive.

Other single and multi-day demonstrations were held at the State Capital in St. Paul, 216 riders; 3M, 479 riders; City of Rochester, 267 riders; Hennepin County-Midtown Greenway, 413 riders; the University of Minnesota, 454 riders; and the City of Bismarck, North Dakota, 1,037 riders. Responses from riders during all these demonstrations were mostly positive.

MnDOT has outlined possible future steps to build on the testing and demonstrations highlighted here, including strategic planning, additional pilots, and, ultimately, deployments. These activities are anticipated to include the existing project partners, as well as additional public and private-sector groups.

Driverless Shuttles Arlington Entertainment District

The Arlington Entertainment District in the Dallas-Fort Worth Metroplex initiated a one-year pilot in August 2017 using two EasyMile EZ10 autonomous shuttles. The two 12-passenger vehicles — six passengers seated and six standing — operated on trail routes serving Texas Rangers baseball games and Dallas Cowboys football games, as well as other major events at the Globe Life Park and AT&T Stadium. Individuals could also register for rides on certain days.

The demonstration represented a partnership between the City of Arlington, which leased the two EasyMile shuttles, and the Arlington Convention and Visitors Bureau, which contracted with First Transit to operate the shuttles. The shuttles were called Milo (to represent mile zero, the point where visitors arrive at their destination). Figure 2 illustrates one of the vehicles in operation. Although the EZ10 shuttles are autonomous, a certified operator, or ambassador, was always onboard to answer questions and take control of the vehicle, if needed. The preprogrammed routes operated on off-street trails in Richard Greene Park and the Robert Cluck Linear Park. No service was operated on public roads.

Source: Arlington Entertainment District.

Figure 2. Milo Driverless Shuttle — Arlington Entertainment District.

The City of Arlington completed the initial pilot in August 2018. Although no formal assessment is available yet, the feedback on operation of the vehicles and user acceptance has been positive. Building on the initial pilot, the Arlington City Council approved a contract with Drive.ai in August 2018 for a one-year project operating self-driving vans on city streets. Three self-driving, three-passenger vans began service in the Entertainment District in October. The on-demand service is available to residents, employees, and visitors in an area that includes AT&T Stadium, Globe Life Park, Texas Live!, the Arlington Convention Center, and the CenterPoint Office Complex.

The self-driving vans operate on city streets at speeds up to 35 mph. A safety operator is onboard to take control if needed. The free service is available to the public from 11:00 a.m. to 6:00 p.m., Thursday through Sunday. Riders can hail a shuttle at the kiosks inside the Live Arena at Texas Live! and the Arlington Convention Center during regular operating hours. Additional kiosks at other locations are anticipated. Passengers can download the Drive.ai app to request a ride. The vans pick up and drop off passengers at designated locations.

The Arlington City Council also approved a resolution earlier in 2018 supporting and encouraging companies to test electric robotic package delivery devices on city sidewalks. At least one company, Marble, has expressed interest in a possible test, and has begun mapping city sidewalks.

Hop On Driverless Shuttle, Las Vegas

The Hop On Driverless Shuttle in Las Vegas, Nevada, represents a partnership among the AAA Northern California, Nevada, and Utah Chapter; Keolis North America; the City of Las Vegas; and the Regional Transportation Commission of Southern Nevada. Keolis is operating and maintaining the NAVYA Arma fully electric and autonomous shuttle. The eight-passenger shuttle uses LiDAR, GPS, and cameras to navigate the street system. The shuttle also communicates with the city's traffic signals to enhance safety and traffic flow.

The shuttle operates on a 0.6-mile loop in the Fremont East Innovation District of downtown Las Vegas. Launched in November 2017 after an initial test, AAA promotes Hop On as the first long-term autonomous shuttle pilot for the public on open roads. AAA is sponsoring the pilot to introduce driverless vehicles to the public. The shuttle travels without a driver through eight city intersections, with six traffic lights and two stop signs. There are three stops along the route. There is a Keolis attendant and AAA brand ambassadors on-site at the Container Park stop along the route while the shuttle is operating. Real-time information on the location of the shuttle is available online.

After a fender bender with a delivery truck shortly after initiating service, which was cited by police as the truck driver's fault, the shuttle has operated for ten months without any incidents. The online passenger rating for the shuttle is at 4.9 out of 5 stars.

Autonomous Shuttles, Bishop Ranch, San Ramon

The EasyMile EZ10 autonomous shuttles are also being used in a pilot project at Bishop Ranch, a 585-acre multi-use business community in San Ramon, California. The pilot represents a partnership of the Contra Costa Transportation Authority (CCTA), GoMentum Station, Bishop Ranch, and EasyMile.

The pilot represents the third phase of a project focused on testing an autonomous shuttle on public roads in California. During the first phase, the EZ10 shuttles were tested at GoMentum Station, the CCTA's autonomous proving grounds in Concord. The second phase included testing the shuttles in parking lots at Bishop Ranch. The CCTA received permission from the USDOT's National Highway Traffic Safety Administration in October 2017 and permission from the California Department of Motor Vehicles (DMV) in January 2018 to operate the EasyMile shuttles on public streets in Bishop Ranch. The action by the California DMV represents the first permission granted by the department for shared autonomous vehicles to travel on public roads in the state.

The autonomous shuttles will provide connections to Bay Area Rapid Transit stations adjacent to Bishop Ranch. The shuttles will help address the first- and last-mile issues with public transportation services. Currently, the shuttles are being tested with trained operating personnel. It is anticipated that, over the next year, additional predetermined testers and evaluators selected from Bishop Ranch employers will be able to ride the shuttles. Service open to the public is envisioned to occur after this more extensive testing is completed.

Mcity Driverless Shuttle Research Project, University of Michigan North Campus

Two driverless 11-passenger all-electric AUTONOM Shuttles manufactured by NAVYA began operating on the University of Michigan (U-M) campus in June 2018. The shuttles use GPS for location and LiDAR to view the surrounding environment. Although the vehicles operate in an autonomous mode, a safety conductor is onboard to take control if needed and to start the vehicle after a stop sign or pedestrian or bicyclist gets too close. Figure 3 illustrates the shuttle in operation on the U-M North Campus.

Source: University of Michigan.

Figure 3. The Mcity Driverless Shuttle.

The two shuttles operate a one-mile round trip on the U-M North Campus Research Complex, linking parking and bus stops. The shuttles operate on U-M roads. Service is provided free from 9:00 a.m. to 3:00 p.m., Monday through Friday, weather permitting. Riders can track the location of the shuttle via DoubleMap.

The research project represents a partnership involving Mcity, U-M Logistics, Transportation, and Parking, and NAVYA. Prior to initiating the demonstration, approximately 1,000 test runs were completed at Mcity, with additional test runs and training for the safety conductors completed on the North Campus.

During the one-year project, U-M researchers and J.D. Power will be monitoring use levels, rider feedback, and shuttle interaction with bicyclists, pedestrians, and motor vehicles. Interior cameras record passenger reactions and external cameras record the reactions of other road users. J.D. Power is conducting surveys of riders. The results of these activities will provide a better understanding of consumer acceptance of driverless vehicles and assist with planned expansion of the shuttle system.

Autonomous Shuttles, Texas A&M University Campus and Downtown Bryan

Different applications of low-speed autonomous shuttles are being developed and tested by faculty at Texas A&M University and researchers at TTI. Faculty in the Mechanical Engineering Department in the College of Engineering at Texas A&M University have developed low-speed autonomous shuttles and conducted demonstrations on the Texas A&M campus, at a nearby hotel/country club, and in downtown Bryan. A one-day demonstration of a NAVYA autonomous shuttle conducted on the Kyle Field Plaza on the Texas A&M campus was sponsored by TTI and the Texas A&M University Transportation Services as part of the Technology Initiative and the Campus Transformational Mobility Plan.

A demonstration of the NAVYA Autonom Shuttle was conducted on the Texas A&M campus on November 6, 2018. The 12-passenger electric vehicle operated from 10:00 a.m. to 2:00 p.m. on Kyle Field Plaza. As illustrated in Figure 4, the off-road straight-line course was cordoned off by fencing and tape. The vehicle operated down and back, for a total of a quarter-mile trip. The NAVYA Shuttle uses LiDAR sensors, cameras, and GPS TRK, along with interpretive deep learning programs for autonomous operation. A safety operator was onboard at all times during the demonstration, but it was never necessary to take control.

Source: Texas A&M Transportation Institute.

Figure 4. The NAVYA Shuttle on the Texas A&M Campus.

The demonstration introduced the use of a low-speed autonomous shuttle on the Texas A&M campus as a way to improve mobility, connectivity, and safety to support development of the Campus Transformational Mobility Plan and implementation of the recently updated Campus Master Plan. Shuttle riders were surveyed to help gauge interest and use by students, faculty, staff, and visitors. A total of 87 surveys were completed by passengers during the four-hour demonstration. As highlighted below, the responses were very positive to operation of the shuttle on campus.

- Over half of the survey respondents, 56 percent, were students. The remaining respondents included 35 percent faculty and staff, 7 percent visitors, and 2 percent local residents.
- In response to the question on their reaction to riding the shuttle, 73 percent reported being extremely positive and 27 percent were somewhat positive, for a total of 100 percent responding extremely positive and somewhat positive.
- If the shuttle operated regularly, 52 percent responded that it was extremely likely they would use it, with 39 percent reporting that it was somewhat likely they would use it, for a total of 91 percent. The remaining responses were split between somewhat unlikely to use, 3.5 percent; extremely unlikely to use, 2 percent; and not sure, 3.5 percent.
- The vast majority of respondents, 95 percent, strongly agreed (51 percent) or agreed (44 percent) that an autonomous shuttle would be a positive improvement to the campus.

- There was even stronger agreement that an autonomous shuttle would provide a useful mobility option on campus, with 54 percent of the respondents strongly agreeing and 44 percent agreeing, for a total of 98 percent.
- A total of 92 percent of the respondents strongly agreed (48 percent) or agreed (44 percent) that an autonomous shuttle would provide a safe travel option on campus.
- A total of 82 percent of the respondents strongly agreed (37 percent) or agreed (45 percent) that an autonomous shuttle would be safe for bicyclists and pedestrians in its vicinity, while 18 percent were not sure.

The survey results are being used to inform the development of the Campus Transformational Mobility Plan and the implementation of the Updated Campus Master Plan. Based on the positive responses, the plan includes a long-term vision of an electric autonomous transit system, with articulated buses, 45-foot buses, and shuttles matched to service needs and ridership demands. A longer demonstration of a NAVYA shuttle, which might include operation on campus roadways, is being planned for spring 2019.

Faculty in the Texas A&M University Mechanical Engineering Department have developed, tested, and piloted autonomous shuttles on campus, at a nearby hotel/country club, and in downtown Bryan, Texas. Figure 5 illustrates the self-driving trolley pilot in downtown Bryan. Polaris GEM and Yamaha vehicles have been equipped with LiDAR, stereo, and GPS/INS for waypoint following, obstacle determination, and path planning. The shuttles operate at speeds of 5- to 10-mph and have a safety operator onboard who can take control if needed.

The self-driving trolley pilot in downtown Bryan was initiated on October 31, 2018. Two trolleys operated on city streets following a clockwise loop from the Roy Kelly Parking Garage to the Carnegie Library and the commercial downtown area. During the initial pilot, two self-driving trolleys were in service for two hours a day, Monday through Friday, primarily between 10:00 a.m. and 4:00 p.m. The daily schedule varied based on downtown activities, the weather, and student safety operator availability. It is anticipated that the pilot will continue in early 2019 after the holidays.

Figure 5. Self-Driving Trolley Piloted in Downtown Bryan.

European Driverless Transit Shuttles

A variety of pilots and demonstrations of automated and autonomous shuttles have continued in Europe, building on the CityMobil2 projects. Examples of projects in Finland and the United Kingdom are highlighted next.

SOHJOA is an electric driverless minibus or robobus system in the Helsinki Smart Region. SOHJOA, which uses the EasyMile EZ10 vehicles, has been undergoing three years of tests, pilots, and deployments in the area, including operating on public roads. Finnish law does not require that vehicles on public roads have a driver inside the vehicle, making testing the driverless shuttles easier. Helsinki is also moving forward with other mobility on demand systems and mobility as a service concepts as part of a 10-year plan to make vehicle ownership unnecessary.

In addition to developing new types of automated transportation services, SOHJOA also focuses on increasing the understanding of the rapid changes influencing the transportation sector and public response to new services. The project is also establishing open platforms that companies can use to develop additional products and services.

The SOHJOA – 6Cities is one element of the Finnish collaborative 6Aika-project family, which is financed by the European Structural Fund. Partners in the project are Aulto University, Forum Vivium Helsinki, the Finnish Geographical Institute, and the Tempere University of Technology. The City of Helsinki is also supporting the demonstrations, as is the Nordic Way project funded by the Finnish Transport Safety Agency Trafi and the Finnish Transport Agency Liikennevirasto.

The SOHJOA project includes a number of elements. Two EasyMile EZ10 electric minibuses began operating in the Helsinki Hernesaari waterfront district in August 2016. The vehicles operated in an autonomous mode on a straight, quarter-mile course on a public street, with an operator onboard to take control if needed. The tests continued in the summer of 2017, with the shuttles providing service between Helsinki's Mustikkamaa recreation island and the Helsinki Zoo.

The Helsinki RobobusLine initiated service in May 2018 using a NAVYA self-driving electric minibus. The route operates in mixed traffic on roads in the Kivikko district of Helsinki. The service on the 6-month pilot is provided from 9:00 a.m. to 3:00 p.m. on weekdays. An operator is onboard the vehicle to take control if needed and to explain the system to riders. The pilot presents an example of using driverless shuttles for first- and last-mile transit service.

The NAVYA minibus guidance and detection systems use data from LiDAR sensors, cameras, GPS TRK, IMU, and odometry. The data are merged and interpreted using deep-learning programs. The RobobusLine project is supported by the European Union funded by the mySMARTLife project, which focuses on developing commercial-scale solutions to reduce carbon-dioxide emissions.

Driverless, low-speed shuttles have been piloted and demonstrated in a number of cities in the United Kingdom. UK Autodrive, funded by Innovate UK, is piloting the use of self-driving shuttles in Milton Keynes and Coventry. The three-year project includes the initial testing of electric-powered, self-driving pods in the Milton Keynes town center in 2017, as well as the piloting of up to 40 pods focusing on first- and last-mile connections in 2018.

The Pod Zeros are manufactured by Aurrigo, a division of the UK company RDM Group. Ten pods were delivered in May 2018 for initial testing. The full fleet, or "whale of pods," is anticipated by the end of 2018. The pod system includes a control center in the middle of town. The pods travel at speeds of up to 15 mph and operate up to 60 miles off one electric charge. An ongoing assessment of the system, including user reactions, operations, and interaction with other road users, is planned.

SMARTPHONE APPS FOR PEDESTRIANS AND BICYCLISTS

Warning pedestrians and bicyclists of a turning bus via a smartphone app was one of the candidate applications developed in Phase I. As discussed in technical memoranda 1.2 and 2.2, an Android app was developed and tested as part of Phase II. To assist with the app's development, researchers reviewed other related projects. Three related smartphone apps are summarized in this section, including one that provided open architecture for the development of the app in this project.

TravelSafely™ app, Atlanta North Avenue Smart Corridor

The North Avenue Smart Corridor in Atlanta encompasses a 2.3-mile segment from Ponce City Market to Georgia Tech University. The smart corridor incorporates a number of technologies and applications to improve safety and traffic flow. Project elements include sensors, adaptive traffic signals, signal priority for fire trucks and ambulances, vehicle-to-infrastructure communication, and a Bluetooth® travel time and origin/destination system. Connected automated vehicles and low-speed, autonomous shuttles are being piloted. Roadway segments are being restriped to support crash reduction strategies and autonomous vehicles. The project represents a partnership among the Georgia Department of Transportation (GDOT), the City of Atlanta, Georgia Tech, Renew Atlanta, and multiple technology companies.

The TravelSafely smartphone app, developed by Applied Information, is one element of the smart corridor. The app includes numerous features for drivers, pedestrians, and bicyclists. Alerts are provided to pedestrians and bicyclists at intersections if vehicles are approaching too closely. Drivers are alerted to bicyclists and pedestrians, as well as to work and school zones, curves, the potential of a rear-end collision with another vehicle, and the potential to run a red light. The TravelSafely app was introduced in beta mode in December 2017.

Wayfinding App for Transit Riders with Visual Impairments, Houston METRO

In partnership with Houston METRO, TTI was selected for a Google Internet-of-Things Research Pilot grant to assist individuals with visual impairments in locating bus stops. As part of the grant, Google provided METRO with 300 Bluetooth Low Energy (BTLE) beacons to be installed at METRO bus stops.

As illustrated in Figure 6, the beacons are small enough to be installed inconspicuously at bus stops and have a long-enough battery life to make them a scalable alternative to other types of wireless broadcasting devices. The beacons broadcasted a unique bus-stop-specific code using an open Bluetooth, low-energy protocol.

As part of the project, METRO developed a proof-of-concept Android app that allows blind individuals and persons with limited sight to select a specific bus stop, with the app providing distance-to-stop estimates using the strength of the signal from the specific bus stop's beacon.

As illustrated in Figure 7, METRO and TTI pilot tested and evaluated the app with a small group of visually impaired transit riders. A majority of the individuals participating in the pilot reported they would likely use the app if the beacons were installed throughout the METRO system. In addition, most participants reported they would likely use METRO buses and trains more often if the app was fully deployed at all stops.

Based on the results of the initial pilot, METRO is planning a larger pilot test on 12 bus routes. Full deployment of the beacons to all 9,000 bus stops in the system could occur by 2019.

Source: Texas A&M Transportation Institute.

Figure 6. Bluetooth Device on METRO Bus Stop Sign.

Source: Texas A&M Transportation Institute.

Figure 7. Test of App with Visually Impaired Bus Riders.

Federal Highway Administration — Pedestrian Mid-Block Crossing Application

The Federal Highway Administration (FHWA) Turner Fairbank Highway Research Center developed and tested a Pedestrian Mid-Block crossing smartphone app. The project focused on providing pedestrians at configured mid-block crosswalks with a method to communicate their intent to cross the street to approaching drivers. An Android app was developed using a cloud-server component, allowing a pedestrian in the geo-fenced area near the crosswalk to instruct the server to send a message to drivers' devices for the time period needed to cross the street. The driver's Android app, which resembles an in-vehicle navigation app, provides audio-visual feedback to the driver when it receives a broadcast from the server. The system was tested at the center.

The open-source architecture used in the Android app is available on FHWA’s website. As discussed in technical memoranda 1.2 and 2.2, the open-source app was used as the basis for developing the smartphone app for this project.

CURRENT RESEARCH PROJECTS

Research projects and other related activities were included in the ongoing monitoring during Phase II. A few examples of research projects and pilots are summarized in this section.

University of Nevada, Reno and Proterra Partner on Autonomous Public Transit Research

Researchers from the University of Nevada, Reno are working with Proterra (which manufactures electric buses), the City of Reno, and other agencies to instrument city buses with cameras, sensors, and other technologies. The buses are collecting data on roadside objects, traffic, and bicyclists and pedestrians along Virginia Street. Sensors and radios on streetlights are being used to communicate information to the buses on upcoming traffic.

The first phase of the research project focuses on collecting data for at least a year to gather conditions in all seasons. In the second phase, researchers will evaluate the data and develop “robotic” perception algorithms of the environment around the buses throughout the corridor. The algorithms will be used to test operations in different modes. The third phase will include licensing and commercializing the algorithms for use in other areas.

Bluetooth Pedestrian Awareness System (BPAS)

Houston METRO is currently demonstrating Bluetooth beacon technology to warn pedestrians and bicyclists of an approaching METRORail train at selected locations along the Red Line near the Lamar, Wheeler, Sunset, and Dryden crossings. The equipment includes a Bluetooth reader processor and an audio announcement that is triggered when known BTLE beacons are within proximity. The beacons are installed on all trains using the Red Line.

The reader processor is constantly “listening” for the known BTLE beacon associated with the Red Line trains. The process is essentially the reverse of the technique used for the Bluetooth travel-time-monitoring system for TranStar. That system captures media access control addresses from enabled equipment in vehicles and matches them at successive locations to determine travel times.

METRO sponsored a survey of pedestrians and bicyclists, conducted by TTI, at the demonstration locations. Of the 160 individuals surveyed, 83 percent were aware of and recognized hearing the audible warning. Based on follow-up questions, of the respondents who were aware of the audible warning, 44 percent said the audible warning was very useful and 46 percent thought the audible warning was somewhat useful.

METRO is continuing to monitor the demonstration. The use of the BTLE beacons may be expanded to other locations along the METRORail system.

U.S. Department of Transportation (USDOT) and European Commission (EC) Research Projects Using Simulation to Examine the Behavior and Interaction of Drivers, Pedestrians, and Bicyclists

One EC and two USDOT projects using simulators to examine the travel behavior of drivers, pedestrians, and bicyclists are being twinned, a term that refers to the encouragement of collaboration among researchers on all projects, regardless of national borders, without exchanging funds. The EC project is Simulator of Behavior Aspects for Safer Transportation (SIMUSAFE). The two USDOT projects are Developing Connected Simulation to Study Interactions Between Drivers, Pedestrians, and Bicyclists and InterchangeSE: A Federated Multimodal Simulation Environment for Studying Interactions between Different Modes of Travel.

SIMUSAFE focuses on using state-of-the-art simulators, artificial intelligence, virtual reality, and data science methodologies to analyze actor and behavioral models and to reproduce these in controlled traffic simulators, assessing causes and consequences. Different automobile, motorcycle, bicycle, and pedestrian simulators are being used. SIMUSAFE is 42-month project scheduled for June 2017 to November 2020. The project budget is approximately €8 million. The coordinator on SIMUSAFE is the Instituto Tecnológico de Castilla y León, Spain.

The first USDOT project, Developing Connected Simulation to Study Interactions Between Drivers, Pedestrians, and Bicyclists, focuses on developing an innovative mixed-mode connected driving, pedestrian, and bicycling simulator system. It incorporates graphical avatars into the simulation to represent the live movement of drivers, bicyclists, and pedestrians to refine scenario control and data analysis for multi-participant simulation research. The project will design and run intermodal, multi-user simulator experiments. It covers 24 months from September 2017 to September 2019. The project budget is approximately $1.8 million, and it is being conducted by the University of Iowa.

The second USDOT project, InterchangeSE, focuses on simulating CAVs in a partially connected-automated traffic environment. The project is studying the interactions among multiplayers using different modes of travel. Elements being examined include multiplayer interactions, different decision perspectives, and different levels of immersion. Stress data is being collected and analyzed, and a performance monitoring system (PeMS) is under development. The project is also assessing the social impacts of CAVs on transportation safety and mobility. The InterchangeSE project covers the time period from October 2017 to September 2020. The project budget is approximately $1.2 million. Iowa State University and BANC3 Engineering are conducting the InterChangeSE project.

All three projects share some similarities. They all focus on improving traffic safety, especially for vulnerable road users, by utilizing simulation. All three study interactions among stakeholders and use different types of driving, cyclists, and pedestrian simulators. Twinning activities are anticipated to focus on exchanging expertise, sharing and providing feedback on scenario designs, and sharing experiences with simulation models. Other possible activities include modular exchanges, examining hardware interoperability, and dataset exchanges.

The anticipated benefits from Twinning on these projects will derive from exchanging expertise and experiences on the technical elements associated with the use of different simulators and scenarios and the interpretation of behavioral measurements of road safety impacts. The end results from all three projects will provide traffic safety benefits to all travelers, especially vulnerable road users, in the transition to a more automated and connected vehicle future. The results will help in targeting strategies to reduce conflicts among buses, bicyclists, and pedestrians.

University of Minnesota — Smart Human Centered Collision Warning System: Sensors, Intelligent Algorithms and Human-Computer Interfaces for Safe and Minimally Intrusive Car-Bicycle Interactions

The Phase I report highlighted the Novel Collision Avoidance System for Bicycles project, which included researchers at the University of Minnesota developing and testing a sensor-based system for bicycles that predicts imminent bicycle-motor vehicle crashes and sounds a horn to alert the motorists of the bicycles presence. The system is designed to address two common types of crashes involving bicycles and motor vehicles — rear-end collisions, when a vehicle is approaching a bicycle from behind, and collisions involving bicycles and motor vehicles at intersections. The system uses sonar, laser sonars, and a collision-prediction algorithm. The algorithm was initially tested in simulation studies. The results of tests of a bicycle equipped with sensors, electronics, and a small computer operated on the University of Minnesota campus indicated that the bicycle-sensor system can accurately estimate vehicle position and orientation for the two sensors.

Building on this project, the researchers received a National Science Foundation grant in 2017 to further implement the bicycle collision-warning system, including possibly developing it for commercialization. The research team is partnering with Quality Bicycle Products on the commercialization activities.

III. USE CASES AND ALERT SCENARIOS

This section presents the use cases and alert scenarios for the smart intersection. Figure 8 provides an orientation to a typical four-way signalized roadway intersection used to develop the use cases. Table 1 contains the basic information on the use cases, including the bus location and action, the pedestrian location and action, and comments about the potential bus/pedestrian interaction. The situations when a pedestrian is not present are also noted. No alert of the turning bus is provided in these situations. More detailed descriptions are provided for each use case, including figures illustrating the location of the connected transit bus, the path of the bus, the location of the pedestrian, the pedestrian waiting area, and the street crossing conflict zone. The use cases noted by an asterisk (*) were included in the proof-of-concept test described in Section VI.

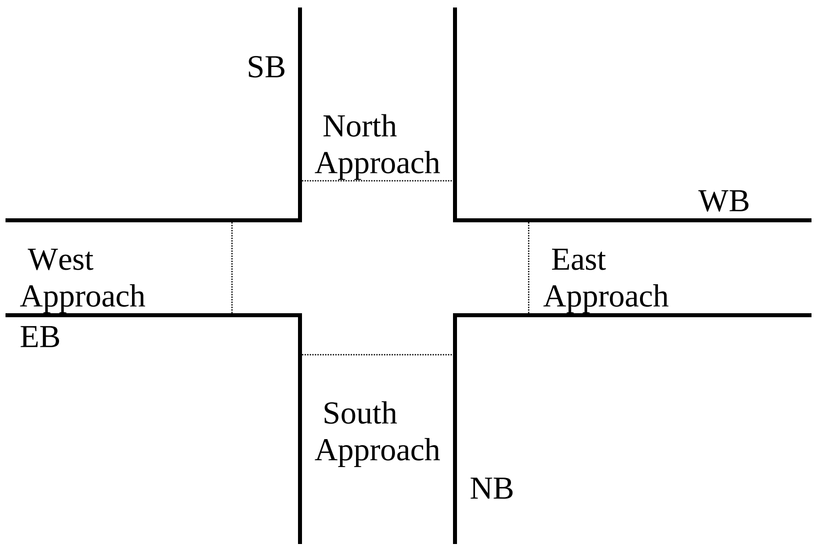


Figure 8. Smart Four-Way Intersection.

Table 1. Smart Intersection Uses Cases.

Number	Bus Location	Bus Action	Pedestrian Waiting Location	Pedestrian Action (Crosswalk)	Comment
1A*	South Approach	Turning Right	Waiting SE Corner	East Approach	Bus is coming from behind the pedestrian
1B*	South Approach	Turning Right	None	None	No pedestrian, so alert is not activated
2A*	North Approach	Turning Left	Waiting NE Corner	East Approach	Bus is coming from behind the pedestrian
3A*	South Approach	Through	Waiting SE Corner	East Approach	Alert would not be activated
3B	South Approach	Through	Waiting SE Corner	East or South Approach	Alert activated if pedestrian in East Approach
4A*	South Approach	Turning Right After Bus Stop	Waiting SE Corner	East Approach	Bus is coming from behind the pedestrian
4B	South Approach	Turing Right After Bus Stop	Waiting SE Corner or at Bus Stop	East Approach or in Road Near Bus Stop	Bus is coming from behind the pedestrian
5A*	South Approach	Bus 1- Through Bus 2 - Turning Right	Waiting SE Corner	East Approach	Bus is coming from behind the pedestrian
5B	Multiple Approaches	Turning and Through	Multiple Locations	Multiple Approaches	Multiple Approaches
6A*	South Approach	Unknown	Waiting SE Corner	East Approach	Bus is coming from behind the pedestrian
6B	South Approach	Unknown	Waiting SE Corner	East Approach	Bus is coming from behind the pedestrian
6C	South Approach	Unknown	Waiting SE Corner	East Approach	Bus is coming from behind the pedestrian

* Denotes use cases included in the proof-of-concept tests described in Section VI.

USE CASE 1A: RIGHT-TURNING CONNECTED BUS WITH A PEDESTRIAN IN THE PEDESTRIAN DETECTION ZONE

This use case represents the base condition defining normal operations of the smart intersection. As illustrated in Figure 9, in this scenario, a connected bus approaches the intersection from the south, heading northbound. The bus route requires the bus to make a right turn at the intersection and travel eastbound on the cross street. The bus, equipped with a dedicated short range communication (DSRC) onboard radio unit (OBU), broadcasts Part I of the basic safety message (BSM). Part I of the BSM contains information about the position of the bus (latitude and longitude) and the speed and heading of the bus, as well as other information associated with the current route and turning movements of the bus based on data from the transit agency's automated routing and scheduling system. In addition to Part I of the BSM, the bus would also broadcast the elements containing the agency and bus identification number. This information is contained in Part II of the BSM. Since Part II is optional, the transit agency would have to configure their equipment to provide this information.

When the bus comes within range, the roadside unit (RSU) receives both parts of the BSM (hereafter referred to as the enhanced BSM) from the bus. An application in a cabinet on the roadside processes the enhanced BSM message from the bus and extracts the agency and bus identification number associated with the bus. The application compares these values with the route/bus trip information uploaded from the transit management center (TMC). Using this information, the application determines that the route of the bus requires it to make a right turn at the intersection.

When the bus reaches the designated distance from the intersection, the application residing on the roadside equipment (RSE) in the traffic signal cabinet uses information from the pedestrian detection system to determine if a pedestrian is located in the pedestrian detection zone conflicting with the bus movements at the intersection. A pedestrian detection zone is defined as the waiting area on the curb or the conflict zone in the crosswalk. If the pedestrian detection system detects that a pedestrian is located within the pedestrian detection zone, the application will activate the pedestrian alert system. The pedestrian alert system (PAS) could take a number of different forms including an audible alert through an annunciator mounted at the intersection, a visual warning on the traffic signal, or a smartphone app. The smart intersection application could also send a roadside alert (RSA) message to the bus operator indicating the need to watch for pedestrians in the crosswalk.

The smart intersection application will continue to broadcast the alert until either 1) the pedestrian leaves the pedestrian detection zone or 2) the bus completes its turn and the rear of the bus clears the intersection. Once the bus clears the intersection, the application deactivates the alert messaging system and returns to processing incoming BSMs to locate other potential conflicts between buses and pedestrians. As described in Use Case 1B, if the application does not detect a pedestrian in the pedestrian detection zone, the application does not activate the PAS.

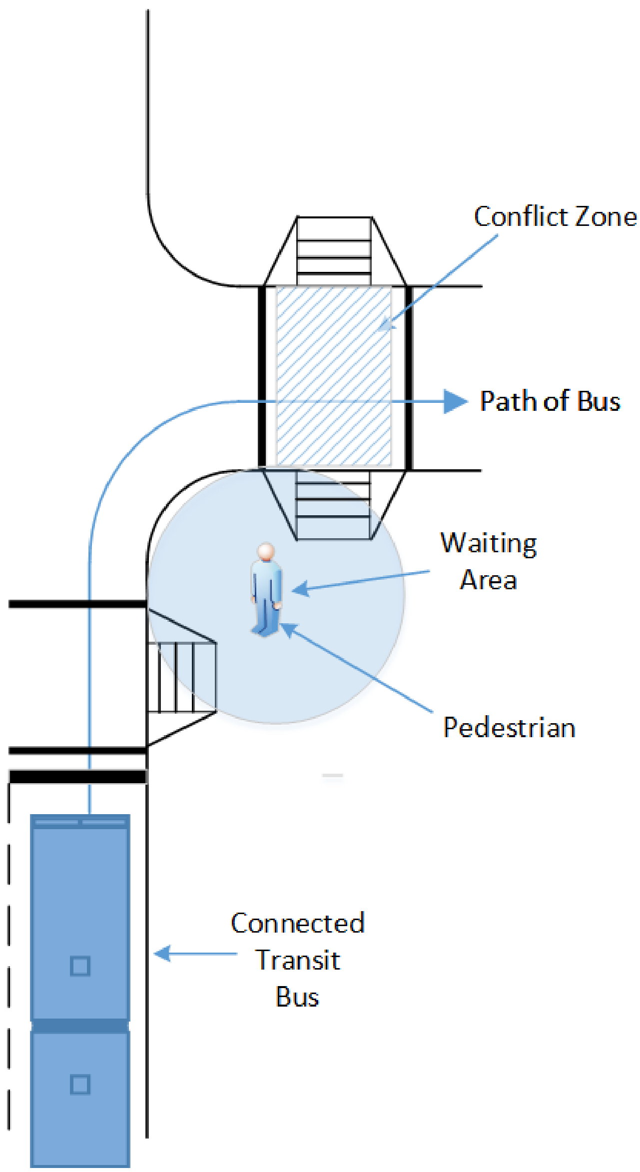


Figure 9. Use Case 1A: Right-Turning Bus with a Pedestrian in the Pedestrian Detection Zone.

USE CASE 1B: RIGHT-TURNING BUS WITH NO PEDESTRIAN IN THE PEDESTRIAN DETECTION ZONE

As illustrated in Figure 10, in this variation of Use Case 1 no pedestrian is present in the waiting area or the crosswalk conflict zone. As in Use Case 1, the BSMs of all connected vehicles approaching the intersection are being monitored. When the system detects that it has received an enhanced BSM from a bus, the system compares the agency and bus information contained in the enhanced BSM message to the route and bus trip information provided by the TMC to determine if the route of the bus requires it to turn right at the intersection. If the application determines that the bus is going to turn right, the application then determines if there is a pedestrian located in the pedestrian detection zone. In this use case, no pedestrian is detected in the pedestrian zone. As a result, the PAS is not activated, and no alert is provided to the bus operator.

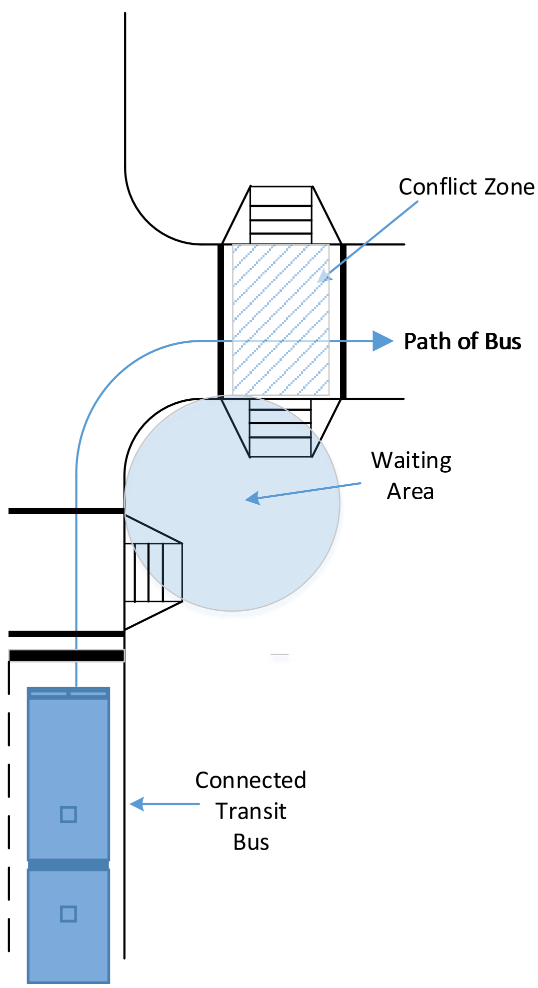


Figure 10. Use Case 1B: Right-Turning Bus with No Pedestrian in the Waiting Area or Conflict Zone.

USE CASE 2A: LEFT-TURNING BUS WITH A PEDESTRIAN LOCATED IN THE OPPOSITE CORNER OF THE PEDESTRIAN DETECTION ZONE

This use case involves a left-turning bus and a pedestrian waiting to cross the street on the opposite corner, as illustrated in Figure 11. As in the other use cases, the bus approaching the intersection would be broadcasting its enhanced BSM, which includes agency and bus identification information. The application would use this information along with the route and bus trip information received from the TMC to determine that the bus will turn left at the intersection. The detection system would alert the application that a pedestrian is located in the pedestrian detection zone. The application would issue an alert indicating that a bus is approaching the crosswalk and that pedestrians should watch for a left-turning bus. The application could also send an RSA message to the bus driver indicating to watch for pedestrians in the opposing crosswalk.

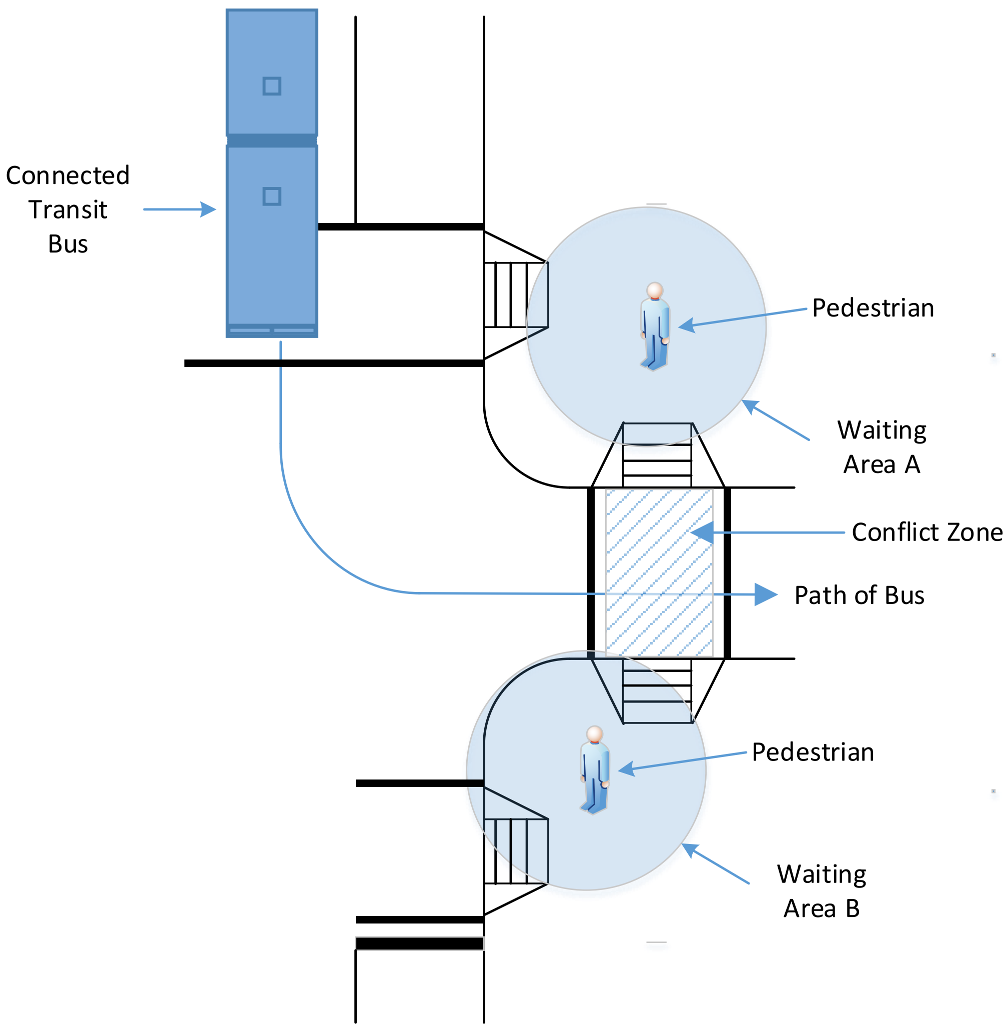


Figure 11. Use Case 2A: Left-Turning Bus with a Pedestrian Located in the Pedestrian Detection Zone on the Opposite Corner.

USE CASE 3A: THROUGH BUS WITH A PEDESTRIAN LOCATED IN THE PEDESTRIAN DETECTION ZONE.

This use case is similar to Use Case 1A except that instead of turning right, the route of the bus is straight through the intersection. Figure 12 illustrates this use case. As the bus approaches the intersection, the application, using the enhanced BSM from the bus, compares the agency and vehicle ID of the bus to the route and bus trip information uploaded by the TMC and determines that the route of the approaching bus does not require it to make a right turn at the intersection. As the bus is not expected to turn right at the intersection, the application would not activate the pedestrian alert system when a pedestrian is located in the pedestrian detection zone.

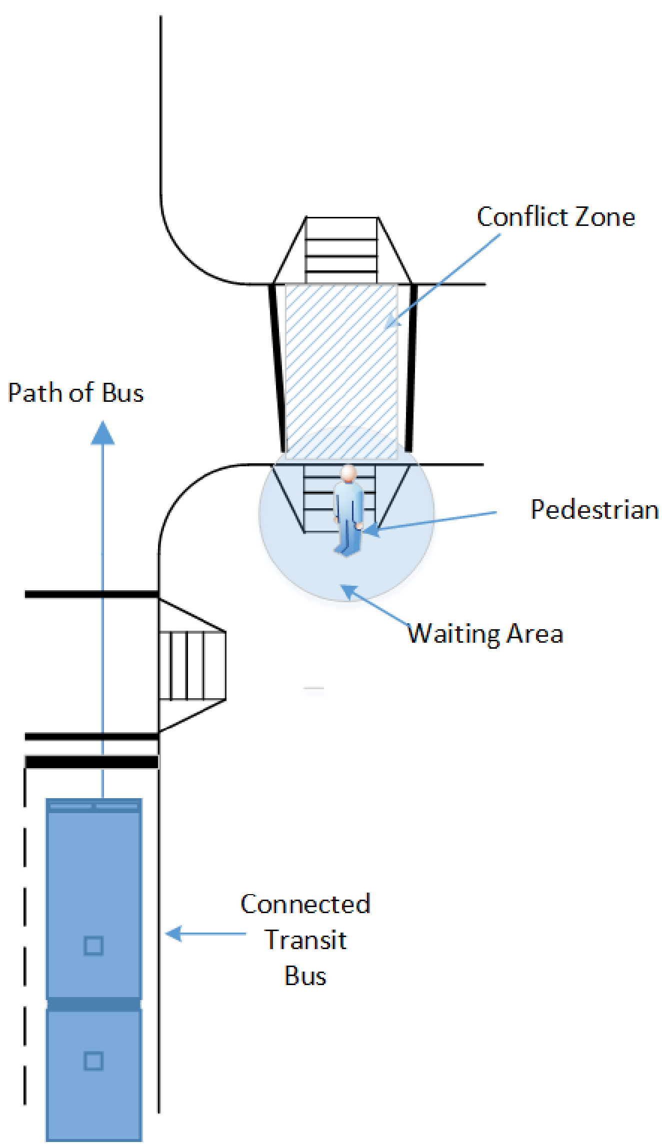


Figure 12. Use Case 3A: Through Bus with a Pedestrian Located in the Pedestrian Detection Zone.

USE CASE 3B: THROUGH BUS WITH TWO PEDESTRIAN DETECTION ZONES.

An alternative to Use Case 3A is overlapping pedestrian detection zones — one on each leg of the intersection. Figure 13 illustrates this use case. The pedestrian detection system would be configured to determine whether the pedestrian is located in Pedestrian Detection Zone A, facing the path of the through bus, or Pedestrian Detection Zone B. If the pedestrian is located in Pedestrian Detection Zone A, an alert would be issued. If the pedestrian is located in Pedestrian Detection Zone B, no alert would be issued.

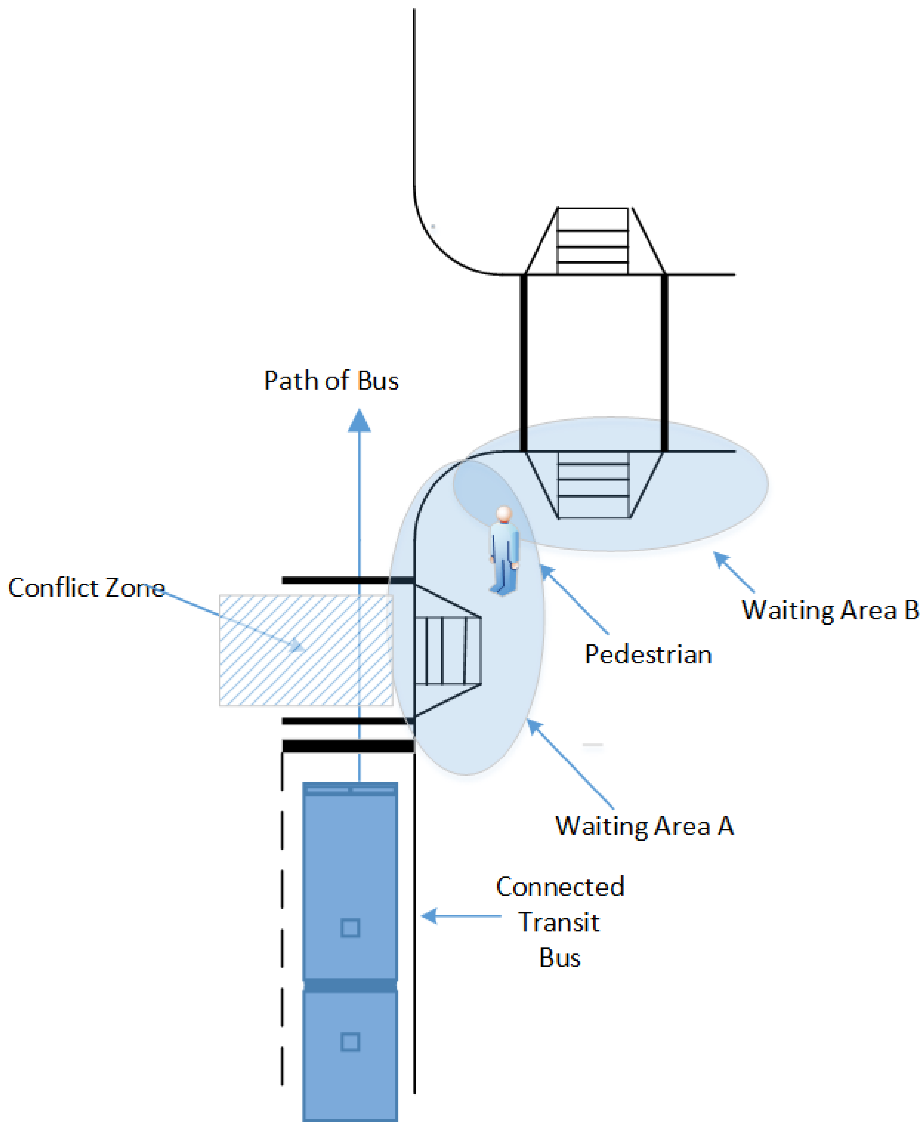


Figure 13. Use Case 3B: Through Bus with Two Pedestrian Detection Zones.

In both Use Cases 3A and 3B, an RSA message can be sent to the bus alerting the driver that there is a pedestrian located in the pedestrian detection zone. Several automobile manufacturers have already implemented pedestrian detection warnings that provide this type of warning to drivers of automobiles using forward-looking radar systems.

USE CASE 4A: TURNING BUS STOPPING AT A NEARSIDE BUS STOP

As illustrated in Figure 14, in this use case, a connected bus approaching an intersection stops at a nearside bus stop before reaching the intersection. The system detects that it has received an enhanced BSM from the bus and compares it to the route and bus trip information uploaded by the TMC; the system then determines that the bus will be turning right at the intersection but that there is a nearside bus stop. In this use case, no alert message would be triggered as the bus approaches the bus stop. Once the bus completes discharging and/or loading passengers at the bus stop and begins moving forward, the application detects that the bus is no longer stopped at the bus stop but is now approaching the intersection to begin its turn. The application would then use information from the pedestrian detection system to determine whether a pedestrian is located within the pedestrian detection zone. The appropriate alerts would be issued to the pedestrian and the bus operator if a pedestrian was detected in the zone.

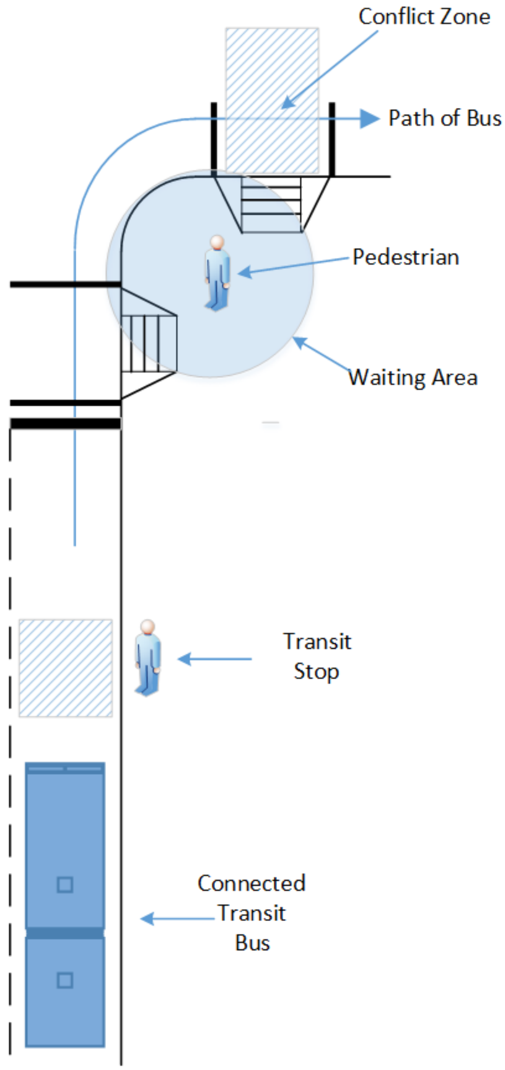


Figure 14. Use Case 4A: Turning Bus Stopping at a Nearside Bus Stop before Initiating Turn.

USE CASE 4B: TURNING BUS STOPPING AT A NEARSIDE BUS STOP WITH TWO PEDESTRIAN DETECTION ZONES

Figure 15 presents an alternative to Use Case 4A. Two distinct pedestrian detection zones are established in this use case — one covering the intersection and one covering the bus stop. In this use case, separate alerts would be issued for pedestrians located in each detection zone. As the bus approaches the bus stop, the system would alert pedestrians near that bus stop that a bus is approaching. The pedestrian detection zone could be designed only to cover the pedestrian located in the street or very near the edge of the roadway. This alert would continue until the doors of the bus opened. Once the doors of the bus are closed and the bus moved up to the intersection, a separate alert would be issued for pedestrians located in the detection zone near the intersection.

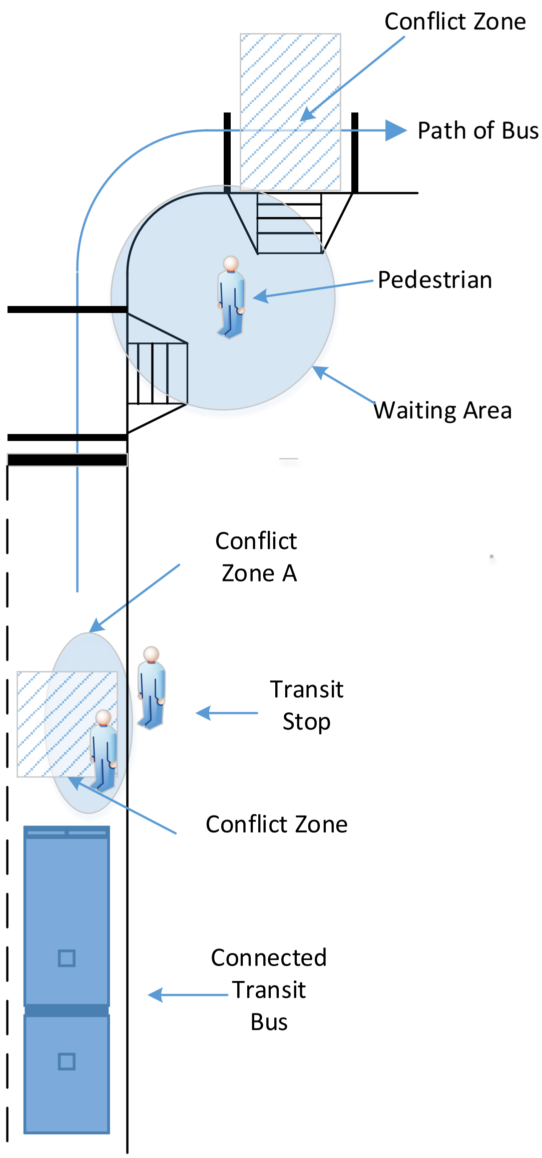


Figure 15. Use Case 4B: Turning Bus Stopping at a Nearside Stop with Two Pedestrian Detection Zones.

USE CASE 5A: TWO BUSES APPROACHING THE INTERSECTION IN SAME DIRECTION

In this use case, two buses are approaching the intersection in the same direction. The route for one of the buses is traveling straight through the intersection, while the route of the other bus is turning right at the intersection. These buses may or may not stop at the nearside bus stop. Using the enhanced BSM information from each bus, the application would determine the maneuver for each bus and issue the appropriate alert at the appropriate time if a pedestrian is located in the detection zone. No alert would be provided for the through bus, while an alert for the right-turning bus would be provided if a pedestrian is detected in the intersection detection zone. Figure 16 illustrates this use case. The leading bus is traveling straight through the intersection while the trailing bus is turning right at the intersection. The application would wait to issue the alert for the right-turning bus until the through bus has entered the intersection. The application would issue an alert if a pedestrian is in the detection zone when the trailing bus reaches the intersection.

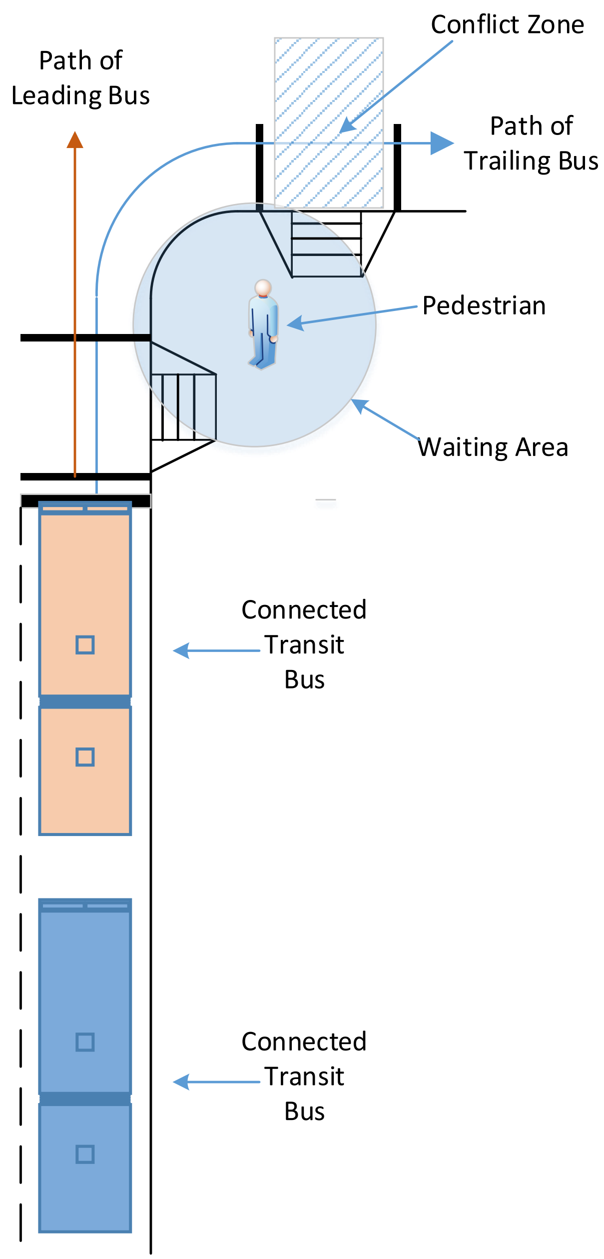


Figure 16. Use Case 5A: Two Buses Approaching the Intersection in the Same Direction.

USE CASE 5B: MULTIPLE BUSES APPROACHING THE INTERSECTION SIMULTANEOUSLY FROM DIFFERENT DIRECTIONS

In this use case, multiple buses approach the intersection from different directions, each with different routes and intersection turning maneuvers. The application would handle each process as described in previous use cases. The application would be able to prioritize alert requests to initiate the most important alerts at the right time and to avoid duplicate or overlapping alerts. The application could prioritize which alert is activated at a pedestrian waiting area based on which bus is expected to perform its intersection maneuver first. Maneuver timing would be a function of distance from the intersection, current signal phase, and average duration of maneuvers, as well as the presence of pedestrians in the detection zones.

USE CASE 6A: BUS VEHICLE ID NOT MATCHED TO ROUTE

In this use case, a bus successfully transmits the enhanced BSM information. The application is unable to determine the bus's route from data in the TMC, however, and is unable to predict the bus's maneuvers at the intersection. This situation may occur if a bus is not in service and not operating on a route, or if the bus was not assigned to the route by the TMC. In any situation where the application is not able to match the enhanced BSM information to the TMC route and bus trip information and verify the movement of the bus, the application will default to a fail-safe mode and issue an alert of a turning bus if a pedestrian has been detected in the detection zone.

USE CASE 6B: INCORRECT BUS ROUTE IN THE TRANSIT MANAGEMENT CENTER

In this use case, a bus successfully transmits the enhanced BSM and the TMC has a route assignment for the bus. The route assignment for the bus is incorrect, however, and does not match the route at the intersection. This situation may occur if a bus is reassigned due to maintenance or operational issues. As with use case 6A, the application will default to a fail-safe mode and issue an alert of a turning bus if a pedestrian has been detected in the detection zone.

USE CASE 6C: TEMPORARY OR LONG-TERM DETOURS

In this use case, a bus is on a detour from its regularly scheduled route that impacts its maneuvers at the intersection. Because detours may be initiated without much advance notice, the TMC may or may not have the detour in its records. In addition, the detail of the detour record could range from a single field to indicate whether the route is detoured to a complete route trace of the detour. As with Use Case 6A, the application will default to a fail-safe mode and issue an alert of a turning bus if a pedestrian has been detected in the detection zone.

IV. SYSTEM REQUIREMENTS

This section presents the system requirements for the smart intersection application. Elements of the system requirements include the system description, system configuration, system detection, system alerts, bus-route information, connected-bus information, and data-logging information. Information on each of these elements is presented in a table format and briefly summarized in this section.

SYSTEM DESCRIPTION

Table 2 presents the system description requirements category. The system name is the Connected Vehicle Transit Pedestrian Alert System (CV-TPAS). The CV-TPAS is located in a traffic-signal cabinet at a signalized intersection on the roadside. The CV-TPAS interfaces with the traffic-signal controller (TSC) at a signalized intersection. It also interfaces with the pedestrian detection system at a signalized intersection and is able to receive pedestrian detection inputs/calls from the pedestrian detection system when a pedestrian, bicyclist, or individual using a wheelchair is detected in a defined waiting or crossing area. The CV-TPAS will interface with a TMC, as well as a PAS and a DSRC RSU. The CV-TPAS will have the capability to broadcast and receive the Society of Automotive Engineers (SAE) I2735 2016 messages from equipped connected devices.

Table 2. Requirement Category: System Description.

Number	High-Level Requirement
1.1	The system shall be called the Connected Vehicle Transit Ped Alert System (CV-TPAS)
1.2	The CV-TPAS shall be located on the roadside in a traffic-signal cabinet at a signalized intersection
1.3	The CV-TPAS shall interface with the TSC at a signalized intersection
1.4	The CV-TPAS shall interface with the pedestrian detection system at a signalized intersection
1.5	The CV-TPAS shall be able to receive pedestrian detection inputs/calls from the pedestrian detection system at a signalized intersection when a pedestrian/wheelchair is detected in a pedestrian detection zone
1.6	The CV-TPAS shall interface with the TMC
1.7	The CV-TPAS shall interface with the PAS at a signalized intersection
1.8	The CV-TPAS shall interface with a DSRC RSU
1.9	The CV-TPAS shall have the capability to broadcast and receive SAE J2735 2016 messages from equipped connected devices

SYSTEM CONFIGURATION

Table 3 presents the elements in the system configuration requirement category. The CV-TPAS will have a Msg MapData (MAP) of the intersection as defined in the SAE J2735 2016-03 standard. The MAP will include geometric information about all the available vehicle lanes and the available pedestrian crosswalks at the intersection. The MAP will include the available movements from each lane at the intersection. The CV-TPAS will include a configuration file containing a mapping between the pedestrian waiting areas at the intersection and the pedestrians crosswalks defined in the MAP. The CV-TPAS will have a configuration file that maps between the available turning movements from traffic lanes and the affected pedestrian crossings at the intersection.

Table 3. Requirement Category: Configuration.

Number	High-Level Requirement	Rationale
2.1	The CV-TPAS shall have a MAP of the intersection as defined in the SAE J2735 2016-03 standard	The MAP of the intersection is necessary to geo-locate the bus at the intersection
2.2	The MAP shall include all the available vehicle lanes at the intersection	The lane information in the MAP is necessary to identify the lane in which the bus is traveling at the intersection
2.3	The MAP shall include all the available pedestrian crosswalks at the intersection	The crosswalk information in the MAP is necessary to determine which crosswalk conflicts with bus-turning movements at an intersection
2.4	The MAP shall include all the available movements from each vehicle lane at the intersection	The lane movement information is necessary to determine if a bus can make a left or right turn from a lane
2.5	The MAP shall include the location of the bus stops at the intersection	The information is needed to alert affected pedestrians at a bus stop close to the intersection and not to issue alerts to pedestrians at the intersection when the bus is stopped at the bus stop
2.6	The CV-TPAS shall have a configuration file that maps between the pedestrian detection zones at the intersection and the pedestrian crosswalks defined in the MAP	This configuration information is necessary to determine if a bus turning left or right at the intersection conflicts with a pedestrian waiting at a crosswalk
2.7	The CV-TPAS shall have a configuration file that maps between the available turning movements from lanes and the affected pedestrian crossings at the intersection	This information is necessary to determine if a bus turning left or right at an intersection conflicts with a pedestrian crossing the intersection

SYSTEM DETECTION

The system detection requirements are outlined in Table 4. The detection system will have the capacity to configure individual and multiple pedestrian detection zones. The system will have the ability to detect pedestrians, individuals using wheelchairs, and bicyclists in the pedestrian detection zone. The detection system will send a signal to the CV-TPAS when a pedestrian, wheelchair, or bicyclist is in a pedestrian detection zone and will remove the call when the pedestrian, wheelchair, or bicyclist is no longer present. The detection system will perform at all times of the day and night, as well as under all weather conditions.

Table 4. Requirement Category: Detection.

Number	High-Level Requirement	Rationale
3.1	The detection system shall have the capability to configure pedestrian detection zones	A pedestrian detection zone is defined as a waiting area on the curb or a conflict zone in the crosswalk
3.2	The detection system shall have the capability to configure multiple pedestrian detection zones	The pedestrian detection system shall be able to support multiple pedestrian detection zones
3.3	The detection system shall have the ability to detect pedestrians in a pedestrian detection zone	This functionality is necessary to provide alerts to pedestrians waiting to cross an intersection
3.4	The detection system shall have the ability to detect a wheelchair in a pedestrian detection zone	This functionality is necessary to provide alerts to pedestrians in a wheelchair waiting to cross an intersection
3.5	The detection system shall provide a unique output for each pedestrian detection zone	This functionality is necessary to provide alerts to pedestrians waiting at a crosswalk that a turning bus is approaching
3.6	The detection system shall send signal/call to the CV-TPAS when a pedestrian/wheelchair is in a pedestrian detection zone	This functionality is necessary for the CV-TPAS to know if a pedestrian is waiting in a pedestrian detection zone
3.7	The detection system shall remove the signal/call when a pedestrian/wheelchair is no longer in a pedestrian detection zone	This functionality is necessary for the CV-TPAS to know if a pedestrian is waiting in a pedestrian detection zone
3.8	The detection system shall perform under all weather conditions (rain, fog, snow, etc.)	This functionality is necessary to provide alerts to pedestrians in all weather conditions
3.9	The detection system shall perform under all lighting conditions (night, day, dawn, dusk)	This functionality is necessary to provide alerts to pedestrians during the day or night

SYSTEM ALERTS

Table 4 presents the elements in the system alerts requirement category. The CV-TPAS will issue alerts to pedestrians in the detection zone when a bus on a route turning left or right at the intersection is at a designated distance from the intersection. The system will remove the alert when the bus has completed the turn through the intersection. The system will not issue an alert when a bus is stopped at a nearside bus stop before the intersection, but will issue an alert as a turning bus moves toward the intersection. The system alert will continue during the walk signal phase if a pedestrian is detected in the waiting area or the crosswalk conflict zone.

Table 5. Requirement Category: Alerts.

Number	High-Level Requirement	Rationale
4.1	The CV-TPAS system shall issue alerts to pedestrians detected in pedestrian detection zones at the intersection when a turning bus is approaching the intersection	
4.2	The CV-TPAS system shall issue alerts to pedestrians in pedestrian detection zones only when the bus route conflicts with the crosswalk where the pedestrian might be crossing	To prevent a bus hitting pedestrians while turning left or right at an intersection
4.3	The CV-TPAS system shall issue alerts to pedestrians in pedestrian detection zones when the bus is at a designated distance from making a left or right turn	
4.4	The CV-TPAS system shall remove alerts to pedestrians in pedestrian detection zones when the bus leaves the intersection	
4.5	The CV-TPAS system shall not issue an alert to pedestrians waiting at the intersection when the bus is stopped at a bus stop near the intersection	
4.6	The CV-TPAS system shall issue an alert to affected pedestrians in pedestrian detection zones at the intersection when the bus is in-service	To prevent a bus hitting pedestrians while turning left or right at an intersection
4.7	The CV-TPAS system shall issue an alert to all pedestrians in pedestrian detection zones at the intersection when the detected bus is out-of-service or anytime a bus cannot be matched to a route or its route is undetermined	The system will operate in a fail-safe mode anytime the movement of a bus cannot be verified
4.8	The CV-TPAS system shall issue an alert to pedestrians waiting in the street or very close to the curb at a bus stop close to the intersection if a bus makes a stop at that bus stop	The requirement will necessitate the installation of a pedestrian detection system at the bus stop to detect the presence of pedestrians and communication equipment to send the information to the CV-TPAS at the nearby intersection
4.9	The CV-TPAS system shall issue an alert of a turning bus during the walk interval for crosswalks that conflict with the bus turning movement	This alert is provided to satisfy the scenarios where a pedestrian might already be in the crosswalk when a bus is detected at the intersection and making a turn that conflicts with the crosswalk where the pedestrian is present. This alert is issued based on the status of the walk signal when the bus is detected and irrespective of the presence of a pedestrian in the crosswalk or not

BUS ROUTE

Table 6 presents the elements of the system bus route requirement category. The CV-TPAS will interface with the TMC to obtain daily route and run information, which will include the bus ID, the in-service designation of the bus, and the bus stop number. The system will be able to accept and process updated bus route, bus ID, and in-service information from the TMC.

Table 6. Requirement Category: Bus Route.

Number	High-Level Requirement	Rationale
5.1	The CV-TPAS shall interface with a TMC to obtain daily route/run information	The bus-route information is necessary to determine if a bus is turning right or left, or going through at an intersection
5.2	The bus route information shall include the bus ID	Each bus shall have a unique ID that shall be used when defining a bus route
5.3	The bus route information shall include the bus stop number	The information is needed to alert affected pedestrians at a bus stop close to intersection in case of the presence of multiple bus stops at the intersection
5.4	The CV-TPAS shall be able to accept notifications to update its bus route information when a change is made	The bus ID is critical in determining the route of the bus at the intersection, and if it is turning left or right at the intersection. Any changes in the bus route information should be communicated immediately to the CV-TPAS
5.5	The CV-TPAS shall immediately update its bus route information when it receives a notification of changes have been made to the bus route information	The bus ID is critical in determining the route of the bus at the intersection and if it is turning left or right at the intersection. Any changes in the bus route information should be communicated immediately to the CV-TPAS so that it can update its information immediately
5.6	The bus route information shall include information about when the bus is in service	The bus in-service information is necessary to determine if a bus is following its scheduled route

SYSTEM CONNECTED BUS INFORMATION

Table 7 presents the elements of the connected bus system requirements. The connected bus will have a DSRC OBU, which will broadcast the BSM as specified in SAE J2735-201603 at a rate of 10 times per second. The BSM will include the bus ID used in the bus route and run information provided by the TMC.

Table 7. Requirement Category: Connected Bus Information.

Number	High-Level Requirement	Rationale
6.1	The bus shall have an OBU	The bus shall be equipped with a DSRC OBU to broadcast its BSM
6.2	The bus OBU shall broadcast BSMs as specified in SAE J2735-201603	The bus shall broadcast its location, heading, speed, and other basic information included in BSM Part 1
6.3	The bus OBU shall broadcast BSMs at a rate of 10 times in a second	The bus shall broadcast the BSM information 10 times in a second to be able to locate the bus movement at the intersection in real time
6.4	The bus BSMs shall include the bus ID used in the bus route/run information	The BSM shall include the bus unique ID to be able to identify the bus route at the intersection

SYSTEM DATA LOGGING

Table 8 presents the elements of the system data logging requirement category. The CV-TPAS will log all information it receives from the pedestrian detection system, the traffic signal system, connected buses, and the TMC into daily log files with timestamps. The system will also log all alerts issued into a daily log file with a timestamp.

Table 8. Requirement Category: Data Logging.

Number	High-Level Requirement	Rationale
7.1	The CV-TPAS shall log all information it receives from the pedestrian detection system into a daily log file with a timestamp	The purpose of the daily log file is to analyze system performance and troubleshoot problems when they arise
7.2	The CV-TPAS shall log all information it receives from the traffic signal system into a daily log file with a timestamp	
7.3	The CV-TPAS shall log all information it receives from the TMC into a daily log file with a timestamp	
7.4	The CV-TPAS shall log all information it receives from buses at an intersection into a daily log file with a timestamp	
7.5	The CV-TPAS shall log all alerts it issues into a daily log file with a timestamp	

V. INPUT ON POTENTIAL WARNING TECHNOLOGIES, METHODS, AND MESSAGES

PRELIMINARY PILOT TEST OF PEDESTRIAN ALERT METHODS

This section summarizes a preliminary pilot test of possible technologies to alert pedestrians about buses turning at intersections conducted on the Texas A&M campus in summer 2017. Technologies tested included a smartphone app, an audible message, a supplemental bus warning sign, and a warning sign projected on the sidewalk. The methodology and the results of the field observations and the participant surveys are presented in this section.

Methodology

The protocol for the preliminary pilot test included recruiting test subjects, obtaining informed consent from the test subjects, providing information on the test activities and safety procedures, walking the course, and completing the post-walk survey. The protocol wad developed by TTI researchers and submitted to the Texas A&M Institutional Review Board (IRB) as required for research involving human subjects. The IRB approved the protocol, and TTI researchers initiated recruiting test subjects.

As illustrated in Figure 17, the preliminary pilot test involved test subjects encountering alerts from different devised while walking with a TTI researcher on a short course of sidewalks adjacent to the TTI State Headquarters and Research Building (SHRB) on the Texas A&M University West Campus in College Station. The four devices used to provide alerts to the test subjects included a warning sign projected on the sidewalk, a ringing smartphone, an audible warning, and a supplemental bus warning sign on a traffic signal. These warning devices were selected to mimic the technologies anticipated to be developed and used in the proof-of-concept pilot at the RELLIS Campus.

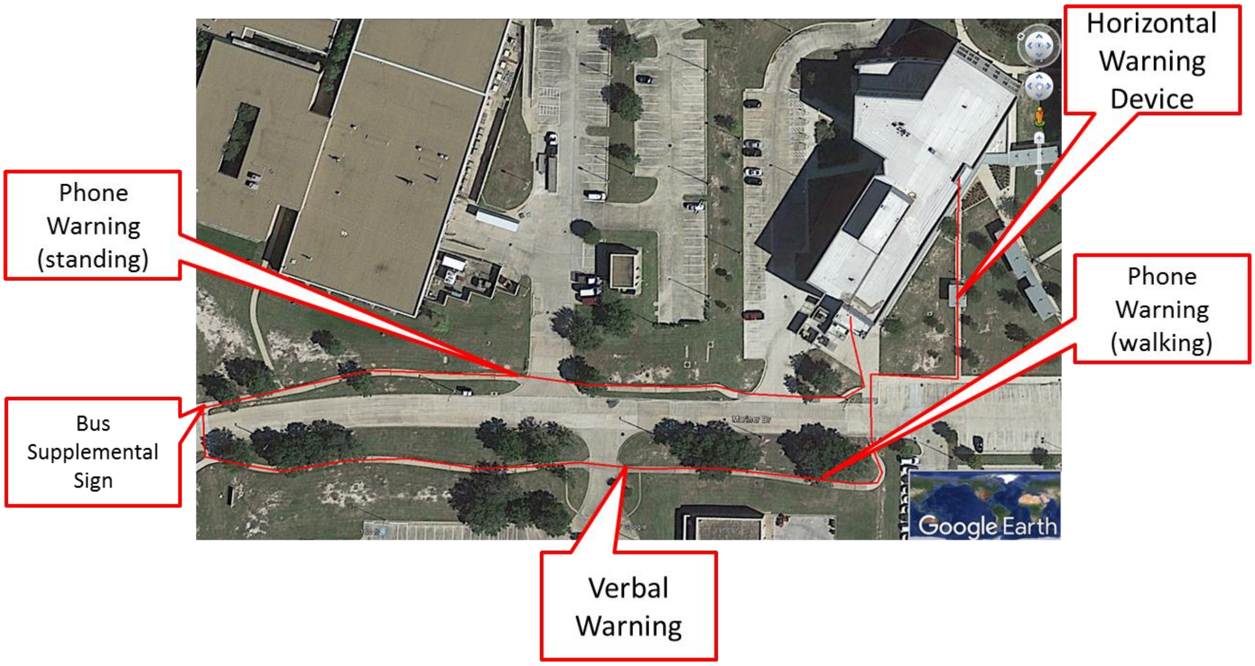


Figure 17. Preliminary Pilot Test Course and Location of Pedestrian Alert Devices.

Projected Warning Sign

A projected warning sign on the sidewalk was the first alert encountered by the pilot test subjects. A Gobo projector was used to display a stop sign on the sidewalk. Figure 18 illustrates the projected stop sign, which was placed in a shaded area to ensure its visibility.

Figure 18. Projected Warning Sign.

Ringing Smartphone

A ringing smartphone with text messages was used to simulate a smartphone app during the preliminary pilot test. Test subjects were given a prepaid smartphone to use as they walked the course. TTI researchers sent a text to the test subjects at two locations along the walking path. The smartphone was set to vibrate, and a continuously ringing bell ringtone was used to alert the test subject. The first text message sent to test subjects when they were walking read "look left." The second text message sent to test subjects when they were stopped at a driveway read "raise hand."

Audible Warning Message

As illustrated in Figure 19, a push button and a traffic pole were installed along the course sidewalk. A Bluetooth speaker on the top of the traffic pole projected the message "bus turning" when the test subject pushed the button. The verbal message was activated by TTI researchers when the test subject pushed the button. Located at a driveway along the walking route, the audible warning was the third device encountered by test subjects.

Figure 19. Audible Warning Message Set-Up.

Supplemental Bus Warning Sign

The fourth device was a supplemental bus warning sign located above a pedestrian signal head. Figure 20 illustrates the location of this alert device. A computer monitor was used in the preliminary pilot to illustrate the pedestrian signal head. Initially, the words BUS TURNING in yellow letters on a black background developed using PowerPoint slides was used with the sign.

Once the sign was installed outdoors, however, this message was difficult to read due to sunlight. To make the sign more visible, the message was changed to display the word BUS in yellow letters, with the background alternating between black and yellow in order to simulate a flashing pattern. Two TTI researchers assisted with this alert device. One researcher operated the signal, and one researcher monitored traffic to be sure it was safe for the test subject to cross the street. The sign turned out to be difficult for test subjects to see due to sun glare during the preliminary pilot.

(a) (b)

Figure 20. Supplemental Bus Warning Sign.

Conducting the Preliminary Pilot Test

The preliminary pilot test subjects were recruited using an existing pool of potential participants developed through previous projects. Emails and text messages were sent to individuals in this group, as well as to other contacts. The target was to recruit 12 test subjects in different age categories. As presented in Table 9, a total of 14 test subjects were recruited with the desired mix of gender and age distribution.

Table 9. Gender and Age Distribution of Test Subjects.

Generation Class	Age Range	Male	Female	Total
Generation Y	18 to 34 year old	4	2	6
Generation X	35 to 50 year old	2	2	4
Baby Boomers	Over 50	2	2	4
Total	NA	8	6	14

The preliminary pilot was conducted on July 25 and 26, 2017, between 7 a.m. and 11 a.m. Test subjects were met at the SHRB by TTI researchers, who explained the pilot and reviewed the test subject informed consent form. Once the confirmed consent form was signed, test subjects were given a visual activity test. Test subjects were shown a PowerPoint presentation that highlights the walking path and warning devices. Pilot test subjects were also given the following safety guidelines.

Test subject were instructed to:

- Stop at all intersections, road crossings, and driveways.
- Be mindful of traffic.
- Report when they saw or heard an alert.
- Follow the direction provided by the alert message.

The test subjects were also informed that a TTI researcher would walk behind them and collect data through field observations. Finally, the test subjects were told they would return to the SHRB to complete a post-walk survey. Test subjects were compensated $30 for completing the walk.

All test subjects had a vision acuity of 20/50 or better. Out of the 14 test subjects, seven were full-time workers, five were students, one was a homemaker, and one was retired. Five test subjects were college graduates, four had a graduate degree, two had some college or vocational education, two test subjects graduated high school, and one test subject completed some graduate school courses.

The pilot test subjects completed the walking course accompanied by a TTI researcher, who helped provide directions on when to stop and when to go. The researcher also recorded the time the test subject reached the various pre-determined time points and when they reacted to the instructions provided by some of the alert devices. The timestamps were recorded by the researcher in a pre-loaded tablet and on a clipboard. The researcher made note of the test subjects' behavior in response to the alert directions. The researcher also recorded how a test subject carried the smartphone (hand or pocket), where a test subject was looking when they crossed a street or driveway, and any other observations about the test subjects' behavior.

The post-walk survey was administered to the pilot test subjects in a conference room at the SHRB. The survey was displayed on a laptop, allowing the test subjects to read the question carefully. The researcher recorded the answers provided by the test subject. The post-walk survey consisted of 24 questions. The first 16 related to the alert devices encountered during the walk, with the test subjects providing feedback on the overall effectiveness of the device in capturing their attention, the message displayed, preferences concerning the messages, and possible negative effects if the devices were deployed. The pilot-test subjects were also asked to rank the effectiveness of the devices' ability to convey a message on a scale of -1 (negative effects) to a scale of 7 (very effective). The final questions focused on ways to improve the effectiveness of the devices and the factors that might affect their use on a busy street, as well as the test subjects use of smartphones, listening to music, and looking out for a turning bus while walking and standing at a crosswalk.

Summary of Walking Course Information

The analysis of the field data included examining the timestamp data to estimate the reaction time of test subjects to the different alert devices and to review the observations recorded by the researcher accompanying the test subjects. This summary provides a general indication of the reaction to the different alert devices. Note that caution should be used when interpreting the data due to the small sample size and the methods used to simulate some of the alert devices.

Researchers used the timestamp data, the distance between timestamps, and the estimated walking speed of pilot test subjects, to identify the approximate distance test subjects saw the projected warning sign. The responses varied widely with one test subject identifying the projected warning sign approximately 78 feet in advance of the projected walking sign and one test subject identifying the projected warning sign after walking past the sign. Three test subjects saw the warning sign less than 10 feet away, five test subjects saw the image between 10 and 30 feet away, and five test subjects noticed the warning sign more than 30 feet away from the image.

The simulated smartphone app was deployed twice during the walking course. During the first walking segment, the smartphone rang while a test subject was walking. During the second walking segment, the smartphone rang when the test subject was standing at the corner of a driveway. The researcher walking with the test subject created a first timestamp when the phone rang, and a second timestamp when the test subject performed the action listed in the text message. The time it took for a test subject to read, understand, and react to the message was calculated from the two timestamps. The timestamps for two test subjects when walking and three test subjects when standing were not recorded due to an oversight on the accompanying researcher's part.

Test subjects were given the choice of carrying the smartphone in their hands or in their pockets. Approximately half of the test subjects carried the smartphone in their hand, and half carried it in their pocket. Only one test subject carrying the smartphone in their pocket did not pull out the smartphone to read the text message. The test subject did indicate when they heard the smartphone ring, however.

Test subjects standing at the driveway crossing took between 4 and 5 seconds to read the text message and raise their hand, regardless of whether the smartphone was in their hand or in their pocket, after an excessively long response time of 18 seconds was removed. The results were different during the walking segment, with test subjects with the smartphone in their pocket appearing to take longer to react to the call, read the message, and look left. On average, test subjects holding the smartphone took 3 seconds to look left compared to 7 seconds for test subjects with the smartphone in their pocket.

It was difficult for researches to determine when the test subject understood and reacted to the audible warning message, which was given simultaneously as the test subject pushed the pedestrian button. Some test subjects showed little or no reaction to the message, while others did look around. As a result, no attempt was made to estimate the response time to the audible warning, although approximately half the test subjects did look around.

Due to sun glare, test subjects were not able to see the message on the computer monitor that acted as the supplemental bus warning sign while they were crossing the street. One test subject was able to read the message when they were half-way across the street, and two test subjects took time to read the supplemental sign after they crossed the street.

Post-Walk Survey Analysis

The post-walk survey included questions concerning the test subjects' assessment of the different alert devices and suggestions for improvements. As presented in Table 10, most test subjects reported recalling the message displayed for the projected warning sign, the audible warning, and the smartphone. Due to the inability to see the supplemental bus warning sign because of sun glare, only two test subjects reported remembering the message on this alert device.

Table 10. Remembered Message Displayed on Alert Devices.

Warning Device	Remember the message of the warning device?	
	Yes	**No**
Projected Warning Sign	14	0
Audible Alert	10	4
Smartphone Text	12	2
Supplemental Bus Warning Sign	2	12

Figure 21 presents the test subjects preferences for the warning used with the different alert devices. Test subjects were able to select more than one message.

What do you believe the **projected warning sign message** should be?

a) Yield — 4 participants
b) Turning bus — 5 participants
c) Look left — 1 participants
d) Other = Stop — 4 participants

What do you believe the **audible warning message** should be?

a) Look for turning bus — 1 participants
b) Yield to turning bus — 3 participants
c) Caution, bus is turning — 9 participants
d) Pedestrians, bus is turning — 0 participant
e) Other = Stop, bus turning — 1 participant

How do you suggest a **phone-based warning message** should be provided?

a) Text message — 1 participant
b) Warning sound — 13 participants
c) As part of an app — 4 participants
d) Other

What do you believe the **supplemental bus warning sign** should say when provided above the pedestrian signal (WALKING PERSON/RAISED HAND)?

a) 

- 1 participant

b) 

- 5 participants

c) 

- 8 participants

d) 
- 0 participants

e) Other - 0 participants

Figure 21. Test Subjects Preference for Warning Messages.

For the projected warning sign, three messages had similar preference: TURNING BUS, YIELD, and STOP. For the audible warning message there was a strong preference for the message CAUTION, BUS IS TURNING. A preference was also present for the supplemental bus warning sign message, with most test subjects preferring the message to be LOOK FOR BUS, followed by the message BUS TURNING. For the potential smartphone app, 13 test subjects responded that the warning should be a specific sound that would not be confused with a ring tone.

Test subjects were asked to assess the effectiveness of the alert device in capturing the attention of pedestrians. The grading scale ranged from not effective to very effective. Table 11 presents the responses from the test subjects.

Table 11. Effectiveness of Alert Device in Capturing the Attention of a Pedestrian.

Effectiveness Grading Scale	Warning Device			
	Projected Warning Sign	Audible Warning	Smartphone App	Supplemental Bus Warning Sign
Not effective	0	0	3	0
Slightly effective	6	3	4	2
Effective	5	6	6	7
Very Effective	3	5	1	4
Average score*	1.79	2.14	1.36	2.15

*Calculated assuming not effective = 0, slightly effective = 1, effective = 2, and very effective = 3.

In general, test subjects graded the projected warning sign and the supplemental bus warning sign as the more effective devices. Test subjects were asked to grade the supplemental bus warning sign given ideal conditions (i.e., visible message). The effectiveness of the projected warning sign and the smartphone app was graded lower by test subjects.

In addition to evaluating the effectiveness of a device, participants were given the opportunity to address possible concerns about the application of these warning devices at a busy urban intersection. When asked about possible negative consequences associated with the use of the projected warning sign at a busy intersection, three participants suggested that pedestrians would not look on the ground for a warning sign. Six participants suggested that the projected image might be blocked by other pedestrians standing at the corner. Four participants suggested that the projected warning sign might not be highly visible throughout the day. Two test subjects did not identify any potential negative effects with the projected warning sign.

Many test subjects, 64 percent, suggested that the warning sound from a smartphone might be difficult to hear at a busy intersection. Other possible limitations of the smartphone app suggested by test subjects were pedestrians being too busy to check their smartphone, delays in reading the text, and making people too dependent on their smartphones. Two test subjects did not identify any issues with using a smartphone app at a busy intersection.

Possible concerns limiting the effectiveness of the audible warning suggested by test subjects were that people wearing headphones might not hear the warning and that traffic noise may block out the warning. The major potential concern with the effectiveness of the supplemental bus warning sign was that pedestrians might not look up to see the sign above the pedestrian signal. One test subject suggested placing the supplemental bus warning sign to the left of the pedestrian walk signal.

The survey also asked test subjects to rate the effectiveness of a given alert device in comparison to other devices. This approach provided the chance for the participant to indicate if they thought a particular device was more effective in comparison to another device. The participants were asked to rate the four devices on a scale from −1 (negative effects) to 7 (very effective). Table 12 presents the scores given by the test subjects. Overall, the audible warning and the supplemental bus warning sign were rated as the most effective alert devices.

Table 12. Effectiveness of Devices Conveying the Alert Message.

Test Subject	Projected Warning Sign	Smartphone Warning	Audible Warning	Supplemental Bus Warning Sign
1	7	6	7	7
2	2	2	4	4
3	5	5	7	5
4	2	4	6	5
5	3	-1	4	5.5
6	4	5	3	5
7	1	4	7	6
8	3	0	4	7
9	1	0	5	5
10	3	1	6	7
11	3	4	4	6
12	5	4	7	7
13	2	4	4	5
14	4	7	6	1
Average	3.21	3.21	5.29	5.39

Where:

- −1 = Negative effects
- 0 = No effects
- 1= Minimal effects
- 2-6 = varying degrees of effectiveness
- 7= very effective

Table 13 presents the average score for the responses to the questions on the effectiveness of the different alert devices in capturing pedestrians’ attention and in conveying a message. Test subjects rated the audible warning and the supplemental bus warning sign the most effective in both categories. Even though the supplemental bus warning sign was not visible to test subjects during the walk, most test subjects indicated that it would be the best device to warn pedestrians about a turning bus. Some test subjects mentioned that a supplemental bus warning sign would be best if used in combination with the audible warning device. While the smartphone warning received lower scores, many test subjects noted the potential for the smartphone to be an effective method of warning pedestrians.

Table 13. Average Scores of Alert Devices.

Device	Effectiveness in Capturing Attention (average score)	Effectiveness in Conveying Message (average score)
Projected Warning Sign	1.79	3.21
Smartphone Warning	1.36	3.21
Audible Warning	2.14	5.29
Supplemental Bus Warning Sign	2.15	5.39

In the pre-walk briefing, seven test subjects reported walking less than 15 minutes a day, six participants said they walk between 15-and-30 minutes a day, and one participant reported walking over 30 minutes a day.

During the post-walk survey, less than half of the test subjects reported listening to music while waiting at an intersection. Of the test subjects reporting that they listen to music while waiting at an intersection, half said they listen to music half the time they are stopped at an intersection. Nine of the 14 test subjects reported looking at their smartphone at least occasionally while standing at an intersection. One participant reported never looking at their cellphone while walking.

PEDESTRIAN INTERCEPT SURVEYS AND FOCUS GROUP

This section summarizes the results from the pedestrian intercept surveys and focus groups with disabled individuals to gain additional insights into possible methods and messages to warn pedestrians of turning buses at intersections. The surveys and focus groups were conducted in Houston to obtain input from diverse population groups with experience using public transit unavailable in College Station.

Pedestrian Intercept Surveys

TTI researchers conducted intercept surveys with pedestrians near the following three intersections in Houston's Montrose neighborhood.

- Westheimer Road at Montrose Boulevard.
- Montrose Boulevard at Hawthorne Street.
- Richmond Avenue at Montrose Boulevard.

Figure 22 illustrates the location of these intersections, which all have Houston METRO bus routes. The intersections were selected in consultation with METRO staff to ensure that pedestrians would have previous experience with turning buses.

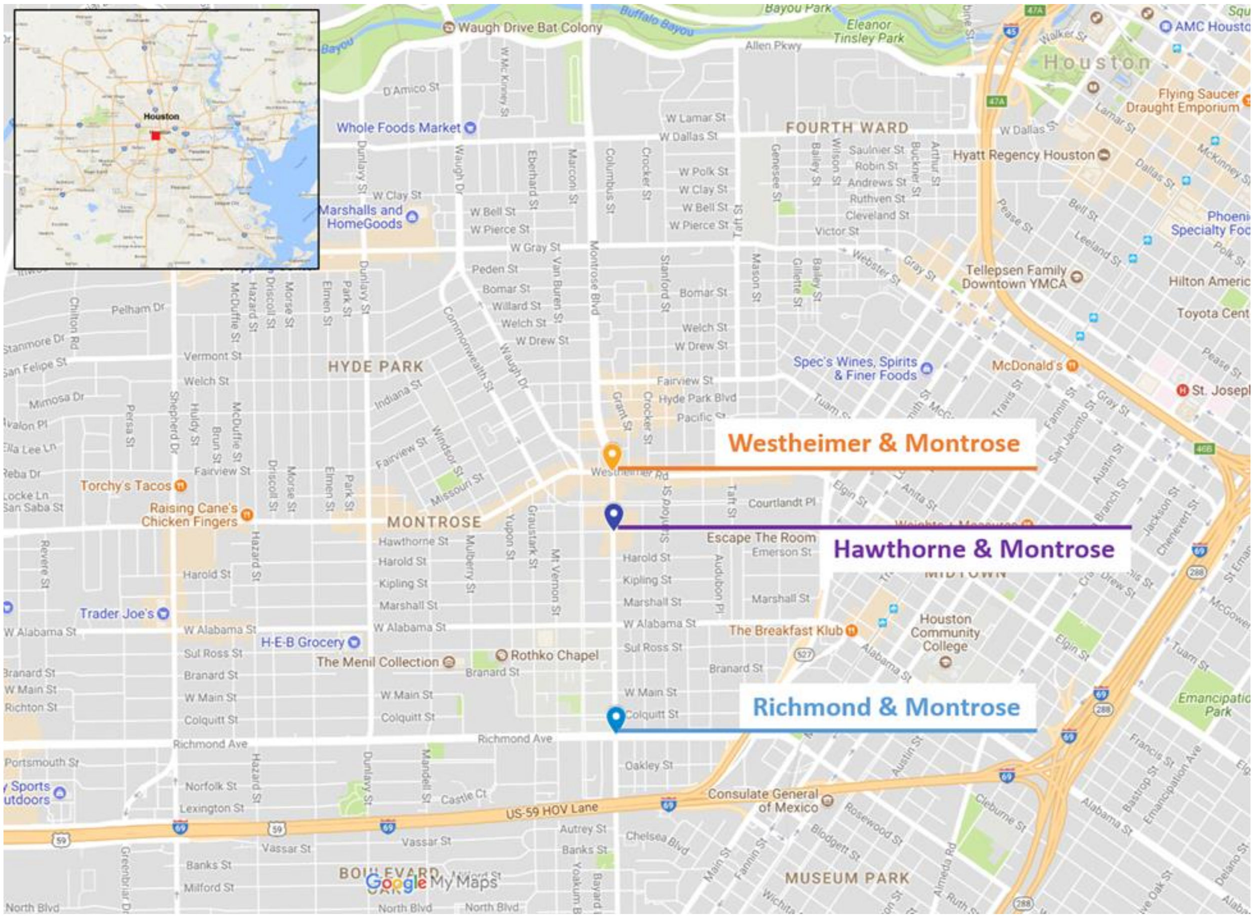


Figure 22. Intersection Locations with METRO Bus Routes.

The intercept surveys were conducted on Tuesday, July 17, and Wednesday, July 18, 2018. TTI researchers approached pedestrians who appeared at least 18 years of age. After confirming an individual met this age requirement, researchers asked the pedestrian if they would be willing to answer a short survey lasting no more than 60 seconds. If a pedestrian agreed to participate, the surveyor asked the following two to six questions, depending on the participant's answers:

1. If a bus was about to turn across this crosswalk as you are crossing, would you like a warning that the bus is turning? (If the answer was "no," the surveyor skipped to question 5).
2. Would you prefer to (1) see the warning message on or near the pedestrian signal, (2) see a warning on the crosswalk, (3) hear a warning message broadcast from the pedestrian signal, or (4) get a warning on your phone or other mobile device?
3. What is your second preference to receive a warning message about a bus turning across the crosswalk you are about to enter?
4. Would you want to be told which direction the bus is turning (right or left), or just that a bus is turning?
5. Have you ever had to stop walking or move out of the way because a bus was turning across the crosswalk?
6. How did you first realize the bus was there?

The complete survey form is included as Appendix A.

Researchers entered the participant's verbal responses on a tablet computer using multiple-choice answers. Any related comments volunteered by the participants were also entered into the tablet computer. After completing the survey, the researcher entered as many of the following observations as possible about the participating pedestrian:

- Gender.
- Approximate age.
- If a phone or mobile device was visible.
- If the pedestrian was wearing/using headphones.
- If the pedestrian was riding or walking a bicycle.
- Whether the pedestrian was about to cross or had just crossed the intersection.
- Whether the pedestrian obeyed the pedestrian crossing signal.
- Whether the pedestrian looked both ways before entering the crosswalk.

The surveyor also had the option of entering additional comments or notes about the survey or the participant's responses. Figure 23 shows a TTI researcher completing a pedestrian intercept survey.

Source: Texas A&M Transportation Institute.

Figure 23. TTI Researcher Conducting a Pedestrian Intercept Survey.

A total of 97 pedestrians participated in the intercept surveys over the two days. Each of the surveys was conducted in English. Because not every pedestrian answered every question, the results are calculated as percentages of the total responses to each question.

Participant Characteristics

The majority of participating pedestrians were male (68 out of 97, or 71 percent). According to participant ages estimated by the surveyors, 40 participants (41 percent) were between 18 and 30 years old, 30 (31 percent) were between 31 to 50 years of age, and 27 (28 percent) were over 50 years old. Table 14 provides a breakout by both gender and estimated age of the 97 participants.

Table 14. Survey Participant Characteristics.

Gender	Estimated Age			Total
	18–30	*31–50*	*Over 50*	
Male	27	20	21	68
Female	11	10	6	27
Uncertain	2	0	0	2
Total	40	30	27	97

A total of 13 percent of the participants were observed carrying a smartphone or a mobile device, while 14 percent were observed wearing headphones. Four percent of the participants were observed riding or walking a bicycle.

Sixty-one percent of the pedestrians surveyed were about to cross at an intersection when asked to complete the survey. The remaining 39 percent had just completed crossing a street. TTI researchers observed that nearly two-thirds of the participants obeyed the pedestrian crossing signal at the intersection. Only three percent of the participants were observed not obeying the crossing signal, while researchers were unable to determine if the remaining 31 percent obeyed the crossing signal. A total of 47 percent of the participating pedestrians were observed looking both ways before entering the crosswalk, while 3 percent were observed not looking both ways before crossing the intersection. Researchers did not observe the behavior of the remaining 49 percent of the participants.

Interest in Receiving a Warning

In response to the question "if a bus was about to turn across this crosswalk as you were crossing, would you like a warning that the bus was turning?" 68 percent of participating pedestrians answered "yes." Several participants who answered in the negative commented that bus drivers already watch for pedestrians, that private vehicles are more of a problem than buses at intersections, or that pedestrians have a responsibility to watch out for their own safety.

Warning Format and Delivery

A total of 66 participants, or 68 percent, answered the question on possible warning messages and delivery methods. Of the four choices offered, 34 participants (52 percent) selected "see the warning on or near the pedestrian signal" as the first choice. Twenty participants (31 percent) selected "hear the warning message," 9 participants (14 percent) selected "see the warning on the crosswalk," and 2 participants (3 percent) selected "receive a warning on a mobile device." One participant was not sure which warning format was her first choice.

When asked for a second choice of warning format, 22 participants (33 percent) selected “see the warning on the crosswalk,” 19 participants (29 percent) selected “see the warning on or near the pedestrian signal,” 18 participants (27 percent) selected “hear the warning message,” and four (6 percent) selected “receive the warning on a mobile device.” Three participants were not sure which warning format was their second choice. Figure 24 presents participants’ first and second choices.

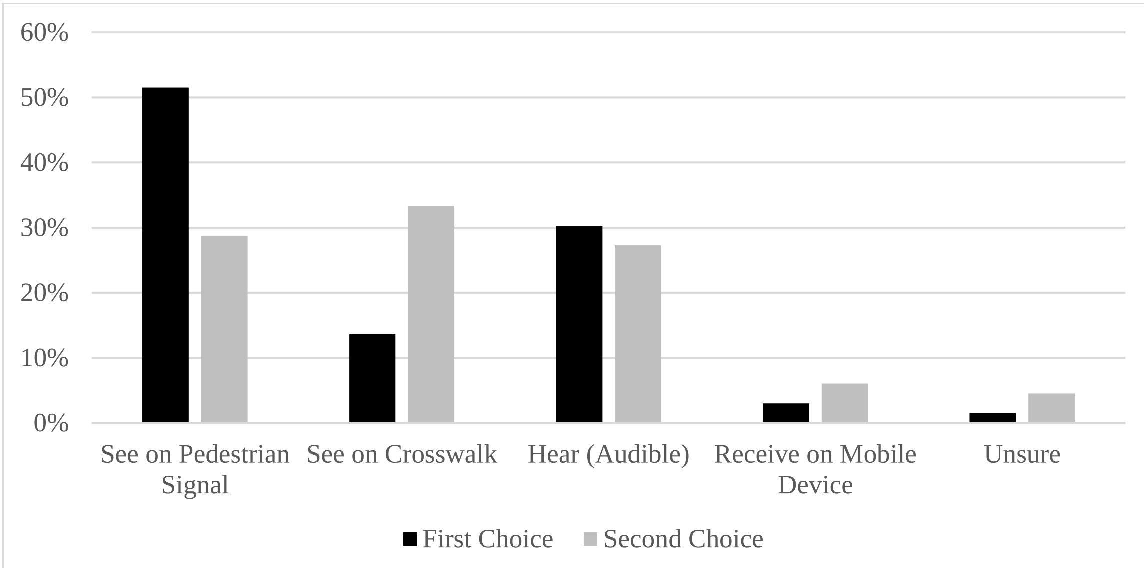


Figure 24. Survey Participants’ First and Second Choices for Warning Format.

Warning Message

A total of 66 participants, or 68 percent of the total participants, answered the question “would you want to be told which direction the bus is turning (right or left), or just that the bus is turning?” A total of 35 participants (53 percent) wanted to know just that the bus was turning, 29 participants (44 percent) wanted to know the direction the bus was turning, and two (3 percent) were not sure.

Past Experience with Turning Bus Conflicts

A total of 93 participants, or 96 percent of the total participants, answered the question “have you ever had to stop walking or move out of the way because a bus was turning across the crosswalk?” A total of 39 participants (42 percent) responded yes, 50 participants (54 percent) said no, and four participants (4 percent) were not sure.

Although 39 participants indicated that they had had close encounters with turning buses before, a total of 42 participants answered the subsequent question “how did you first notice the bus?” Of these, 20 participants (48 percent) answered “I saw the bus,” and 16 participants (38 percent) answered “I heard the bus.” The remaining six responding participants (14 percent) were not sure or indicated that someone had told them the bus was there.

Participant Comments

Several participants provided additional comments on their choices of visible, audible, or mobile-application warnings. The most frequent comment was that both visible and audible warnings should be broadcast if possible to accommodate pedestrians with visual or hearing limitations and/or to overcome distractions such as cell phones and headphones. Some participating pedestrians commented that other vehicles conflict with pedestrians in crosswalks more often than buses.

Focus Groups

TTI researchers conducted three focus groups to gather additional information on preferences regarding warning messages and methods from pedestrians with disabilities. Houston METRO staff assisted with identifying meetings of appropriate user groups and making arrangements for TTI's participation in the meetings. Figure 25 illustrates the focus group conducted on July 10, 2018. The discussion guide provided as Appendix B was developed with input from other members of the research team, and was used with all three focus groups.

The participants in the three focus groups are summarized below:

- **Focus Group 1 — Predominately Spanish-Speaking Wheelchair Users.** The first focus group was conducted on Tuesday, July 10, 2018, during a regular meeting of a nonprofit organization. The focus group participants included 25 primarily Spanish-speaking wheelchair users. A Spanish-speaking moderator from the organization led the discussion using a Spanish translation of the focus group guide, provided as Appendix C. Ages were not collected from the participants, but all participants were adults whose ages appeared to range between 25 and 65 years.
- **Focus Group 2 — Blind or Visually Impaired Individuals.** The second focus group was conducted on Wednesday, July 11, 2018. It included 12 blind or visually impaired individuals. A TTI researcher moderated this focus group. Ages were not collected from the participants, but all participants were adults whose ages appeared to range between 30 and 60 years. The moderator led the discussion in English.
- **Focus Group 3 — Deaf or Hearing Impaired Individuals.** The third focus group was conducted on Saturday, August 11, 2018, during a regular meeting of a nonprofit organization. It included 13 individuals. Participants had hearing impairments and most used hearing aids. A captioner assisted the TTI researchers conducting the focus group by providing real-time captioning on a large screen. Ages of the participants were not recorded, but all were adults whose age appeared to be 25 to 60 years.

Source: Texas A&M Transportation Institute.
Figure 25. Focus Groups Conducted on July 10, 2018.

The discussion guides in Appendix B and Appendix C were used with all the focus groups, depending on language needs. The actual discussions in each group examined the topics and questions of most interest to the participants of that group.

The responses from each of the three focus groups are summarized below by general questions and topics.

Interest in Receiving a Warning

Most participants in all three focus groups indicated interest in receiving a warning that a bus was turning or about to turn at an intersection that they were crossing.

- **Focus Group 1 — Predominately Spanish-Speaking Wheelchair Users.** Participants in Focus Group 1 were largely in favor of receiving a warning about a bus turning at an intersection they were crossing.
- **Focus Group 2 — Blind or Visually Impaired Individuals.** Nine of the 12 participants in Focus Group 2 said they would be interested in receiving some sort of warning that a bus was turning at an intersection. The three participants who did not think a warning would be helpful all assumed the warning would be audible and said the warning would be redundant to their existing situational cues or that it would be too difficult to hear over the ambient traffic noises. Most of the participants had some familiarity with accessible pedestrian signals that communicate WALK/DON'T WALK information in non-visual formats (i.e., audible tones and vibrotactiles signals). One participant commented that she could not always hear the direction of the sound for WALK and DON'T WALK.

- **Focus Group 3 — Deaf or Hearing Impaired Individuals.** Most of the 13 participants expressed interest in receiving a warning that a bus was turning at an intersection. Participants commented that individuals with hearing loss cannot hear normal traffic sounds, including the sound of a vehicle turning, so an additional warning is helpful. Focus group participants suggested using audio warnings that are detectable by hearing aids.

Warning Delivery/Medium Preferences

The moderator asked the focus group participants if they would prefer to (1) see the warning message on or near the pedestrian signal, (2) see a warning on the crosswalk, (3) hear a warning message broadcast from the pedestrian signal, or (4) get a warning on your phone or other mobile device?

- **Focus Group 1 — Predominately Spanish-Speaking Wheelchair Users.** Participants in this focus group preferred to see the warning message on or near the pedestrian signal and also hear a warning message broadcast from the pedestrian signal and/or delivered audibly via a mobile application.
- **Focus Group 2 — Blind or Visually Impaired Individuals.** Most participants in this group preferred to hear a warning message broadcast from the pedestrian signal. Several focus group participants expressed an interest in a phone application.
- **Focus Group 3 — Deaf or Hearing Impaired Individuals.** Participants expressed the most interest in receiving a visual and audio warning from the pedestrian signal. A visual warning on the pavement and a phone app were the next two choices.

Warning Format Preferences

The moderator asked focus group participants if they would prefer the warning in an audible, visual, and/or tactile format.

- **Focus Group 1 — Predominately Spanish-Speaking Wheelchair Users.** Participants in this focus group preferred an audible, bilingual warning or a unique, non-verbal audible signal. Participants used the example of the audible Amber Alert that many people receive on mobile phones but emphasized that the bus-warning signal should be distinguishable from the Amber Alert signal. Most participants agreed that an audible warning broadcast from the pedestrian signal would be effective, if the warning was loud and clear enough to hear above the ambient sounds near the intersection. Most participants in this focus group also liked the idea of a visible warning at the pavement level. Embedded lights on the pavement were preferred over a projected image.

  If possible, participants preferred to have both visual and audible warnings broadcast/displayed at the intersection. There was also interest in a phone application, with participants requesting that the mobile warning have a unique sound that they could learn to identify immediately as a turning-bus warning without having to look at the phone. The focus group participants did not express an interest in a tactile signal from a phone application.

- **Focus Group 2 — Blind or Visually Impaired Individuals.** Since this group was comprised of individuals who were blind or had visual impairments, an audible warning was the participants' first preference. However, five of the 12 participants said that a visual warning at the pedestrian signal would also be helpful; one said that for people with low vision, placing that signal at or close to eye level would be the most beneficial. Visual signals on the pavement were not favored; participants were concerned that an on-pavement visual warning might be easily obstructed by other pedestrians or by dirt and debris. One participant suggested a vibrotactile warning in the sidewalk or crosswalk surface at the intersection.

  Participants in this focus group also indicated that an audible or tactile warning from a mobile application would work for many people with limited vision or no sight. Participants suggested that an app that would allow the individual user to select the particular audible signal or vibration pattern for his or her warning (similar to being able to select your phone's ringtone and text-message notification) would be beneficial.

- **Focus Group 3 — Deaf or Hearing Impaired Individuals.** Many participants preferred a visual warning due to limited hearing. Participants discussed the location, type, and characteristics of effective visual warnings. Some participants suggested that the height of intersection pedestrian signals is too high, noting that a visual warning closer to standing eye height would be better. Several participants agreed that a flashing bus symbol would be helpful. Investigating intensity and brightness levels to determine the intensity that is most likely to draw attention was suggested.

  Five out of the 13 participants said that a visual warning on the pavement would be helpful, but concerns were noted that wear on the pavement might reduce the effectiveness of images or messages projected on the walk path. Participants preferred a set of flashing lights on the pavement prior to the crosswalk.

  Although participants had hearing limitations, they supported audio warnings, pointing out that people might not be looking at the pedestrian signal when the warning is activated. They recommended audio warnings that can be detected by hearing aids and cochlear implants. A participant described the hearing loop system used for the meeting to help those with a hearing loss. A hearing loop (sometimes called an audio induction loop) is a special type of sound system for use by people with hearing aids. The hearing loop provides a magnetic, wireless signal picked up by the hearing aid when it is set to "T" (Telecoil) setting. It was noted that the non-profit Hearing Loss Association of America can provide references to understand how technology can help audio messages to be effective for individuals with hearing loss.

  Five out of the thirteen participants were interested in a warning delivered via a smartphone or mobile device. Participants suggested that a mobile application provide distinctive visual, audible, and tactile warnings. One participant commented that she keeps her smartphone on vibrate and often is not aware of incoming messages, so would be unlikely to notice an alert delivered through her phone. Like Group 1, participants referred to the mobile-device Amber Alert as an example of an effective warning.

Message/Information Preferences

The moderator asked the focus group participants if they wanted to know the direction the bus was approaching/turning.

- **Focus Group 1 — Predominately Spanish-Speaking Wheelchair Users.** Participants in this focus group were primarily interested in knowing that a bus was about to turn, but not necessarily the direction of the turning bus. Participants discussed the need for a "bus turning" warning to be clearly audible, instantly recognizable, and provided in English and Spanish. There was limited discussion about an interest in knowing the bus's direction.
- **Focus Group 2 — Blind or Visually Impaired Individuals.** Most of the discussion in this focus group centered on audible messages. Participants discussed the amount of information to be provided in a warning. Some participants wanted the message to include "bus is turning left/right." One participant suggested using cardinal directions (north/south/east/west) as part of the message, but other participants commented that they do not often know cardinal directions. Two participants wanted to know that the bus would be turning in "(number) of feet" or "(number) of seconds." Other participants, however, thought that too much information would be confusing to a pedestrian, especially in an urban environment with competing sounds. Participants then discussed the need for any message to be short, so that it can be repeated; they also recommended that any audible messages be in both English and Spanish.
- **Focus Group 3 — Deaf or Hearing Impaired Individuals.** Most participants favored basic "bus turning" message. Three out of 13 participants said they would like to know if the bus was turning left or right. One participant commented that not everyone knows left and right directions.

Timing Preferences

Participants were asked about the timing of alert messages and the distance of a bus to a crosswalk.

- **Focus Group 1 — Predominately Spanish-Speaking Wheelchair Users.** One participant specified that the warning should be provided 20 seconds before a pedestrian reaches the intersection; several others agreed.
- **Focus Group 2 — Blind or Visually Impaired Individuals.** Participants in this focus group did not have definite opinions on the timing of the message relative to the pedestrian and/or bus arrival at the intersection. One participant suggested that the message timing should be based on traffic engineering calculations pertaining to traffic speeds and distances.
- **Focus Group 3 — Deaf or Hearing Impaired Individuals.** One participant suggested a countdown signal showing seconds for an approaching turning bus. Several participants suggested that the warning should be more urgent or intense if a pedestrian is already in the crosswalk when the bus is turning. One participant suggested strobe lights as a visual indication of danger if the pedestrian started across the crosswalk when a bus was turning.

Conclusions from Pedestrian Surveys and Focus Groups

The input received from pedestrians who participated in the intercept surveys and the focus groups highlight the following general preferences regarding a smart intersection to notify pedestrians about a turning bus:

- Pedestrian survey participants preferred a visible warning message on or near the pedestrian signal. The predominately Spanish-speaking wheelchair users in the first focus group preferred both visible and audible warning messages. The blind and visually impaired individuals in the second focus group preferred an audible warning. The hearing impaired participants in the third focus group preferred a visual warning, but several survey and focus group participants commented that both visual and audible warnings should be broadcast.
- The wheelchair users in the first group and the hearing impaired individuals in the third group supported a visible warning on the pavement. The blind and visually impaired individuals in the second focus group and the hearing impaired individuals in the third focus group commented that visible messages should be at eye level for pedestrians.
- The comments concerning audible warnings noted by participants in all groups included ensuring that the warning can be heard clearly over ambient sounds at the intersection and announcing the warning message in both English and Spanish.
- Focus group participants expressed more interest in a mobile app than participants in the pedestrian survey. Focus group participants who were wheelchair users and participants who were blind or had low vision both favored audible warnings delivered via a mobile device; the latter group also expressed interest in a vibrotactile warning option. Both groups commented that a unique and potentially customizable signal would be the most useful. Some participants with hearing impairments expressed interest in a smartphone app that could deliver visual, audible, and tactile alerts.
- A majority of pedestrian survey and focus group participants preferred a short, simple audible warning message or a visual warning. Concerns about a longer, more detailed message included the additional time needed to mentally process the information and the greater potential for confusion. Some participants also wanted to keep an audible message short so that the message can be repeated and/or delivered in more than one language.

VI. TEST PLAN, TEST SCENARIOS, TEST PROCEDURES, AND PROOF-OF-CONCEPT TEST

This section presents the test plan, test scenarios, and test procedures for the proof-of-concept test conducted at the RELLIS Campus proving ground. The proof-of-concept test for the smart intersection application and the smart pedestrian and bicyclist application were coordinated.

TEST PLAN

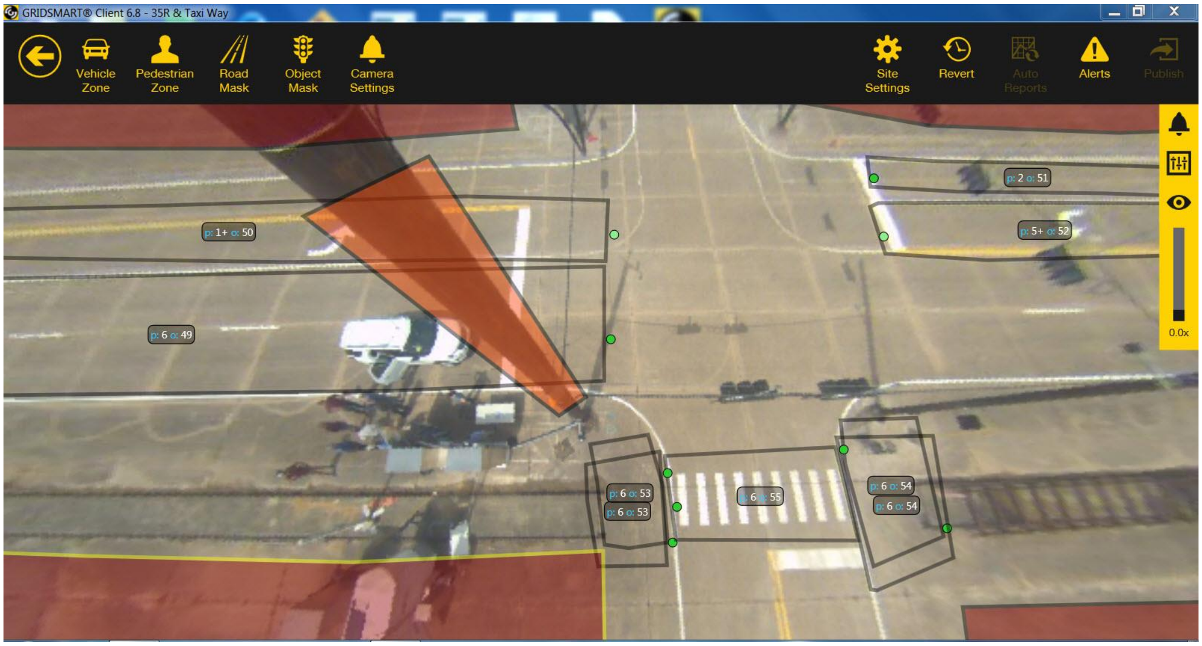
The proof-of-concept test was conducted at the RELLIS Campus proving ground. A state of the art traffic signal was developed and installed at the RELLIS Campus as part of this project. The smart intersection represents contributions from TTI, Econolite, and TxDOT. TTI capital equipment funds supported the construction of the intersection; Econolite donated most of the signal control and detection equipment and traffic signal cabinets; and this TxDOT project supported the purchase of the remaining equipment as well as the staff time to design and oversee the installation and development of initial applications demonstrated at the intersection.

As illustrated in Figure 26, the traffic signal is a four-legged high speed intersection using span wire across four wooden poles. These poles are 32 feet in height and can accommodate multiple detection and communication equipment for testing. Currently the intersection has protected-permitted operations in the north-south direction using flashing yellow arrows and permitted operations in the east-west direction. The intersection is equipped with an Econolite Cobalt Controller in an Econolite TS-2 Cabinet. A second interconnected cabinet beside the signal controller cabinet contains additional research equipment.

Source: Texas A&M Transportation Institute.

Figure 26. TTI Smart Intersection at RELLIS Campus.

High-speed, advance Accuscan Radar is installed in the northbound and southbound directions. Autoscope video detection provides detection in the eastbound and westbound direction. A GRIDSMART system has been installed to facilitate stop bar and pedestrian detection. The GRIDSMART system, funded by the TxDOT project, is a single-camera system that uses a bell camera, and vision-based tracking algorithms to detect various pedestrians and vehicles at an intersection. Figure 27 illustrates the GRIDSMART vision-based tracking feature. A Savari DSRC Roadside Unit is also installed to support research in connected infrastructure. The intersection also has a painted crosswalk and Polara Accessible Pedestrian System (APS) on both ends of the cross walk. The entire intersection is powered by a 3000 watt Honda generator.



Source: Texas A&M Transportation Institute

Figure 27. GRIDSMART Vision-Based Tracking Feature.

The proof-of-concept test represents the first use of the smart intersection. The system developed and being tested relies on a bus communicating with the traffic signal equipment using DSRC Radio, the signal determining the route of the bus, and if pedestrians are detected by the GRIDSMART system, a warning "caution, bus turning" is provided via an audio alert by the APS and a supplemental bus sign above the pedestrian head lights up. It also alerts pedestrians via a smartphone app developed for the project.

The smart pedestrian and bicyclist application proof-of-concept pilot focuses on the technologies used to transmit information from the intersection pedestrian detection system about approaching buses that will be turning at an intersection to pedestrians, individuals using wheelchairs, and bicyclists.

The three-alert systems used in this proof-of-concept test include an audible alert system, a visual alert system on a traffic signal, and a smartphone app. The technologies used in the proof-of-concept test are highlighted in this section.

Based on the system requirements, the TTI research team selected the POLARA APS system to provide an audible alert system. The POLARA APS system communicates information about the WALK/DON'T WALK intervals at signalized intersections in audible formats to visually impaired pedestrians. The POLARA APS system can be programmed with custom messages providing street names and the street being crossed. The direction of travel can also be added to the custom message.

Most POLARA APS buttons have a built-in microphone that measures ambient sound and increases the volume level played by the button as needed to be heard over traffic noise. Further, some APS buttons have the capability to increase the volume for one walk cycle if the button receives an extended push. The APS system can also be programmed to reduce the audible volume during certain times of the day. Some APS systems can be programmed to issue warning messages when emergency vehicles or trains are approaching. Further, some systems can also mute sounds from other crosswalks, with only the crosswalk in which the button was pushed providing an audible alert.

The TTI research team developed a custom message that is triggered from the CV-TPAS system. The message will alert pedestrians detected in the pedestrian detection zone that an approaching bus will be turning at the intersection. Figure 28 illustrates the New Intelligent Navigator POLARA APS system that the research team used to provide pedestrians with an audible custom alert message at an intersection during the proof-of-concept test.

Source: POLARA.

Figure 28. POLARA APS System.

The system requirements include providing pedestrians detected in the pedestrian detection zone with a visual alert to warn them about a bus turning at the intersection. The visual alert technology tested was an outline of a bus on the signal head above the pedestrian signal head. The signal will provide a visual alert that a bus is turning at the intersection through the crosswalk where a pedestrian has been detected in a pedestrian detection zone. When the sign is triggered, the bus outline is displayed. The sign is mounted above the pedestrian signal head at one crosswalk in the proof-of-concept test. When the CV-TPAS system identifies a bus approaching an intersection where a pedestrian has been detected in the pedestrian detection zone, the CV-TPAS system triggers the bus sign to illuminate. When the back of the bus clears the crosswalk, the CV-TPAS system powers off the sign. Figure 29 illustrates the bus signal used in the proof-of-concept test, and Figure 30 shows its placement at the smart intersection.

The third technology to be used in proof-of-concept test is a smartphone app designed to provide notifications to pedestrians located near the corner of an intersection when the roadside equipment detects a potential conflict with a turning bus. The vehicle events are detected by connected vehicle radios installed near the intersection which feeds BSMs from the bus's OBU into a computer in the field. Software installed on the field computer determines if a vehicle event merits notification to pedestrians at a corner corresponding with the bus's movement, as well as what specific message should accompany that notification.

Source: Texas A&M Transportation Institute.

Figure 29. Supplemental Bus Design.

Source: Texas A&M Transportation Institute.

Figure 30. Location of Bus Signal at Smart Intersection.

The Pedestrian Mid-Block Crossing Application, developed by the FHWA[1] provided an existing, open-source application used in a similar situation. The Android app provides a means of communicating between a driver and a pedestrian using an HTTP application programming interface and a cloud server. The approach provided both a communication platform and user interface that were customized for the smartphone app in this project.

The Mid-Block Crossing Application produces driver data events from the Android app running in driver mode. The app sends periodic DriverDataReport events as JavaScript Object Notation objects to the cloud server at a HTTP endpoint: /driver/data.

The TTI research team used the software installed at the smart intersection's roadside unit to construct and send DriverDataReport objects from sensor data, which replaces the need for the Android device to supply input data, yet retains the server as the data collector.

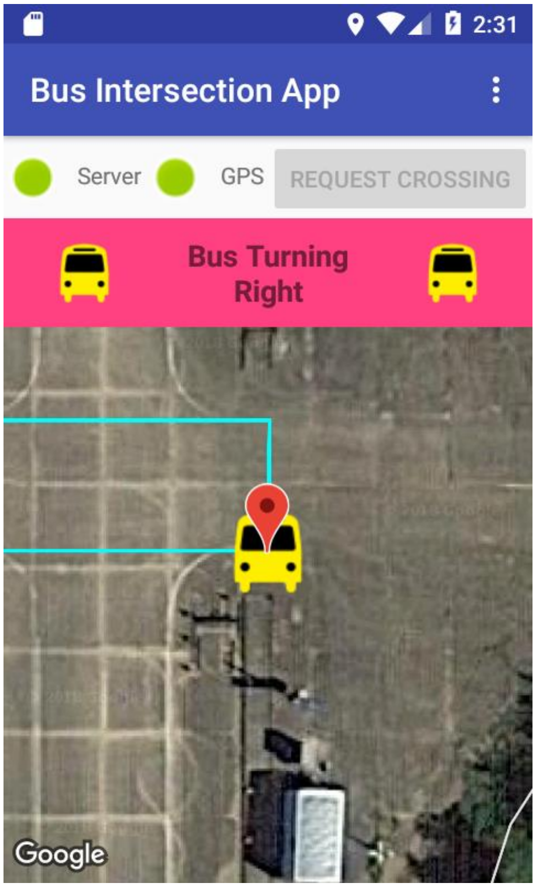
While DriverDataReports contain many useful data fields (such as timestamp, location, heading, and speed information), this application's notifications needed fewer fields. The roadside equipment determines if a bus is turning before sending a notification, reducing the essential fields to only an event latitude, longitude, and message. Therefore, the roadside equipment logic

[1] FHWA. Application and documentation available at: https://www.itsforge.net/index.php/community/explore-applications#/35/149

sends the location of the affected corner. The cloud server appends a timestamp to the event report upon receipt of the report.

A new RSUDataReport object was created to match this reduced set of fields following the example of DriverDataReports. The roadside unit sends the RSUDataReport, which is a comma-separated string of data, to the cloud server at the /rsu/csv HTTP endpoint. The cloud server retains RSUDataReports for 30 seconds. It also presents them to the Android app when a request is made to the HTTP endpoint /rsu/reports, completing the transmission of the vehicle event to the Android device.

TTI researchers modified the Mid-Block Crossing Application's Pedestrian mode to regularly poll the /rsu/reports endpoint to receive new RSUDataReport objects. New reports will render a blue vehicle icon onto a Google Map shown in satellite mode. If the pedestrian's Android device is located inside a 20-foot radius of the location sent in the notification, the pedestrian will be alerted in several ways: An audible alarm will beep several times, and the message from the RSUDataReport will be spoken using a text-to-speech module, and the text will be displayed in a small pop-up message. The Android app keeps a list of already-displayed reports to prevent duplicate notifications. Reports are retained for 30 seconds before being purged and their associated icon removed from the Google map. Figure 31 displays an example of the Android app during a notification.



Source: Texas A&M Transportation Institute.

Figure 31. Example of Android App Notification.

To maintain a low-latency notification to the pedestrian, polling of the cloud server by the Android app occurs at a period of 750 milliseconds. While HTTP is convenient to continue to use for all communication, a polling strategy has its setbacks. Improvements in bandwidth and battery life can be achieved if the delivery of notifications from the cloud server to the Android device employs push notifications via the MQTT protocol instead of a polling strategy.

Some modifications were made based on the field testing of the app. To reduce time delays, which sometimes occurred, the messages were delivered via the UBP protocol rather than the HTTP protocol. To save bandwidth and improve smartphone battery usage, an alternative HTTP polling method was developed. A MQTT broker service was set up on the cloud server to provide a single push notification to the smartphone at the time of the RSU event. The cloud server code was modified to establish a client connection with the MQTT broker. Data reports coming to the cloud server from the RSU are also published via MQTT to the /rsu/cy topic, causing them to be received by the smartphone via their subscription. The combination of these changes resulted in reducing the total latency between the RSU and smartphone, lowering bandwidth requirements, and reducing smartphone battery use.

TEST SCENARIOS, PROCEDURES, AND PROOF-OF-CONCEPT TEST

The test scenarios, procedures, and proof-of-concept test at the RELLIS Campus proving grounds are presented in this section. The test scenarios are based on the use cases presented in Section III. TTI researchers used the scenarios and procedures in the proof-of-concept test to test and verify that the CV-TPAS met the system requirements.

A TTI vehicle was used in the initial proof-of-concept test. A Brazos Transit bus, equipped with the necessary technology, was used during the proof-of-concept demonstrations at the October 23 roundtable forum, which is documented in Section VII. The results from the proof-of-concept test for the use cases identified in Table 1 are presented in Table 14 through Table 20. Table 21 through Table 24 present the proof-of-concept results for the audible alert device, the supplemental bus warning sign, and the smartphone app. Each of the scenarios and procedures includes the following information.

- The test objectives.
- The system requirements being tested under the scenario.
- A brief description the test and expected performance of the CV-TPAS in the test scenario.
- The initial setup and configuration of the test scenario.
- The procedures used to conduct the verification test.
- An indication of whether the CV-TPAS passed or failed to meet the system requirements.

Table 15. Test Scenario and Procedures for Use Case 1A.

Test Case No. and Title	**Use Case 1A: Right-Turning Connected Bus with a Pedestrian Present in the Pedestrian Detection Zone.**
Verification Phase	**II — Field Test Verification**
Test Objectives	• To test the basic functionality of the CV-TPAS system — that CV-TPAS provided alerts to a pedestrian waiting in the pedestrian detection zone when an approaching bus was turning right at the intersection. • To verify that the system provided alerts via visual, audible, and smartphone to pedestrians located at the intersection. • To verify that the system returned to standby state after the event is over.
Requirements Verified	1.1, 1.2, 1.3,1.4, 1.5, 1.7,1.8, 1.9, 2.1, 2.2, 2.3, 2.4, 2.6, 2.7, 3.1, 3.3, 3.6, 4,1, 4.2, 4.6, 5.1, 5.2, 6.1, 6.2, 6.4, 7.1, 7.2, 7.4, 7.5

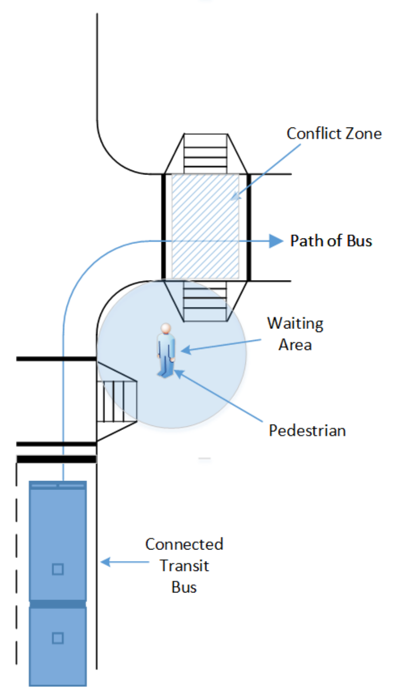
Brief Description	This test represents the base operational scenario. In this scenario, a connected bus (CB) approached the intersection from the south heading northbound. The route of the bus required the bus to make a right turn at the intersection and travel eastbound on the cross street. When the bus was within range of the RSU, the following occurred:
	• The bus transmitted its BSM to the CV-TPAS system at the intersection.
	• The system determined if the route of the bus required it to turn right.
	• The system detected that a pedestrian was located in the pedestrian detection zone.
	• As the bus executed a right turn at the intersection, the system performed the following:
	    ○ Activated an audible alert to the pedestrian in the pedestrian detection zone;
	    ○ Activated the pedestrian warning device located at the crosswalk; and
	    ○ Activated the smartphone app.
	• As the rear of the bus passed through the crosswalk, the system performed the following:
	    ○ Deactivated the audible alert to the pedestrian in the pedestrian detection zone;
	    ○ Deactivated the pedestrian warning device located at the crosswalk; and
	    ○ Deactivated the smartphone app.
	• The system returned to the standby mode.
	

Table 15. Test Scenario and Procedures for Use Case 1A (Continued).

Test Case No. and Title	**Use Case 1A: Right-Turning Connected Bus with a Pedestrian Present in the Pedestrian Detection Zone.**			
Test Set-Up and Configuration	• Transit vehicle was located approximately 500 feet upstream of an intersection. • A pedestrian was located in the pedestrian detection zone.			
Test Procedure/ Script	• At the signal of the test administrator, the vehicle was driven toward the intersection at a speed of approximately 30 mph. • At the appropriate distance from the intersection, the vehicle operator executed a right turn and traveled down the departure leg. • The test administrator logged the outcomes of the test.			
Pass/Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)			
Expected Results [requirements]	**Met?**		**Notes**	
	Y	**N**		
Did the CV-TPAS system receive the BSM message from the transit bus?	✓			
Did the system accurately determine the route of the bus (i.e., the bus was supposed to turn right at the intersection)?	✓		For the initial test, this process was being done using the MAC address of the OBU. Researchers are examining a way to embed the bus ID in Part 2 of the BSM.	
Did the pedestrian detection system detect the pedestrian in the pedestrian detection zone?	✓		For the initial test, the pedestrian detection triggered manually through the cabinet test panel. Work is continuing to allow the GRIDSMART system to provide pedestrian inputs.	
Did the system activate the pedestrian alert system (audible/visual warning[s] and/or smartphone app) to provide an alert to the pedestrian waiting in the pedestrian detection zone?	✓		Pedestrian alerts were provided through the pedestrian annunciator in both English and Spanish. A supplemental bus sign was displayed as the bus made the turn, and the smartphone application played the alert message to the pedestrian.	
Did the alert persist until the rear of the bus passed through the crosswalk?	✓		For the initial test, this process was time based. Researchers are working to adjust the program to have the decision based on the position of the bus and not on time.	

Table 16. Test Scenario and Procedures for Use Case 1B.

Test Case No. and Title	**Use Case 1B: Right-Turning Connected Bus with No Pedestrian Present in the Pedestrian Detection Zone.**
Verification Phase	**II — Field Test Verification**
Test Objectives	• To verify that the system does not provide an alert when there is no pedestrian waiting in the pedestrian detection zone. • To verify that the system returned to a standby state after the event is over.
Requirements Verified	3.1, 3.3, 3.7, 4.2
Brief Description	This test represents the base operational scenario. This scenario is the same as Scenario 1A, except there is no pedestrian waiting in the pedestrian detection zone. In this situation, the system should not issue an alert at the intersection.
Test Set-Up and Configuration	• The vehicle was located approximately 500 feet upstream of an intersection. • The pedestrian was initially located in the pedestrian detection zone but left the pedestrian detection zone as the bus approached.
Test Procedure/ Script	• At the signal of the test administrator, the vehicle drove toward the intersection at a speed of approximately 30 mph. • At the appropriate distance from the intersection, the transit vehicle operator executed a right turn and traveled down the departure leg. • As the vehicle began to decelerate, the pedestrian walked out of the detection zone. • The test administrator logged the outcomes of the test.
Pass/Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)

Expected Results [requirements]	**Met?**		**Notes**
	Y	**N**	
Did the bus receive the BSM message from the transit vehicle?	✓		
Did the system accurately determine the route of the bus (i.e., the bus was supposed to turn right at the intersection)?	✓		

Table 16. Test Scenario and Procedures for Use Case 1B (Continued).

Test Case No. and Title	**Use Case 1B: Right-Turning Connected Bus with No Pedestrian Present in the Pedestrian Detection Zone.**		
Expected Results [requirements]	**Met?**		**Notes**
	Y	**Y**	
Did the pedestrian detection system detect that there was no pedestrian in the pedestrian detection zone?	✓		No pedestrian was simulated by removing the pedestrian call into the controller.
Did the system not activate the pedestrian alert system (audible/visual warning[s] and/or smartphone app), since no pedestrian was waiting in the pedestrian detection zone?	✓		

Table 17. Test Scenario and Procedures for Use Case 2A.

Test Case No. and Title	**Use Case 2A: Left-Turning Bus with Pedestrian Located in the Pedestrian Detection Zone (Opposite Corner).**
Verification Phase	**II — Field Test Verification**
Test Objectives	• To test the basic functionality of the system — that the system provided an alert to a pedestrian in the pedestrian detection zone that a left-turning bus was approaching the intersection. • To verify that the system provided alerts via visual and audible warnings and smartphone app to a pedestrian located at the intersection. • To verify that the system returned to standby state after the event is over.
Requirements Verified	1.1, 1.2, 1.3, 1.4, 1.5, 1.7, 1.8, 1.9, 2.1, 2.2, 2.3, 2.4, 2.6, 2.7, 3.1, 3.3, 3.6, 4,1, 4.2, 4.6, 5.1, 5.2, 6.1, 6.2, 6.4, 7.1, 7.2, 7.4, 7.5

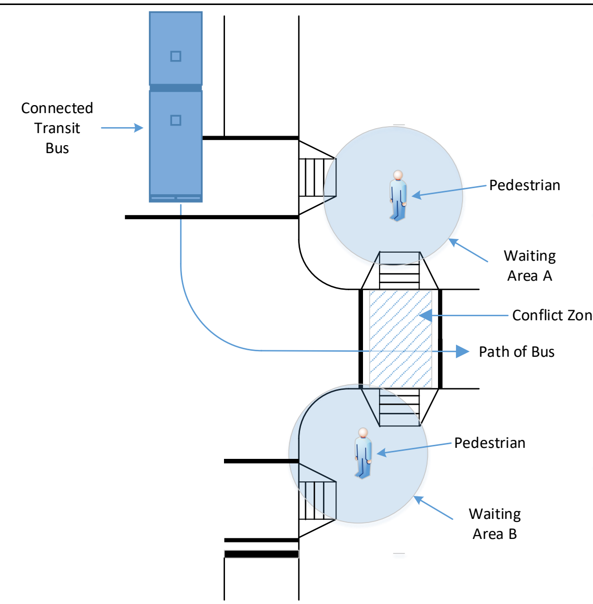
Brief Description	In this scenario, a vehicle approached the intersection from the north heading southbound. The route of the vehicle required it to make a left turn at the intersection and travel eastbound on the cross street. When the vehicle was within range of the RSU, the following occurred:
	• The bus transmitted its BSM to the system at the intersection.
	• The system determined if the route of the bus requires it to turn left.
	• The system detected that a pedestrian was located in the pedestrian detection zone.
	• As the vehicle executed a left turn at the intersection, the system performed the following:
	    ○ Activated an audible alert to the pedestrian in the detection zone;
	    ○ Activated the supplemental bus sign located at the crosswalk; and
	    ○ Activated the smartphone app.
	• As the rear of the bus passed through the crosswalk, the system performed the following:
	    ○ Deactivated an audible alert to the pedestrian in the pedestrian detection zone;
	    ○ Deactivated the supplemental bus sign located at the crosswalk; and
	    ○ Deactivated the smartphone app.
	• The system then returned to the standby mode.
	

Table 17. Test Scenario and Procedures for Use Case 2A (Continued).

Test Case No. and Title	**Use Case 2A: Left-Turning Bus with a Pedestrian Located in the Pedestrian Detection Zone (Opposite Corner).**
Test Set-Up and Configuration	• The vehicle was located approximately 500 feet upstream of the intersection. • A pedestrian was located in the pedestrian detection zone.
Test Procedure/ Script	• At the signal of the test administrator, the vehicle was driven toward the intersection at a speed of approximately 30 mph. • At the appropriate distance from the intersection, the vehicle operator executed a left turn and traveled down the departure leg. • The test administrator documented the outcomes of the test.
Pass/Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)

Expected Results [requirements]	**Met?**		**Notes**
	Y	**N**	
Did the system receive the BSM message from the bus?	✓		
Did the system accurately determine the route of the bus (i.e., the bus was supposed to turn left at the intersection)?	✓		
Did the pedestrian detection system detect the pedestrian in the pedestrian detection zone?	✓		
Did the system activate the pedestrian alert system (audible/visual warning[s] and/or smartphone app) to provide an alert to the pedestrian waiting in the pedestrian detection zone?	✓		
Did the alert persist until the rear of the bus passed through the crosswalk?	✓		

Table 18. Test Scenario and Procedures for Use Case 3A.

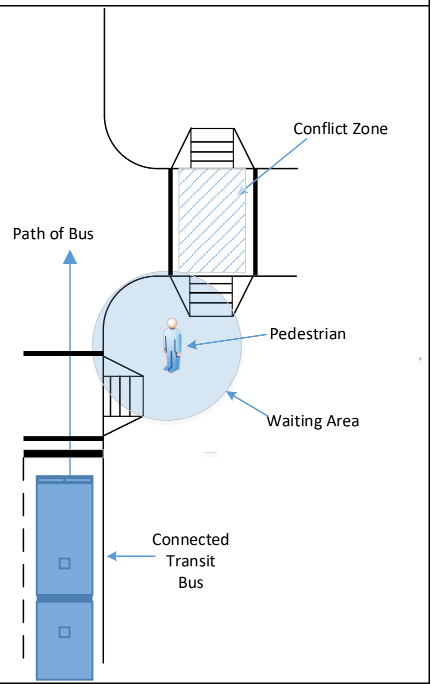
Test Case No. and Title	**Use Case 3A: Through Connected Bus with a Pedestrian Located in the Pedestrian Detection Zone.**
Verification Phase	**II — Field Test Verification**
Test Objectives	• To verify that the system did not provide an alert when the bus is traveling straight through the intersection, even with a pedestrian waiting in the pedestrian detection zone. • To verify that the system returned to standby state after the event was over.
Requirements Verified	3.1, 3.3, 3.7, 4.2
Brief Description	This test represents the base operational scenario. This scenario is the same as Scenario 1A, except the route of the bus has it traveling straight through the intersection. In this situation, the system should not issue alerts to a pedestrian in the pedestrian detection zone at the intersection. 
Test Set-Up and Configuration	• The vehicle was located approximately 500 feet upstream of an intersection. • The pedestrian was located in the pedestrian detection zone.

Table 18. Test Scenario and Procedures for Use Case 3A (Continued).

Test Case No. and Title	**Use Case 3A: Through Connected Bus with a Pedestrian Located in the Pedestrian Detection Zone.**		
Test Procedure/ Script	• At the signal of the test administrator, the vehicle was driven toward the intersection at a speed of approximately 30 mph and proceeded through the intersection. • The test administrator documented the outcomes of the test.		
Pass/Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)		
Expected Results [requirements]	**Met?**		**Notes**
	Y	**N**	
Did the system receive the BSM message from the transit vehicle?	✓		
Did the system accurately determine the route of the bus (i.e., the bus was supposed to travel through at the intersection)?	✓		
Did the pedestrian detection system detect the presence of a pedestrian in the pedestrian detection zone?	✓		
Did the system activate the pedestrian alert system (audible/visual warning[s] and/or smartphone app) to provide an alert to the pedestrian waiting in the pedestrian detection zone?	✓		

Table 19. Test Scenarios and Procedures for Use Case 4A.

Test Case No. and Title	**Use Case 4A: Turning Bus Stopping at a Nearside Bus Stop.**
Verification Phase	**II — Field Test Verification**
Test Objectives	• To test the basic functionality of the system — that the system provided an alert to a pedestrian in the pedestrian detection zone that a right turning bus was approaching the intersection. • To verify that the system provided a warning ONLY after the passengers were discharged and/or loaded onto the bus stopped at the bus stop and the bus began to move to the intersection. • To verify that the system provided alerts via audible/visual warning[s] and/or smartphone app to a pedestrian located at the intersection. • To verify that the system returned to a standby state after the event was over.
Requirements Verified	1.1, 1.2, 1.3, 1.4, 1.5, 1.7, 1.8, 1.9, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 3.1, 3.3, 3.6, 4,1, 4.2, 4.8, 4,9, 5.1, 5.2, 6.1, 6.2, 6.4, 7.1, 7.2, 7.4, 7.5

Table 19. Test Scenarios and Procedures for Use Case 4A (Continued).

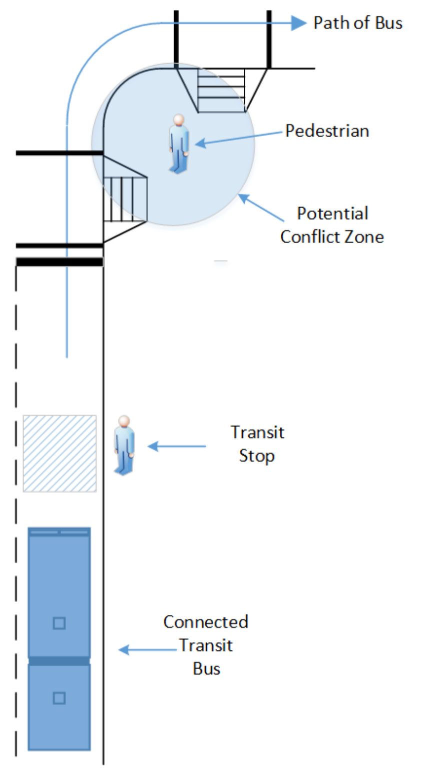
<table>
<tr><th>Test Case No. and Title</th><th>Use Case 4A: Turning Bus Stopping at a Nearside Bus Stop.</th></tr>
<tr><td>Brief Description</td><td>
In this scenario, a bus approaches the intersection from the south heading northbound. The route of the bus requires the bus to make a right turn at the intersection and travel eastbound on the cross street. However, the bus needs to make a stop at a nearside bus stop to load/discharge passengers while within the range of the RSU. The bus then proceeds toward the intersection to make the right turn, and the following occurred:

The bus transmitted its BSM to the system at the intersection.
The system determined if the bus is scheduled to stop at the nearside bus stop and shall ignore the BSM if the bus is scheduled to stop at the bus stop.
The system determined when the bus started from the bus stop.
The system determined if the route of the bus required it to turn right.
The system detected that a pedestrian was located in the pedestrian detection zone.
Before the bus executed a right turn at the intersection, the system performed the following:

Activated an audible alert to the pedestrian in the pedestrian detection zone;
Activated the supplemental bus sign located at the crosswalk; and
Activated the smartphone app.

As the rear of the bus passed through the crosswalk, the system performed the following:

Deactivated an audible alert to the pedestrian in the pedestrian detection zone;
Deactivated the supplemental bus sign located at the crosswalk;
Deactivated the smartphone app; and
Returned to the standby mode.



</td></tr>
<tr><td>Test Set-Up and Configuration</td><td>

The vehicle was located approximately 500 feet upstream of the intersection.
A pedestrian was located in the pedestrian detection zone.
</td></tr>
<tr><td>Test Procedure/ Script</td><td>

At the signal of the test administrator, the vehicle was driven toward the intersection at a speed of approximately 30 mph.
At the location of the nearside bus stop, the vehicle stopped for a pre-determined duration.
The vehicle started and moved toward the intersection.
At the appropriate distance from the intersection, the vehicle operator executed a right turn and traveled down the departure leg.
The test administrator documented the outcomes of the test.
</td></tr>
</table>

Table 19. Test Scenarios and Procedures for Use Case 4A (Continued).

Test Case No. and Title	**Use Case 4A: Turning Bus Stopping at Nearside Bus Stop.**		
Pass / Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)		
Expected Results [requirements]	**Met?**		**Notes**
	Y	**N**	
Did the system receive the BSM message from the transit vehicle before the bus stop?	✓		
Did the system accurately determine the route of the bus (i.e., the bus was supposed to turn right at the intersection)?	✓		
Did the pedestrian detection system detect that there was a pedestrian in the pedestrian detection zone?	✓		
Did the system activate the pedestrian alert system (audible/visual warning[s] and/or smartphone app) to provide an alert to the pedestrian waiting in the pedestrian detection zone?	✓		

Table 20. Test Scenarios and Procedures for Use Case 5A.

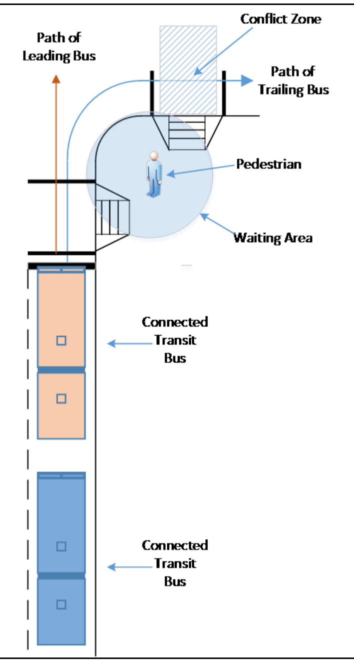
Test Case No. and Title	**Use Case 5A: Two Connected Buses (Lead Bus Going Through and Trailing Bus Turning Right) with a Pedestrian Present in the Waiting Area.**
Verification Phase	**II — Field Test Verification**
Test Objectives	**Primary Objectives:** • To test the ability of the system to communicate with multiple connected buses approaching an intersection — that the system did not provide an alert to the through bus and did provide an alert to the right-turning bus approaching the intersection. • To verify that the system waited until after the through bus has entered the intersection (crossed the crosswalk) to issue a warning on the right-turning bus.
Requirements Verified	1.1, 1.2, 1.3, 1.4, 1.5, 1.7, 1.8, 1.9, 2.1, 2.2, 2.3, 2.4, 2.6, 2.7, 3.1, 3.3, 3.6, 4,1, 4.2, 4.5, 4.8, 4,9, 5.1, 5.2, 6.1, 6.2, 6.4, 7.1, 7.2, 7.4, 7.5
Brief Description	Under this operational scenario, two vehicles approached the intersection simultaneously. The route for one of the vehicles traveled straight through the intersection, while the route of the other vehicle turned right at the intersection. When the vehicles were within range of the RSU, the following occurred: • The vehicles transmitted BSMs to the system at the intersection. • The system used the enhanced BSM information to determine which vehicle was projected to perform each maneuver. • The system detected that a pedestrian was located in pedestrian detection zone. • As the through vehicle traveled straight through the intersection, the system did not issue a warning until after the vehicle entered the intersection (crossed the crosswalk). • The trailing vehicle followed the same procedure as Scenario 1A after the lead vehicle entered the intersection. 

Table 20. Test Scenarios and Procedures for Use Case 5A (Continued).

Test Case No. and Title	**Use Case 5A: Two Connected Buses (Lead Bus Going Through and Trailing Bus Turning Right) with a Pedestrian Present in the Waiting Area.**		
Test Set-Up and Configuration	• Two vehicles were located approximately 500 feet upstream of an intersection, stopped one behind the other. • A pedestrian was located in the pedestrian detection zone.		
Test Procedure/ Script	• At the signal of the test administrator, the vehicles traveled to the intersection at a speed of approximately 30 mph. • The first vehicle proceeded straight through the intersection. • At the appropriate distance from the intersection, the operator of the second vehicle executed a right turn and traveled down the departure leg. • The test administrator recorded the outcomes of the test.		
Pass/Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)		
Expected Results [requirements]	**Met?**		**Notes**
	Y	**N**	
Did the system receive the BSM messages from the 2 buses?	✓		
Did the system accurately determine the route of the buses (i.e., the first bus was supposed to go straight through and the second bus was supposed to turn right at the intersection)?	✓		
Did the pedestrian detection system detect the pedestrian in the pedestrian waiting zone?	✓		
Did the system activate the pedestrian alert system (audible/visual warning[s] and/or smartphone app) to provide an alert to the pedestrian waiting in the pedestrian detection zone only for the right-turning bus?	✓		

Table 20. Test Scenarios and Procedures for Use Case 5A (Continued).

Test Case No. and Title	**Use Case 5A: Two Connected Buses (Lead Bus Going Through and Trailing Bus Turning Right) with a Pedestrian Present in the Waiting Area.**		
Expected Results [requirements]	**Met?**		**Notes**
	Y	**Y**	
Did the alert persist until the rear of the right-turning bus passed through the crosswalk?	✓		

Table 21. Test Scenarios and Procedures for Use Cases 6A, 6B, and 6C.

Test Case No. and Title	**Use Case 6A: Bus Vehicle ID Not Matched to Route** **Use Case 6B: Incorrect Bus Route in the Traffic Management Center** **Use Case 6C: Temporary or Long-Term Detours**
Verification Phase	**II — Field Test Verification**
Test Objectives	• To verify that the system provided a fail-safe operation and issued an alert to a pedestrian in the pedestrian detection zone. • To verify that the system provided alerts via audible/visual warning(s) and/or smartphone app. • To verify that the system returned to standby state after the event is over.
Requirements Verified	4.7
Brief Description	This test is a variation of the base operational scenario. Under this operational scenario, a bus successfully transmits the enhanced BSM information; however, the application is unable to determine the bus's route from data received from the transit management center (TMC) and, therefore, is unable to predict the bus's maneuvers at the intersection. This situation may occur either because the bus is currently not operating a route (i.e., the bus is not in service) or because the bus was not assigned to its route in the TMC. Another situation in which the system must prove fail-safe is if a temporary or long-term detour has been established. Under this operational scenario, a bus is on a detour from its regularly scheduled route, which impacts its maneuvers at the intersection. Because detours may be initiated without much advance notice, the TMC may or may not have the detour in its records. In addition, the detail of the detour record could range from a single field (to indicate whether the route is detoured) to a complete route trace of the detour. This would be the same case if the system was not able to match the bus to a route. A final scenario where fail-safe operation may be needed is if the incorrect bus route was assigned to the bus. Under this operational scenario, a bus successfully transmits the enhanced BSM, and the TMC knows the bus's route; however, the route assignment for the bus is incorrect. The incorrect assignment of a bus to a route may happen due to operational issues. For example, buses are sometimes assigned to different routes by transit agency staff without timely input of this change in the TMC. To assess these scenarios, the test will be configured to begin with Scenario 1A; however, in this case, bus ID to the route has been changed so that the bus cannot be associated with a particular bus route. Under this condition, the system should fail-safe and provide an alert to pedestrians located in the pedestrian detection zone. This alert shall occur for buses either turning right or traveling straight through the intersection.
Test Set-Up and Configuration	• The vehicle was located approximately 500 feet upstream of an intersection. • The bus ID was changed to a value not used in the route table. • A pedestrian was located in the pedestrian detection zone.

Table 21. Test Scenarios and Procedures for Use Case 6A, 6B, and 6C (Continued).

Test Case No. and Title	**Use Case 6A: Bus Vehicle ID Not Matched to Route** **Use Case 6B: Incorrect Bus Route in the Traffic Management Center** **Use Case 6C: Temporary or Long-Term Detours**
Test Procedure/ Script	• Run #1: ○ At the signal of the test administrator, the vehicle was driven toward the intersection at a speed of approximately 30 mph. ○ At the appropriate distance from the intersection, the vehicle operator executed a right turn and traveled down the departure leg. ○ The test administrator recorded the outcomes of the test. • Run #2 ○ At the signal of the test administrator, the vehicle was driven toward the intersection at a speed of approximately 30 mph. ○ The vehicle operator continued driving straight through the intersection. ○ The test administrator recorded the outcomes of the test.
Pass/Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)

Expected Results [requirements]	**Met?**		**Notes**
	Y	**N**	
For unmatched right-turning buses, did the system provide an audible alert to the pedestrian waiting in the pedestrian detection zone?	✓		
For unmatched right-turning buses, did the system activate the visual warning device alerting the pedestrian waiting in the pedestrian detection zone of an approaching bus?	✓		
For unmatched through buses, did the system activate the pedestrian alert system (audible/visual warning[s] and/or smartphone app) to provide an alert?	✓		

Table 22. Test Scenario and Procedures for the Audible Alert Device.

Test Case No. and Title	**Test 1: Test the functionality of the audible-alert device**
Verification Phase	**II — Field Test Verification**
Test Objectives	**Objectives:** • To test the basic functionality of the audible alert device to provide a suitable audible alert to the pedestrian detected in the pedestrian detection zone in response to a message form the CV-TPAS.
Requirements Verified	4.1, 4.4, 4.7, 4.8
Brief Description	This test was a verification of the functionality of the audible alert system. In this test, an audible alert-system trigger was installed in a signal-controller cabinet and the audible-alert system was installed in a scenario resembling an intersection and the alert system tested as follows: • Using a trigger, the audible system was activated. • The pedestrian was directed to step onto the crosswalk and walk to the other end of the crosswalk. • The functionality of the audible-alert system was observed and recorded.
Test Set-Up and Configuration	• A pedestrian was located in the pedestrian detection zone.
Test Procedure/Script	• At the signal of the test administrator, the audible-alert system was activated. • The test administrator logged the outcomes of the test.
Pass / Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)

Expected Results [requirements]	**Met?**		**Notes**
	Y	**N**	
Did the audible-alert system become activated upon being triggered?	**X**		

Table 22. Test Scenario and Procedures for the Audible Alert Device (Continued).

Test Case No. and Title	**Test 1: Test the functionality of the audible-alert device**		
Expected Results [requirements]	**Met?**		**Notes**
	Yes	**No**	
Did the audible-alert system stay on for the duration that the trigger was applied?	**X**		
Did the audible-alert system turn off when the trigger was cancelled?	**X**		
Is the audible-alert system message customizable for the location and the type of warning required?	**X**		Based on the input from participants in the focus groups and the pedestrian intercept surveys, a simple "caution, bus turning" message was used in the proof-of-concept test. The message was available in English and Spanish. The system is capable of using multiple messages.
Was the audible alert loud enough to be heard by the pedestrian in the pedestrian detection zone?	**X**		
Was the audible alert loud enough to be heard by the pedestrian at the far end of the crosswalk?	**X**		

Table 23. Scenario and Procedures for the Supplemental Bus Warning Sign.

Test Case No. and Title	**Test 2: Test the functionality of the supplemental bus-warning sign**
Verification Phase	**II — Field Test Verification**
Test Objectives	**Objectives:** • To test the basic functionality of the supplemental bus-warning sign to provide a suitable alert to the pedestrian at a typical intersection about the arrival of a turning bus.
Requirements Verified	4.1, 4.4, 4.7, 4.8
Brief Description	This test was a verification of the functionality of the supplemental bus-warning sign. In this test, a supplemental bus-warning-sign trigger was installed in a signal-controller cabinet and the visual-alert system was installed in a scenario resembling an intersection. The alert system was tested as follows: • Using a trigger, the supplemental bus-warning sign was activated. • The pedestrian was directed to step onto the crosswalk and walk to the other end of the crosswalk. • The functionality of the supplemental bus-warning sign was observed and recorded by the test administrator.
Test Set-Up and Configuration	• A pedestrian was located in the pedestrian detection zone.
Test Procedure/Script	• At the signal of the test administrator, the supplemental bus-warning sign was activated. • The test administrator logged the outcomes of the test.
Pass / Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)

Expected Results [requirements]	**Met?**		**Notes**
	Y	**N**	
Did the supplemental bus-warning sign become activated upon being triggered?	**X**		
Did the supplemental bus-warning sign stay on for the duration that the trigger was applied?	**X**		

Table 23. Scenario and Procedures for the Supplemental Bus Warning Sign (Continued).

Test Case No. and Title	Test 2: Test the functionality of the supplemental bus-warning sign		
Expected Results [requirements]	**Met?**		**Notes**
	Yes	**No**	
Did the supplemental bus-warning sign turn off when the trigger was cancelled?	**X**		
Was the supplemental bus-warning sign installed at one end of the crosswalk visible to the pedestrian in the pedestrian waiting area on the opposite side?	**X**		
Was the supplemental bus-warning sign installed at one end of the crosswalk legible to the pedestrian in the pedestrian detection zone on the opposite side?	**X**		
Was the supplemental bus-warning sign installed at one end of the crosswalk visible to the pedestrian in the crosswalk?	**X**		
Was the supplemental bus-warning sign installed at one end of the crosswalk visible to the pedestrian in the crosswalk?	**X**		

Table 24. Test Scenario and Procedures for the Smartphone app.

Test Case No. and Title	**Test 3: Test the functionality of the smartphone app**
Verification Phase	**II — Field Test Verification**
Test Objectives	**Objectives:** • To test the basic functionality of the smartphone app to provide a suitable alert to the pedestrian at a typical intersection about the arrival of a turning bus.
Requirements Verified	4.1, 4.4, 4.7, 4.8
Brief Description	This test was a verification of the functionality of the smartphone app using a projected image. In this test, the smartphone app trigger was installed in a signal-controller cabinet and the smartphone app was installed in a scenario resembling an intersection and the alert system was tested as follows: • Using a trigger, the smartphone app was activated. • The pedestrian was directed to step onto the crosswalk and walk to the other end of the crosswalk. • The functionality of the smartphone app was observed and recorded by the test administrator.
Test Set-Up and Configuration	• A pedestrian was located in the pedestrian detection zone.
Test Procedure/Script	• At the signal of the test administrator, the smartphone app was activated. • The test administrator logged the outcomes of the test.
Pass / Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)

Expected Results [requirements]	**Met?**		**Notes**
	Y	**N**	
Did the smartphone app become activated upon being triggered?	**X**		
Did the smartphone app stay on for the duration that the trigger was applied?	**X**		

Table 24. Test Scenario and Procedures for the Smartphone app (Continued).

Test Case No. and Title	**Test 3: Test the functionality of the smartphone app**		
Expected Results [requirements]	**Met?**		**Notes**
	Yes	**No**	
Did the smartphone app turn off when the trigger was cancelled?	**X**		
Is the smartphone app visible to the pedestrian in the pedestrian waiting area before they step on to the crosswalk?	**X**		
Is the smartphone app visible to the pedestrian in the crosswalk?	**X**		

VII. ROUNDTABLE FORUM

OVERVIEW

This section summarizes the October 23, 2018, roundtable forum held in College Station. Topics covered in the roundtable forum included a project update and a demonstration of the Mobileye Shield+™ collision-warning system on a Texas A&M bus piloted in Phase I of the project. Participants viewed the proof-of-concept demonstration of the smart intersection and smartphone app at the RELLIS Campus. The roundtable forum concluded with a discussion of possible next steps, including support for Phase III deployment projects.

AGENDA AND PARTICIPANTS

Figure 32 presents the electronic invitation to the roundtable forum and the agenda. The electronic invitation was sent to individuals participating in the workshops and roundtable forums held in 2015 and 2016 as part of Phase I of the project. This list was updated and expanded to account for changes in personnel and outreach to additional organizations. Table 25 lists the participants at the roundtable forum, which included representatives from TxDOT, transit agencies, metropolitan planning organizations (MPOs), the U.S. Department of Transportation (USDOT), Texas A&M University Transportation Services, Brazos Transit District (BTD), Bike Texas, and TTI researchers.

The Texas A&M Transportation Institute
Invites You to the

Roundtable Forum
Automated and Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, and Pedestrian Safety

Details
Date: Tuesday October 23, 2018
Time: 10 AM – 2 PM

Location
Texas A&M Transportation Institute (TTI)
State Headquarters and Research Building (SHRB)
Room 144
2935 Research Parkway, College Station, TX 77845
Parking is available behind the building.

Background

As part of a research project sponsored by the Texas Department of Transportation (TxDOT), the Texas A&M Transportation Institute (TTI) is examining automated vehicle and connected vehicle (AV/CV) applications to improve transit, bicycle, and pedestrian safety.

Building on the meetings and workshops held in 2015 and the first Roundtable Forum in 2016, this Roundtable Forum will highlight the development and operation of a Smart Intersection at the RELLIS campus and a Smartphone App to alert pedestrians and bicyclists of turning buses. Participants will travel by bus to the RELLIS campus for a demonstration of the Smart Intersection, which provides audible alerts in English and Spanish via the signal pedestrian system and the Smartphone App, and a visual alert by a supplemental bus sign. The Texas A&M University bus equipped the Mobileye Shield+ collision avoidance system, which was piloted in the first phase of the project and continues in daily operation on campus, will also be demonstrated. Participants will have the opportunity to discuss possible next steps in the TxDOT project focusing on implementing the Smart Intersection and Smartphone App, as well as other activities.

Roundtable Forum Agenda

> 10:00 AM Welcome and Introductions
> 10:15 AM Project Update and Overview of the Smart Intersection and Smartphone App
> 10:45 AM Travel by Bus to the RELLIS Campus
> 11:00 AM Demonstration of the Smart Intersection
> 12:15 PM Return to SHRB
> 12:30 PM Lunch
> 1:00 PM Discussion of Possible Next Steps and Wrap Up

Contact Information

Katie Turnbull
Executive Associate Director, Principal Investigator
Phone: (979) 845-6005 Email: k-turnbull@tamu.edu

Please RSVP by October 18 to:
Rachael Sears
Phone: (979) 458-3933 Email: R-Sears@tti.tamu.edu

Texas A&M Transportation Institute

Figure 32. Electronic Invitation and Agenda.

Table 25. Participants in the October 23, 2018, Roundtable Forum.

Name	Agency/Organization
Balke, Kevin	TTI
Bratlien, Chris	TTI
Bruchez, Elizabeth	Brazos Transit District
Charra, Hassan	TTI
Cherrington, Linda	TTI
Copley, Stephen	TxDOT
Dillard, Madeline	TAMU Transportation Services
Fitzpatrick, Kay	TTI
Gay, Kevin	USDOT
Hass, Lynn	Bike Texas
Hempel, Phillip	TxDOT
Higgins, Laura	TTI
Hoffmann, Debbie	TAMU Transportation Services
Jacob, Maurice	TxDOT
Kelly, Tim	Houston METRO
Kokes, Kevin	NCTCOG
Lange, Peter	TAMU Transportation Services
Lomax, Tim	TTI
Ma, Jianming	TxDOT
Martinez, David	VIA Metropolitan Transit
McCarty, Matthew	TxDOT
Metsker-Galarza, Madison	TTI
Nelson, Cody	NCTCOG
Odell, Wade	TxDOT
Ramirez, Christopher	TxDOT
Resendes, Ray	USDOT
Rudge, Daniel	B/CS MPO
Sherman, Bonnie	TxDOT
Sunkari, Srinivasa	TTI
Tobin, Bill	TxDOT
Turnbull, Katie	TTI

PROJECT UPDATE

Katie Turnbull, the TTI Research Supervisor, provided an overview of the project. She covered the following points in her presentation.

- The project focuses on reducing or eliminating crashes involving transit vehicles, bicyclists, and pedestrians through the use of AV/CV technology.
- The project was initiated in 2015. Phase I of the project included five major work tasks. The first work task was monitoring demonstrations and research projects throughout the country and internationally. In the second task, researchers conducted 25 meetings, four workshops, and four roundtable forums to gain insight into safety concerns associated

with transit vehicles, bicyclists, and pedestrians. The third task included a review of federal and state legislation relating to AV/CVs. In the fourth task, researchers developed a concept of operations (ConOps) plan for the AV/CV test bed to improve transit, bicycle, and pedestrian safety. A pilot of the Roscoe Mobileye Shield + collision warning system on one Texas A&M University bus was conducted in the final task.

- Phase II work tasks included the ongoing monitoring of demonstrations and research projects. TTI researchers conducted a survey of pedestrians at three intersections in Houston and facilitated three focus groups with individuals in wheelchairs, individuals with visual impairments, and individuals with hearing impairments. The construction of the smart intersection at the RELLIS Campus was completed, and the beta version of the Android smartphone app was developed. The proof-of-concept tests of the smart intersection and the smartphone app were conducted.
- A video of the Mobileye collision warning system on the Texas A&M University bus was presented and discussed. The data available from the system on the locations of alerts was also described.
- The ongoing monitoring of demonstrations and research projects in Phase II focused on bus-based collision warning systems, low-speed autonomous shuttles, and pedestrian and bicyclist smartphone apps. Pilots, demonstrations, and research projects underway throughout the country and the world were also monitored.
- Pedestrian intercept surveys were conducted at three intersections in Houston. Three focus groups were also conducted in Houston with transit riders who have disabilities. The three focus groups included predominantly Spanish-speaking wheelchair users, individuals who are blind or visually impaired, and individuals who are deaf or hearing impaired. Key results from the surveys and focus groups included interest in all alert methods, providing multiple warnings using audio and visual alerts, keeping the message simple ("caution bus turning"), and providing alerts in both English and Spanish.
- The smart intersection was developed through a public-private partnership. Econolite donated the traffic signals and cabinets. This TxDOT project funded the GRIDSMART fisheye camera. Construction of the intersection, painting the crosswalk, and purchase of the supplemental bus head was funded by TTI.
- The smart intersection is similar to a typical signalized intersection on an arterial. It includes protected, permitted operation in the north/south direction and permitted operation in the east/west direction. In addition to the normal traffic signal system components, the intersection is equipped with AccuScan radar, an Autoscope video detector, the GRIDSMART fisheye camera, a Savari DSRC roadside unit, and a Polara accessible pedestrian system.
- Three communication methods are used at the intersection as part of this project. An audible alert, "caution, bus turning," in English and Spanish is provided through the Polara accessible pedestrian system. A visual alert is provided using a supplemental bus signal head. A beta smartphone app provides an audible warning. The beta Android app was developed by TTI using the Federal Highway Administration (FHWA) mid-block crossing app open-sourced platform as a starting point.
- A number of use cases were developed as part of the project. The three use cases included in the proof-of-concept tests are a right-turning bus, a left-turning bus, and a through bus. Each of these use cases was reviewed and highlighted with a video. The assistance of Brazos Transit District and Texas A&M Transportation Services in

providing buses for the proof-of-concept tests and the roundtable forum were acknowledged.
- The potential benefits to TxDOT from the project were reviewed and discussed. These benefits include the safer operation of signalized roadways in the state and supporting the TxDOT Public Transportation Division, which administers funding to 30 urban and 37 rural transit districts in the state. The project also enhances TxDOT's strong working relationships with transit and local agencies and strengthens TxDOT's partnerships with diverse groups.
- Possible Phase III projects at intersections, transit centers, and other locations were reviewed. Possible intersections in Houston, Austin, and Bryan/College Station were identified. Transit centers in Houston, Bryan/College Station, San Marcos, Waco, Brownsville, McAllen, and Laredo were noted as possible locations for Phase III projects. Projects associated with Texas A&M Game Day app and enhancing the Houston METRO smartphone app for individuals with visual impairments were also highlighted.

PROOF-OF-CONCEPT DEMONSTRATION

Participants traveled by bus to the RELLIS Campus for the proof-of-concept demonstration at the smart intersection. Participants observed the Mobileye collision warning system on the bus during the trip to and from the RELLIS Campus. Figure 33 through Figure 36 illustrate the right-turning bus use case, which was described by TTI researchers during the proof-of-concept demonstration. The figures illustrate:

- The before situation, with the bus outside the range of the intersection.
- The bus approaching the intersection with the supplemental bus sign illuminated.
- The bus turning through the intersection with the bus sign still illuminated.
- The bus clearing the intersection with the bus sign off.

Figure 37 highlights the roundtable forum participants at the smart intersection.

Figure 33. Right Turning Bus Use Case — Before Situation.

Figure 34. Right Turning Bus Use Case — Bus Approaching the Intersection.

Figure 35. Right Turning Bus Use Case — Bus Turning through the Intersection.

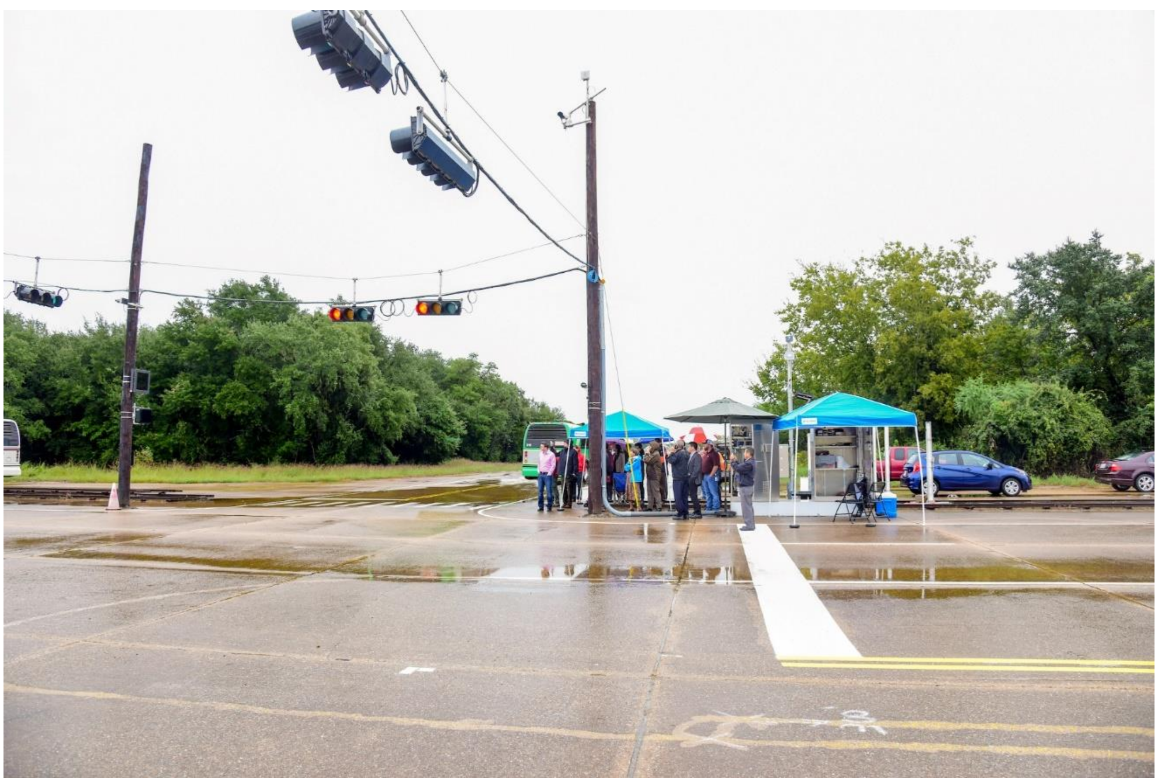


Figure 36. Right Turning Bus Use Case — Bus Clears the Intersection.

Figure 37. Roundtable Forum Participants at the Smart Intersection Proof-of-Concept Test.

POSSIBLE PHASE III PROJECTS AND WRAP-UP DISCUSSION

Wade Odell, TxDOT Project Manager, facilitated a discussion of reactions to the proof-of-concept tests and possible Phase III projects. Comments from participants are summarized in this section.

- Participants from transit agencies and transportation operators expressed interest in the elements included in the proof-of-concept tests and voiced support for possible Phase III projects. Potential intersections and other locations for Phase III activities were identified. Comments included the need to consider charter and school buses at some locations, the potential to communicate back to the bus operator, the option of leveraging multiple technologies, and examining the needs of pedestrians with disabilities.
- Participants discussed the increase in motorized scooters ("fast pedestrians") on sidewalks, bus lanes, and bicycle lanes, as well as pedestrians not paying attention to the traffic signals. The need to consider crashes involving wheelchairs was also noted. Considering areas with high volumes of pedestrians for Phase III projects was noted as important by some participants.
- Possible human factor topics to consider in Phase III projects were noted by some participants. Examples of potential human factor issues included flashing vs. non-flashing bus signs, the use of in-pavement lighting, the actual audio message provided, and the potential for an app or message to be distracting to pedestrians. The potential of considering human factors issues in Phase III projects by testing different methods

(flashing vs. non-flashing bus signs) was suggested by some participants. Considering non-technology safety counter measures was further suggested by some participants.

- Some participants discussed the complexity of many intersections, especially those with high volumes of traffic, bicyclists, and pedestrians. The potential need to develop customized messages was noted, as was the opportunity to use portable devices to address short-term needs at some intersections and locations. The ability to use multiple technologies and to build on current projects, while maintaining flexibility for future advancements, was suggested as important by some participants.
- The potential of combining a bus-based warning system such as the Mobileye Shield+ system piloted in Phase I, and the intersection-based system developed in Phase II was discussed. The ability of different technologies to function at night and to identify individuals using wheelchairs and scooters was also discussed.
- Some participants noted that pedestrians do not always obey traffic signals — walking when they should not and crossing streets at unmarked locations. Participants commented that the uncertainty of pedestrian and bicyclist behavior creates challenges in designing systems focused on improving their safety.
- The interactions of pedestrians, bicyclists, and scooters were discussed. Some participants voiced concerns with pedestrian safety in locations with numerous bicyclists and scooters. The potential to warn the bus operator, rather than the pedestrian, was discussed by some participants.
- Participants discussed the introduction of AV/CV technologies in all types of vehicles, the turnover in vehicle fleets, and the time period with a mix of legacy, automated, and autonomous vehicles. Participants discussed the long-term vision of autonomous vehicles, the different levels of automation, and deployment readiness. They also discussed the potential for bus operators and passenger vehicle drivers to become overly reliant on technology and to not pay attention in potentially dangerous situations. Some participants discussed related research projects and activities, including projects in Dallas and Houston. Coordinating possible Phase III with these projects was suggested by some participants. A possible project the University of Texas at Tyler was suggested by one participant.
- The importance of pedestrian safety at TxDOT, as well as at FHWA, was noted by some participants. Participants in the roundtable discussion suggested that safety tools and safety considerations for pedestrians and bicyclists should be built into traffic signal systems and other related traffic-control devices.
- Wade Odell asked the TxDOT personnel for their opinion on moving the project forward into Phase III. All of the TxDOT staff supported proceeding to Phase III. Wade requested that possible Phase III projects be included in the final Phase II report so that he could recommend moving forward into Phase III. Wade noted that although no innovative research project had been approved yet for Phase III, TxDOT is interested in considering one or more deployment projects. Factors suggested to consider in developing Phase III projects include locations on the state highway system, facilities used by the small-urban and rural-transit systems receiving funding through TxDOT, and the ability to measure and assess the impact of the project to improve safety.

VIII. POTENTIAL PHASE III DEPLOYMENT PROJECTS

The third phase of the TxDOT innovative research projects focused on deployment. As summarized in Section VII, possible Phase III projects were discussed at the October 23, 2018, roundtable forum. TxDOT staff participating in the roundtable forum unanimously supported moving forward with Phase III.

Researchers reviewed the initial list of potential projects based on the discussion at the roundtable forum. They also held additional conversations with representatives from local agencies about the possible projects. Potential Phase III projects in College Station, Houston, and San Marcos are presented in this section. Expanded proposals will be developed on the projects if TxDOT elects to move forward with Phase III.

UNIVERSITY DRIVE AND ASBURY STREET, COLLEGE STATION

The first proposed location for deployment is the intersection of University Drive and Asbury Street in College Station. The intersection, which is illustrated in Figure 38, is adjacent to the Texas A&M University campus. Texas A&M University buses operating on routes 1 and 2 and Brazos Transit District buses operating on the TAMU express route travel through the intersection.

Preliminary conversations on the smart intersection deployment at University Drive and Asbury Street have been held with representatives from Texas A&M University Transportation Services, Brazos Transit District, and the City of College Station. All have voiced support for the project. Contacts will be made with TxDOT Bryan District staff if a decision is made to request proposals on the Phase III projects.

The deployment of the smart intersection at this location supports the objectives of this research project, as well as the update of the Texas A&M University Campus Master Plan and the Campus Transformational Mobility Plan. It also supports the current TxDOT project, which is making major improvements on University Drive. Large volumes of pedestrians, bicyclists, buses, and private vehicles travel through the intersection, which is a main crossing point for pedestrians and bicyclists from campus to the Northgate area.

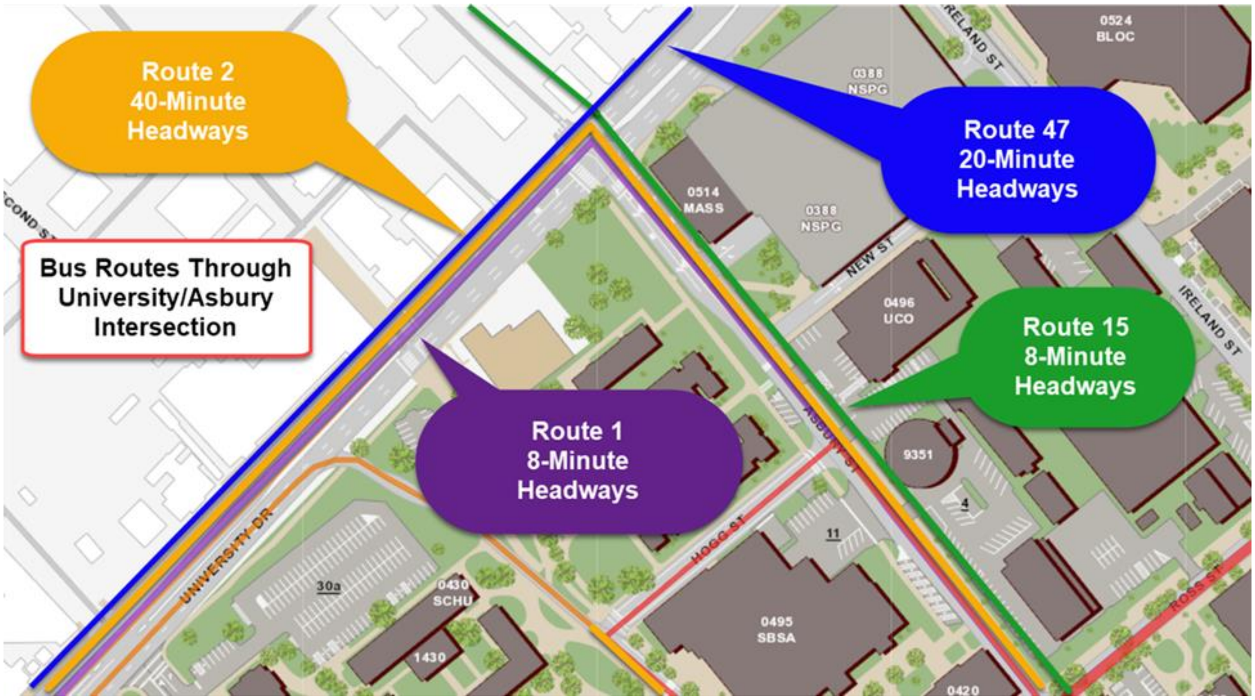


Figure 38. University Drive and Asbury Street, College Station.

GESSNER ROAD AND LONG POINT ROAD, HOUSTON

The second proposed location for deployment is the Gessner Road and Long Point Road intersection in Houston. Over the last five years, vehicles crashed into more than 8,700 people walking and biking across Houston based on LINK Houston's analysis of TxDOT data. The City of Houston has been addressing public safety on the city's streets, including a city-wide Safer Streets initiative to identify and fix locations of concern for pedestrians and bicyclists.

Long Point and Gessner is one intersection, identified by LINK Houston as a priority intersection for safety improvements. This intersection, illustrated in Figure 39, carries high volumes of buses, personal vehicles, pedestrians, and bicyclists. METRO Route 26 Long Point/Cavalcade turns right from Gessner onto Long Point going eastbound and turns left from Long Point to Gessner going westbound. METRO Route 46 Gessner runs north-south through the intersection on Gessner without turning.

Anticipated partners in this project include Houston METRO, the City of Houston, LINK Houston, and local business groups. Preliminary discussions with Houston METRO indicate support for the project. The TxDOT Houston District will be contacted if the decision is made to move forward with Phase II project proposals.

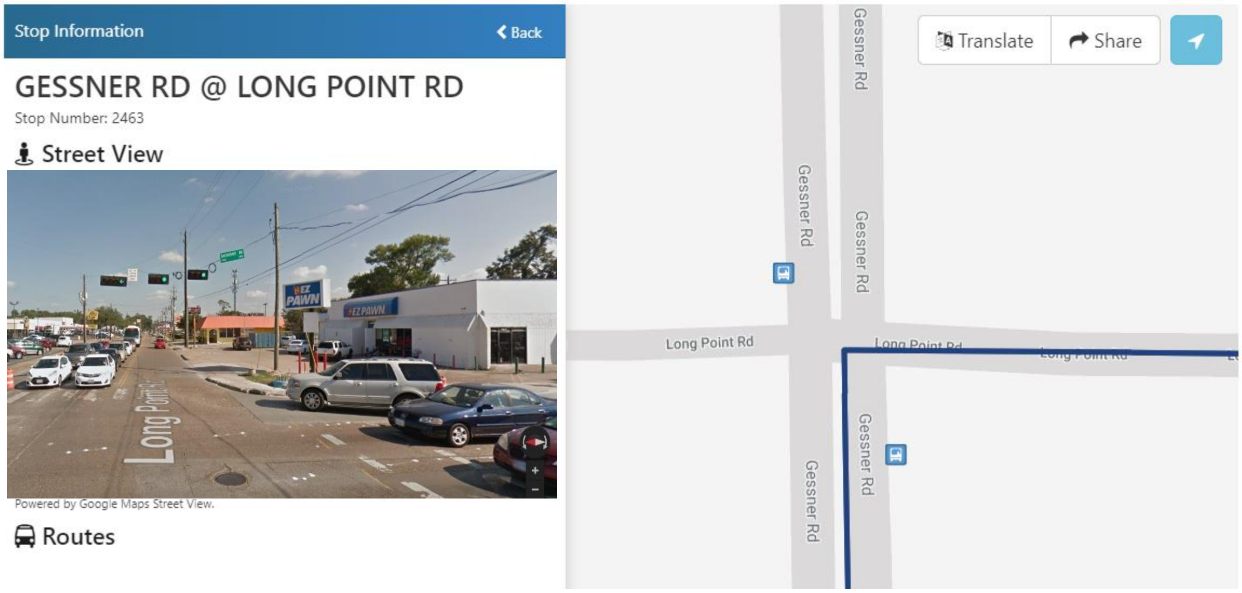


Figure 39. Gessner Road and Long Point Road, Houston.

NORTH LBJ DRIVE (LOOP 82) AND EAST HUTCHINSON STREET, SAN MARCOS

The third proposed location for deployment of the smart intersection is in downtown San Marcos. The local participants would include the Capital Area Rural Transportation System (CARTS), the City of San Marcos, and Texas State University. Contacts will be made with the TxDOT Austin District to obtain their participation if a Phase III proposal is requested on this project.

A comprehensive revitalization program fostering a unique and a culturally vibrant downtown area is underway in San Marcos. Relocating the transit hub from its existing location near Interstate 35 to a site near the historic Hays County Courthouse Square is one project in the revitalization program. As shown in Figure 40, the proposed location for the transit hub is between East Hutchinson Street and East Hopkins Street and between North LBJ Drive and North Edward Gary Street. The transit hub will be the center of activity for transit riders, pedestrians, and bicyclists in San Marcos. Transit routes will include the CARTS regional services, local San Marcos routes, and the Texas State Bobcat Shuttle.

The city also plans to upgrade the traffic management system, which includes traffic cameras strategically located at the city's busiest intersections. The proposed location for demonstration of the smart intersection is North LBJ Drive, which is part of Texas State Highway Loop 82, and East Hutchinson Street. The opportunity to demonstrate the smart intersection in downtown San Marcos will enable the city to consider deployment of the safety features to additional intersections.

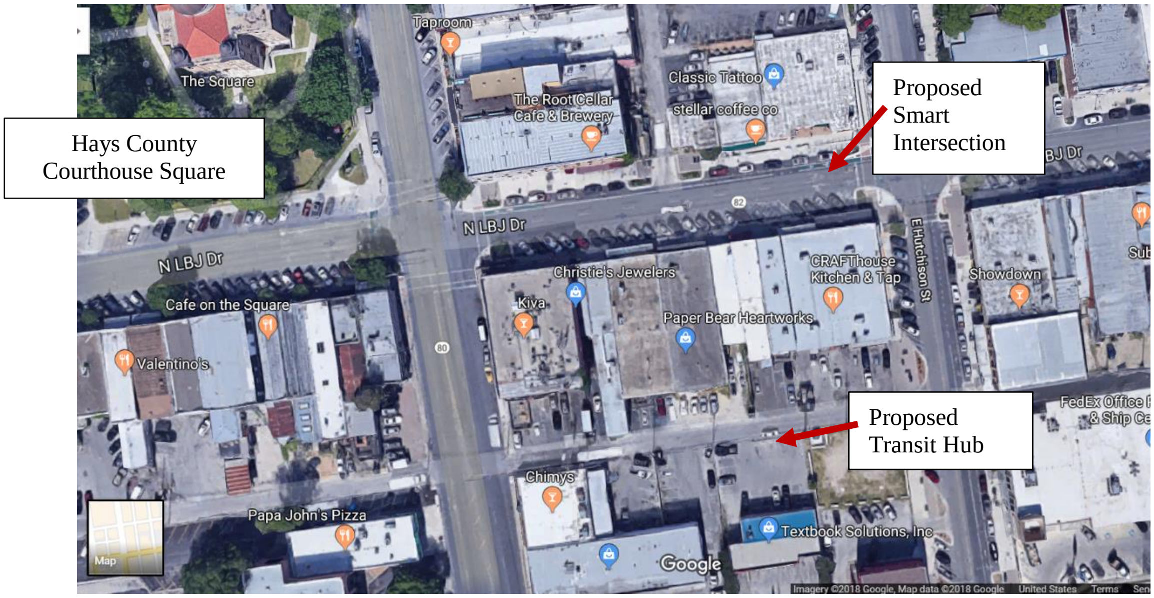
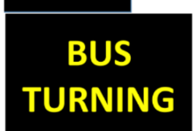


Figure 40. North LBJ Drive and East Hutchinson Street, San Marcos.

APPENDIX A: POST-WALK SURVEY

Following the walking, the participant was asked the following questions via a laptop. The questions were shown to the participant using a Power Point file and the TTI Staff person recorded the answers.

1	What projected **warning sign message** was projected on the sidewalk?
2	What do you believe the projected **warning sign message** should be? e) Yield f) Turning bus g) Look left h) Other
3	Based on your experience as a pedestrian, how effective do you think the **projected warning sign message** would be in warning you a bus is turning at an intersection? a) Not at all effective b) Slightly effective c) Effective d) Very effective e) Not sure
4	The testing today was in a quiet location, now imagine a busy city street. Do you see any potential negative consequences with the use of this device?
5	What was the **audible warning message** provided at the driveway?
6	What do you believe the **audible warning message** should be? f) Look for turning bus g) Yield to turning bus h) Caution, bus is turning i) Pedestrians, bus is turning j) Other
7	Based on your experience as a pedestrian, how effective do you think the **audible warning message** would be in warning you a bus is turning at the intersection? a) Not at all effective b) Slightly effective c) Effective d) Very effective e) Not sure
8	The testing today was in a quiet location; now imagine a busy city street. Do you see any potential negative consequences with the use of this device?
9	What warning message was provided on the **phone**?

10	How do you suggest a **phone-based warning message** should be provided? a) Text message b) Warning sound c) As part of an app d) Other
11	Based on your experience as a pedestrian, how effective do you think the **phone-based warning message** would be in warning you a bus is turning at an intersection? a) Not at all effective b) Slightly effective c) Effective d) Very effective e) Not sure
12	The testing today was in a quiet location, now imagine a busy city street. Do you see any potential negative consequences with the use of this device?
13	What was the **warning message** provided on the **supplemental bus warning sign** above the pedestrian signal (walking man/raised hand)?
14	What do you believe the **supplemental bus warning sign** should say when provided above the pedestrian signal (walking man/raised hand)? e)  f)  g)  h)  i) Other
15	Based on your experience as a pedestrian, how effective do you think the **supplemental bus warning sign** would be in warning you a bus is turning at an intersection? a) Not at all effective b) Slightly effective c) Effective d) Very effective e) Not sure
16	The testing today was in a quiet location, now imagine a busy city street. Do you see any potential negative consequences with the use of this device?

17 For the 4 devices demonstrated, place each device on the following linear scale to show—in your opinion—the **effectiveness of the device in conveying the need for a pedestrian to look for a turning bus**?

- **Projected warning sign** on the sidewalk
- **Phone-based** warning message (text or warning sound)
- **Audible warning** message at the intersection
- **Supplemental bus warning sign** at the intersection

Negative Effects	No Effects	Minimal Effect						Very Effective
-1	0	1	2	3	4	5	6	7

18 Do you have any suggestions of improving these methods of warning pedestrians of oncoming buses?

19 What factors would change your opinion of the effectiveness? (e.g., traffic volume, noise, time of day).

20 While walking on a side walk, how often are you looking at your cellphone?

a) Never
b) Occasionally
c) Half the time
d) Most of the time
e) Always
f) Not sure

21 While walking on a side walk, how often are you listening to music from your cellphone?

a) Never
b) Occasionally
c) Half the time
d) Most of the time
e) Always
f) Not sure

22 While waiting at an intersection, how often are you looking at your cellphone?

a) Never
b) Occasionally
c) Half the time
d) Most of the time
e) Always
f) Not sure

23	While waiting at an intersection, how often are you listening to music from your cellphone? a) Never b) Occasionally c) Half the time d) Most of the time e) Always f) Not sure
24	Before crossing at intersection, how often do you look for turning busses? a) Never b) Occasionally c) Half the time d) Most of the time e) Always f) Not sure

APPENDIX B: "BUS CROSSING" PEDESTRIAN WARNING — INTERCEPT SURVEY

Surveyors will approach pedestrians and cyclists that appear to be age 18 or older, who are preparing to cross or have just crossed the street at the crosswalk. The surveyor will state:

"I am with the Texas A&M Transportation Institute and I'm conducting a research study. Are you age 18 or older? May I have 1 minute to ask you a few questions? Your responses will help us improve safety for pedestrians and cyclists. Participation is voluntary and your responses anonymous."

If the individual agrees, then the surveyor will promptly administer the survey, recording the participant's responses on an electronic tablet for later upload to Qualtrics.

SURVEYOR DIRECT QUESTIONS TO INDIVIDUALS

Q1. If a bus was about to turn across this crosswalk as you are crossing, would you like a warning that the bus is turning?

Yes ***(continues to Q2 & Q3, skips Q4–5)***
No ***(skips to Q4)***
Unsure ***(skips to Q4)***

Q2a. Would you prefer to (1) see the warning message on or near the pedestrian signal, (2) see a warning on the crosswalk, (3) hear a warning message broadcast from the pedestrian signal, or (4) get a warning on your phone or other mobile device?

(1) See the warning on or near the pedestrian signal
(2) See the warning on the crosswalk
(3) Hear the warning message
(4) Receive the warning on your phone or mobile device
Unsure/ I do not know

→If participant picked Unsure, go to Q3, otherwise go to Q2b:

Q2b. What is your second preference to receive a warning message about a bus turning across the crosswalk you are about to enter?

(1) See the warning on or near the pedestrian signal
(2) See the warning on the crosswalk
(3) Hear the warning message
(4) Receive the warning on your phone or mobile device
(5) Unsure/ I do not know

Q3. Would you want to be told which direction the bus is turning (right or left), or just that a bus is turning?

Bus is turning right (or left)
Bus is turning
Unsure

Q4. Have you ever had to stop walking or move out of the way because a bus was turning across the crosswalk?

Yes (go to Q5)
No (skip to Q6)
Unsure (skip to Q6)

Q5. How did you first realize the bus was there?

I saw the bus.

I heard the bus.
Another person told me.
Other:
Unsure

Q6. Comment box: [Only used if a respondent volunteers a comment, observation, or question.]

"Thank you for your time. Have a great, safe day!"

SURVEYOR OBSERVATIONS ABOUT INDIVIDUAL PARTICIPANTS

Q7. Gender? Male / Female / Unsure
Q8. Approximate age? 18-30 / 31-50 / 50+ / Unsure
Q9. Phone/tablet visible? Yes, in-use / No / Unsure
Q10. Headphones visible? Yes, in-use / No / Unsure
Q11. Bike? Yes, cyclist / Yes, walking bike / No
Q12. About to cross, or just crossed? About to cross/just crossed
Q13. Obeyed pedestrian crossing signal? Yes / No/did not observe
Q14. Did the pedestrian look both ways before entering the crosswalk? Yes/No/did not observe

APPENDIX C: "BUS CROSSING" PEDESTRIAN WARNING — FOCUS GROUP GUIDE

WELCOME/INTRODUCTIONS

Thank you all for participating in this discussion group today. My name is [name] and I work at the Texas A&M Transportation Institute. I'll be the moderator for this discussion.

PROTOCOL

Before we get into the discussion, let me make a couple of comments about focus-group protocol. First, as you know from reading your consent forms, we are audio recording the discussion. This is just to be sure we have all of your comments correctly noted for our analysis. We will never quote any of you by name in our results and reports, so feel free to give your honest opinion. Because of the recorder, and to help our note taker, I would ask that you talk one at a time and please speak loudly enough that we and the recorder can hear you clearly.
I encourage you to talk a lot, be candid, and enjoy the discussion.

INTRODUCTION

A smart intersection is a roadway intersection that is equipped with technologies that allow it to detect and, in some cases, communicate with vehicles. Connected vehicles are equipped with technologies that can receive information and also send information to a smart intersection. Smart intersections and connected vehicles provide opportunities to improve safety for road users by warning them about hazards they might not otherwise be able to detect in time to avoid. A bus making a left or right turn at an intersection can pose a hazard to pedestrians or bicyclists who are crossing at the same intersection. Bus drivers are trained to look for and yield to pedestrians and bicyclists. When approaching an intersection, they scan crosswalks and bicycle lanes before and during a turn in order to avoid potential conflicts. Even with training and experience, this can be a challenging maneuver to perform safely.
Today we are going to discuss a system that not only notifies the bus driver that a pedestrian or bicyclist is in the crosswalk, but can also provide an additional warning to a pedestrian or bicyclist at an intersection that a bus will turn across the crosswalk.

MESSAGE MEDIUM

Imagine that you are walking on the sidewalk in an area with traffic and come to an intersection that has a crosswalk with a pedestrian "walk/don't walk" signal. A bus is about to turn left or right across the crosswalk you are about to enter or have already entered.
Q1. Would you want some sort of warning or notification that the bus was about to turn across the crosswalk? Why or why not?

Q2. If you were warned about the bus turning at the intersection, would you want that warning to come to you from the pedestrian signal at the intersection, through your phone or other mobile device, or both?

MESSAGE CONTENT/WORDING/FORMAT

Q3a. If you would prefer the warning to come from the pedestrian signal, would you want to hear a warning about the bus, see a warning about the bus, or both?

Q3b. If you would prefer phone/mobile device, would you want to hear a warning about the bus or receive a tactile warning such as a vibration?

- *Note:* need to record if participants indicate they are not interested in receiving the warning from phone/mobile device.

Q3c. If you would prefer the warning to be on the pavement, how would you like that warning to look?

- *Prompts/Explanation:* Auditory warning/message could be broadcast from the pedestrian signal in the same way that audible "walk" signals/messages are broadcast at some intersections. Visible warning/message could be displayed just above the "walk" signal. Mobile device app could provide any or all of these to an individual user. Warning on the pavement could be a red bar at the curb edge or it could be flashing yellow LEDs within the crosswalk.

Q4. What information would you want to have about the bus?

- *Prompts:* direction the bus is coming from, instructions to look left or right, simply that a bus is about to come through the intersection
- *Probe:* if you want to know the direction — how do you know where the bus is located? What if you hear the message from across the intersection?

Q5. If you were getting an audible warning, what words or sounds would you want to hear to let you know about the bus?

- *Prompts:* answers may be different if they are talking about audible warning from a **phone** or audible warning from the **pedestrian signal.**

Q6. If you were getting a visible warning, what words, pictures, or other visual signals would you want to see to let you know about the bus?

Q7. If you were already partway across the intersection in the crosswalk when the bus was approaching the turn, would you want the warning about the bus to be different than if you had not yet started to cross?

- *Prompts:* would you want different instructions if you were in the crosswalk versus still on the curb? Would you want the warning to sound or look more urgent/intense?

MESSAGE TIMING AND OTHER

Q7. How far away should the bus be from the intersection when the warning is activated?

- *Prompts: When the bus is about to turn; 10 seconds away? 20 seconds away? 30 seconds away? More?*

WRAP-UP/CLOSING

Q8. What would make the bus turning warning most useful to you?

Q9. Do you have additional suggestions, concerns, or comments about this type of warning system?

APPENDIX D: “BUS CROSSING” PEDESTRIAN WARNING — SPANISH FOCUS GROUP GUIDE

BIENVENIDOS / INTRODUCCIONES
Gracias a todos por participar hoy en este grupo de discusión. Mi nombre es [nombre] y trabajo en el Instituto de Transporte de Texas A&M. Seré el moderador de esta discusión.

PROTOCOLO
Antes de entrar en la discusión, permítanme hacer un par de comentarios sobre el protocolo del grupo de enfoque. Primeramente, hoy estaremos grabando la discusión. Esto es solo para asegurarnos de que todos sus comentarios se anoten correctamente para nuestro análisis. Nunca citaremos a ninguno de ustedes por su nombre en nuestros resultados e informes, así que siéntase libre de dar su opinión honesta. Debido a la grabación, y para ayudar a nuestro tomador de notas, les pido que hable uno a la vez y con claridad.
Les invito a que participen durante la discusión, que sean sinceros y disfruten.

INTRODUCCIÓN
Una Intersección Inteligente es una intersección vial que está equipada con tecnologías que le permiten detectar y, en algunos casos, comunicarse con los vehículos. Los vehículos conectados están equipados con tecnologías que pueden recibir y enviar información a una intersección inteligente. Las Intersecciones Inteligentes y los Vehículos Conectados brindan oportunidades para mejorar la seguridad de los usuarios de la carretera. Esta tecnología les advierte sobre peligros que de otra manera no podrían detectar a tiempo para evitarlos.

Un autobús que gire a la izquierda o a la derecha en una intersección puede ser un peligro para los peatones o ciclistas que cruzan en la misma intersección. Los conductores de autobuses están entrenados para buscar y ceder el paso a los peatones y ciclistas. Al acercarse a una intersección, escanean cruces peatonales y carriles para bicicletas antes y durante un turno para evitar posibles conflictos. Aun con entrenamiento y experiencia, esto puede ser una maniobra difícil para realizar de manera segura.

Hoy analizaremos un sistema que puede notificar al conductor del autobús que un peatón o ciclista está en el cruce peatonal. Este sistema también puede proporcionar una notificación adicional a un peatón o ciclista en una intersección que un autobús cruzará en el cruce peatonal.

MESSAGE MEDIUM
Imagine que está caminando en la banqueta, en un área con tráfico y llega a una intersección que tiene un cruce de peatones con una señal peatonal de "caminar / no caminar". Un autobús está a punto de dar vuelta a la izquierda o a la derecha en el paso de peatones que usted está a punto de cruzar o que ya ha cruzado.

Q1. ¿Le gustaría algún tipo de notificación de que el autobús está a punto de cruzar el paso de peatones? ¿Por qué o por qué no?

Q2. Si recibe una notificación que el autobús está dando vuelta en la intersección, ¿le gustaría recibir esta notificación en la señal peatonal de la intersección, a través de su teléfono u otro dispositivo móvil, o por ambas cosas?

CONTENIDO DE MENSAJES / ESTILO / FORMATO

Q3a. Si prefiere que la notificación provenga de la señal peatonal, ¿le gustaría escuchar una notificación sobre el autobús, ver una notificación sobre el autobús, o ambas cosas?

Q3b. Si prefiere una notificación a su teléfono / dispositivo móvil, ¿le gustaría escuchar una notificación sobre el autobús o recibir una notificación táctil como una vibración?

- Note: need to record if participants indicate that they are not interested in receiving the warning from phone/mobile device.

Q3c. Si prefiere que la notificación se anuncie en el pavimento, ¿cómo le gustaría que se vea?

- *Prompts/Explanation*: La notificación auditiva podría transmitirse desde la señal peatonal de la misma manera que se emiten notificaciones audibles de "andar" en algunas intersecciones. La notificación visible podría mostrarse justo encima de la señal de "caminar". La aplicación de dispositivos móviles podría notificar de una o de todas estas maneras a un individuo. El aviso en el pavimento podría ser una barra roja en el borde de la banqueta o podría estar destellando luces LED amarillas dentro del cruce peatonal.

Q4. ¿Qué información le gustaría obtener sobre el autobús?

- *Indicaciones*: dirección de donde viene el autobús, instrucciones para mirar hacia la izquierda o derecha, simplemente que un autobús está a punto de pasar por la intersección
- *Probe*: si desea saber la dirección, ¿cómo sabe dónde se encuentra el autobús? ¿Qué pasa si se escucha el mensaje desde el otro lado de la intersección?

Q5. Si recibiera un aviso audible, ¿qué palabras o sonidos desea escuchar para informarle sobre el autobús?

- *Indicaciones*: las respuestas pueden ser diferentes si están hablando de un aviso audible de un **teléfono** o de un aviso audible de la **señal de peatones**.

Q6. Si recibiera un aviso visible, ¿qué palabras, imágenes u otras señales visuales desea ver para informarle sobre el autobús?

Q7. Si ya estaba a la mitad de la intersección en el paso de peatones cuando el autobús se acercaba para dar vuelta, ¿le gustaría que el aviso sobre el autobús fuera distinto del aviso si aún no había empezado a cruzar?

- *Indicaciones*: ¿Le gustaría que las indicaciones fueran distintas si estuviera caminando sobre el cruce de peatones, vs todavía en la banqueta? [Le gustaría notificaciones distintas si estuviera caminando sobre el cruce de peatones en lugar del aviso en la banqueta?] ¿Le gustaría que la advertencia suene o parezca más urgente?

MENSAJE DE TIEMPO Y OTROS DETALLES
Q7. ¿Qué tan lejos debe estar el autobús de la intersección cuando se active el aviso?

- *Indicaciones*: Cuando el autobús está a punto de girar; 10, 20, o 30 segundos de distancia? ¿Más?

CONFIGURACIÓN / CIERRE
Q8. ¿Qué haría que la notificación de vuelta del autobús fuera más útil para usted?

Q9. ¿Tiene sugerencias, inquietudes o comentarios adicionales sobre este tipo de sistema de aviso?

BIBLIOGRAPHY

Section II — Bus-Based Collision Warning Systems

Driverless Transportation. NVIDIA Goes All In on Driverless Technology. [Online] February 9, 2015. [Cited: March 28, 2018.] http://www.driverlesstransportation.com/tag/adas/page/3.

Federal Transit Administration. Fiscal Year 2016 SRD Program Grant Selections. [Online] January 17, 2017. [Cited: March 1, 2018.] https://www.transit.dot.gov/research-innovation/fiscal-year-2016-srd-program-grant-selections.

Florida Department of Transportation. Florida Automated Vehicles Pilot Projects. [Online] [Cited: March 2, 2018.] http://www.automatedfl.com/Pilot-projects.html.

Florida Department of Transportation. Florida Transit Planning Network Newsletter. [Online] May 2017. [Cited: March 2, 2018.] https://planfortransit.com/wp-content/uploads/2017/05/FTPN-Newsletter-May-2017.pdf.

Florida Department of Transportation. Florida's Automated Vehicle Initiative. American Planning Association Florida Chapter. [Online] September 2015. [Cited: March 28, 2018.] http://www.floridaplanning.org/wp-content/uploads/2015/09/Creating-the-Fraamework-for-Implementation-Ed-Hutchinson.pdf.

Florida Department of Transportation. Florida's Automated Vehicle Initiative. [Online] 2015. [Cited: March 2, 2018.] http://www.fdot.gov/statistics/fav/2015summit/FDOTUpdate.pdf.

Lynn, Adam. Pierce Transit buses to get bionic eyes thanks to big grant. The News Tribune. [Online] January 21, 2017. [Cited: March 1, 2018.] http://www.thenewstribune.com/news/local/article127788074.html.

Metropolitan Transit Authority. Governor Cuomo Announces Roll Out of New Buses with Wi-Fi and USB Charging Parts in Brooklyn and Manhattan: Latest Additions are Part of Upgrade of the MTA Bus Fleet that Will See More Than 2,000 New State-of-the-Art Buses to be Added over Five Years. [Online] April 18, 2017. [Cited: March 23, 2018.] http://www.mta.info/press-release/nyc-transit/governor-cuomo-announces-roll-out-new-buses-wi-fi-and-usb-charging-parts.

Metropolitan Transit Authority. Safety Committee Meeting April 2017. [Online] [Cited: March 1, 2018.] http://web.mta.info/mta/news/books/archive/170426_0830_Safety.pdf.

Metropolitan Transit Authority. Safety Committee Meeting January 2018. [Online] [Cited: March 1, 2018.] http://web.mta.info/mta/news/books/pdf/180124_0830_Safety.pdf.

Metropolitan Transit Authority. Safety Committee Meeting March 2018. [Online] [Cited: March 1, 2018.] http://web.mta.info/mta/news/books/pdf/180319_1030_Transit.pdf.

Metropolitan Transit Authority. Transit & Bus Committee Meeting. [Online] September 26, 2016. [Cited: March 28, 2018.] http://web.mta.info/mta/news/books/archive/160926_1030_Transit.pdf.

Metropolitan Transportation Authority. Closed Government Contracts. BidNet. [Online] [Cited: March 23, 2018.] http://www.bidnet.com/bneattachments?/405330214.pdf.

Miami-Dade County. Mobileye technology aims to increase pedestrian safety. [Online] November 14, 2017. [Cited: March 2, 2018.] https://www.miamidade.gov/releases/2017-11-14-dtpw-mobileye-technology.asp?utm_source=media&utm_medi.

NYC Transit. MTA NYCT Tests New Safety Technology on Buses: Department of Buses will Evaluate Pedestrian Turn Warning, Collision Avoidance Systems. Metropolitan Transit Authority. [Online] October 1, 2015. [Cited: March 1, 2018.] http://www.mta.info/press-release/nyc-transit/mta-nyct-tests-new-safety-technology-buses.

Omidvar, Aschkan, Letter, Clark and Elefteriadou, Lily. University of Florida Advanced Technologies Campus Testbed. Gainesville, FL: Florida Department of Transportation, 2017.

Pierce Transit. Pierce Transit receives $1.66 million grant to install bus safety technology. The Suburban Times. [Online] January 22, 2017. [Cited: March 1, 2018.] https://thesubtimes.com/2017/01/22/pierce-transit-receives-1-66-million-grant-to-install-bus-safety-technology/.

Testing Automated Collision Avoidance Warning Systems for Public Transit Buses. [Online] October 3, 2017. [Cited: March 23, 2018.] http://schd.ws/hosted_files/2017falleducationalforum/76/PublicTransitCollisionWarningTechnology.pdf.

Texas A&M Transportation Institute, Automated and Connected Vehicle Test Bed to Improve Transit, Bicycle, and Pedestrian Safety: Technical Report, Texas Department of Transportation, Austin, Texas, April 2016.

Virginia Commonwealth Transportation Board. Transit Technology Initiatives. [Online] January 10, 2018. [Cited: March 2, 2018.] http://www.ctb.virginia.gov/resources/2018/jan/tech/drpt_-_transit_technology_initiatives_draftv3.pdf.

Webb, Kelsey. Virginia Public Transportation Agencies Implementing Innovative Driver Assistance Technology: Added safety measure alerts bus drivers to pedestrians and bicyclists. Virginia Department of Rail and Public Transportation. [Online] December 28, 2018. [Cited: March 2, 2018.] https://content.govdelivery.com/accounts/VADRPT/bulletins/1cf3643.

Section III — Low-Speed Autonomous Shuttles

AAA. AAA Self Driving Shuttle. [Online] [Cited: August 13, 2018.] http://www.aaahoponlasvegas.com/.

ABC 7 News. California's first driverless bus hits the road in San Ramon. [Online] March 6, 2018. [Cited: July 30, 2018.] http://abc7news.com/technology/californias-first-driverless-bus-hits-the-road-in-san-ramon/3183813/.

Ann Arbor News. Driverless shuttle up and running at University of Michigan. [Online] June 4, 2018. [Cited: August 10, 2018.] https://mlive.com/news/ann-arbor/index.ssf/2018/06/driverless_shuttle_debuts_at_u.html.

City of Helsinki. Self-Driving bus on Helsinki RobobusLine goes to scheduled service. [Online] May 15, 2018. [Cited: Autust13, 2018.] https://www.hel.fi/uutiset/en/helsinki/robobus-line-goes-to-scheduled-service.

Danville San Ramon. Autonomous vehicles now being tested on San Ramon streets. [Online] March 7, 2018. [Cited: July 30, 2018.] https://danvillesanramon.com/news/2018/03/06/autonomous-vehicles-now-being-tested-on-san-ramon-streets.

Fort Worth Business. Arlington goes driverless with autonomous shuttle service. [Online] August 11, 2017. [Cited: July 27, 2018.] http://www.fortworthbusiness.com/news/arlington-goes-driverless-with-autonomous-shuttle-service/article_e7b2d050-7eb9-11e7-ad8f-0b1fc4cf64d7.html.

Helsinki Smart Region. Need a lift? Hop on the SOHJOA driverless robobus! [Online] [Cited August 13, 2018.] https://www.helsinkismart.fi/portfolio-items/sohjoa/.

Mcity. We've launched the Mcity Driverless Shuttle research project on the University of Michigan's North Campus. [Online] [Cited: August 10, 2018.] https://mcity.umich.edu/shuttle/.

Milo — City of Arlington, Texas. [Online] [Cited: July 27, 2018.] http://www.arlington-tx.gov/visitors/milo/.

Production Engineering Services. UK's first driverless pods arrive in Milton Keynes. [Online] May 18, 2018. [Cited: August 10, 2018.] https://www.pesmedia.com/uks-first-driverless-pods-arrive-milton-keynes/.

The Registry. Testing of First Autonomous Shuttle on Public Roads in California Begins. [Online] March 7, 2018. [Cited: July 30, 2018.] https://news.theregistrysf.com/testing-first-autonomous-shuttle-public-roads-california-begins/.

The Verge. Las Vegas is expanding its self-driving shuttle experiment. [Online] November 6, 2017 [Cited: July 30, 2018.] https://www.theverge.com/2017/11/6/16614388/las-vegas-self-driving-shuttle-navya-keolis-aaa.

WSB and AECOM. MnDOT Autonomous Bus Pilot Project Testing and Demonstration Summary, Minnesota Department of Transportation, St. Paul, Minnesota, June 2018.

Section IV — Smartphone Apps for Pedestrians and Bicyclists

Bus Stop Beacon Project PowerPoint. Texas A&M Transportation Institute, 2017.

North Avenue Smart Corridor, Renew Atlanta Website [Online] [Cited: August 11, 2018.] http://renewatlantabond.com/project/north-avenue-smart-corridor/.

Pedestrian Mid-Block Crossing Application [Online] February 2018 [Cited: August 15, 2018.] https://itsforge.net/index.php/community/explore-applications#/35/149.

TravelSafely App Website [Online] [Cited: August 1, 2018.] http://travelsafelyapp.com/the-app/.

Section V — Current Research Projects

Bluetooth Pedestrian Awareness System (BPAS) User Survey PowerPoint. Texas A&M Transportation Institute, February 15, 2018.

Nevada Center for Applied Research. Intelligent Mobility: Solutions for safe, clean and efficient transportation. [Online] [Cited: August 6, 2018.] https://www.unr.edu/ncar/about-us/im.

Texas A&M Transportation Institute. Draft USDOT and EC Twinning Initiative Synthesis Report. Prepared for Federal Highway Administration, May 2018.

UofM researchers receive NSF grant. [Online] January 2017 [Cited: August 14, 2018.] http://www.cts.umn.edu/publications/catalyst/2017/january/grant.