How We Are Testing an Automated Collision Avoidance and Emergency Braking System for Buses and What We Have Learned So Far

Heidi H. Soule
PMO Manager
Pierce Transit
Pierce County Public Transportation Benefit Area Corporation
Lakewood, WA 98499
hsoule@piercetransit.org

Skip Huck
Executive Director of Maintenance
Pierce Transit
Pierce County Public Transportation Benefit Area Corporation
Lakewood, WA 98499
shuck@piercetransit.org

Andrew Krum
Senior Research Associate
Center for Truck and Bus Safety
Virginia Tech Transportation Institute
Blacksburg, VA 24961
akrum@vtti.vt.edu

Yinhai Wang, Ph.D.
Professor and Director
Pacific Northwest Transportation Consortium (PacTrans)
USDOT University Transportation Center for Federal Region 10
University of Washington
Seattle, WA 98195
yinhai@uw.edu

Ruimin Ke, MSCE
Ph.D. Candidate
Smart Transportation Applications and Research Lab
Department of Civil and Environmental Engineering
University of Washington
Seattle, WA 98195
ker27@uw.edu

Dave Valadez
President
DCS Technologies, Inc.
Carmel, IN 46032
dave.valadez@dcstechinc.com

Dan Sellers, P.E.
Senior Engineer
DCS Technologies, Inc.
Carmel, IN 46032
dan.sellers@dcstechinc.com

Corresponding Author
Jerome M. Lutin, Ph.D., P.E., F.ITE
Senior Director of Statewide and Regional Planning
New Jersey Transit (Retired)
South Brunswick, NJ 08852
jerome.lutin@verizon.net

Word count: 4,710 + 3 tables (@250 words per table) = 5,460 words

Submitted July 26, 2019

ABSTRACT

In 2017 the Federal Transit Administration (FTA) awarded Pierce Transit of Lakewood, WA a $1.66 million grant for a bus collision avoidance and mitigation safety research and demonstration project. The project scope includes installation of an advanced technology package, the Pedestrian Avoidance Safety System (PASS) that uses lidar sensors to trigger an automated deceleration and braking system. An "alpha testing" phase included shipping a Pierce Transit bus to Blacksburg, VA for closed-course testing of PASS on Virginia Tech Transportation Institute's (VTTI's) Smart Road facility. In addition, VTTI developed a system to observe, measure, and analyze passenger motion during braking events. Following completion of testing at VTTI, the bus will be returned to Pierce Transit. Together with three additional buses currently being outfitted with PASS, all four will be equipped with Transit Event Logging System (TELS) video processers developed by University of Washington's Smart Transportation Applications & Research (STAR) Lab to analyze PASS system accuracy in terms of "false positives" and "false negatives." Upon successful completion of in-service engineering testing of the initial four buses, an additional 26 buses will be equipped with PASS and all 30 will be monitored using telematics for a year-long demonstration. This paper discusses project background and organization, describes the PASS system being tested, provides an overview of the alpha testing, describes project data collection processes, and reviews the criteria and metrics being used to evaluate the system. The paper concludes with observations about lessons learned to date.

Keywords: automated emergency braking, bus, collision avoidance, collision mitigation, lidar

PROJECT BACKGROUND

While transit bus passengers are more than three times safer than automobile passengers when comparing the rate of fatalities per 100 million passenger miles,[1] they can be made even safer. In 2017, a typical year, transit buses and vans were involved in 4,739 collisions, 16,353 injuries, 98 fatalities, and reported $717 million in casualty and liability expenses.[2]

Of particular concern is the increasing trend in casualty and liability expenses shown in Figure 1. In a recent TRB Innovations Deserving Exploratory Analysis (IDEA) project, researchers estimated that 65 percent of $53 million in bus casualty and liability claims paid out resulted from preventable collisions.[3]

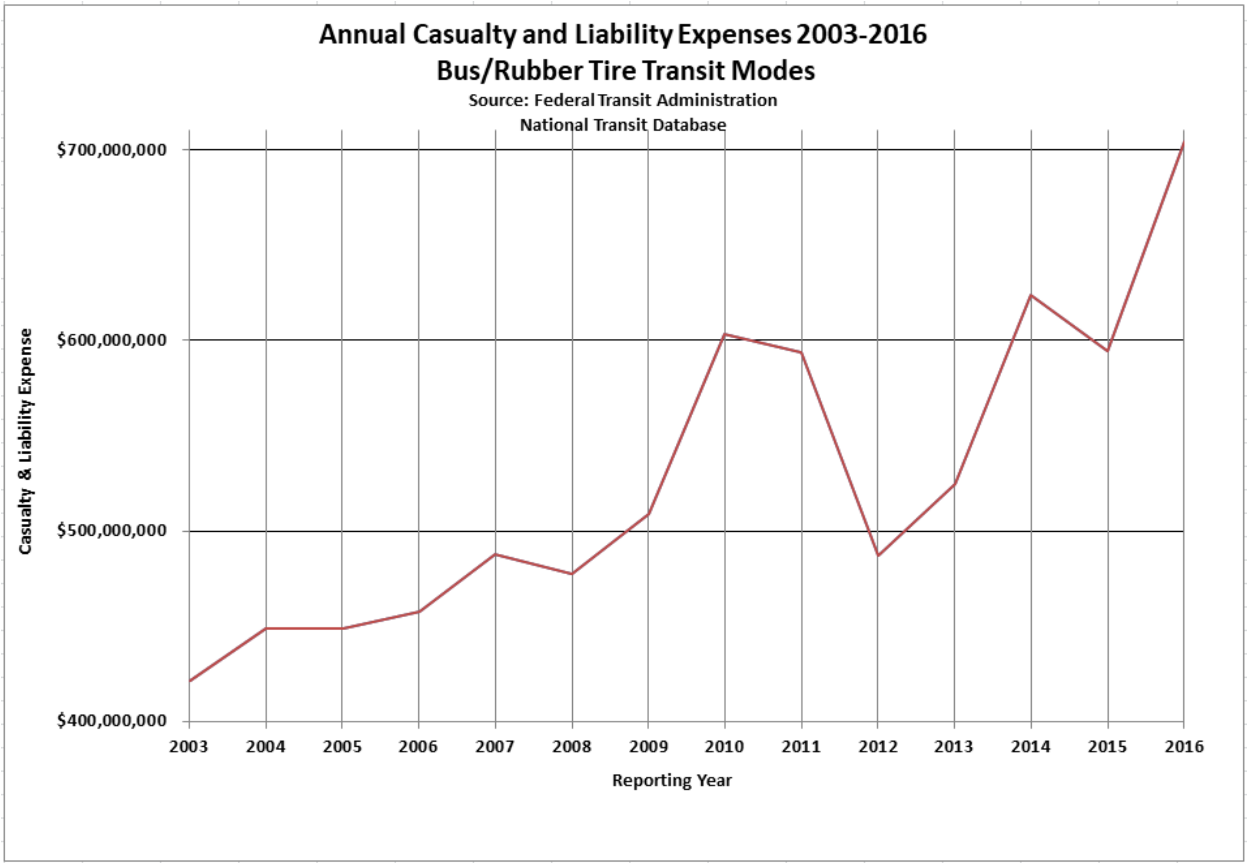

Figure 1 Annual Casualty and Liability Expenses

In 2016 the FTA published a notice of funding opportunity (NOFO) and solicitation of proposals "to demonstrate and evaluate innovative technologies and safer designs to improve public transportation safety.[4]" FTA allocated $7 million for the solicitation and explicitly encouraged the submission of proposals for innovative technologies for collision avoidance and mitigation.

Based on the IDEA project cited above, it was estimated that collision avoidance warning systems had the potential to reduce pedestrian collision claims by 43 percent and forward collision claims by 72 percent.[5] With the addition of automatic emergency braking it was estimated that claims could be reduced even more because the systems have the ability to reduce reaction times. With that in mind, Pierce Transit submitted a proposal in response to the NOFO. Pierce Transit's proposal was one of fourteen projects selected for funding by FTA in 2017. In addition to Pierce Transit, the grantee, the team includes key partners: DCS Technologies, Inc. (DCS), Jerome M. Lutin, PhD, LLC, Munich Reinsurance America Inc., University of Washington (UW), Virginia Tech Transportation Institute (VTTI), Veritas Forensic Accounting (Veritas), and the Washington State Transit Insurance Pool (WSTIP).

PROJECT SCOPE

Pierce Transit's initial proposal was to deploy 176 buses equipped with second generation collision avoidance warning systems (CAWS) and to equip 30 of those buses with automatic deceleration and emergency braking (AEB) provided by another vendor. The initial scope was subsequently modified to eliminate further deployment of collision avoidance warning systems and reallocate resources to focus on automated braking. The primary objective is to not only deploy and demonstrate this life-saving technology, but to accurately determine the business case for investing in CAWS and AEB.

When the project was conceived, an existing CAWS was to be used to trigger a separate AEB system. The CAWS vendor and Pierce Transit were unable to reach agreement on contractual issues and that vendor did not participate in the project. Consequently, the AEB system vendor agreed to undertake development of a sensor package to trigger deceleration and braking. That led to inclusion of the alpha testing phase into the project scope.

The project scope includes five phases. This paper selectively focuses on activities in some of the phases but not all.

- Phase A. Test planning, instrumentation, and documentation
  - Project management setup, work plan development, public board actions, and contract execution
  - Site visits and facility surveys at Pierce Transit and VTTI
  - Develop safety, installation, and test plans
  - Deliver a Pierce Transit bus to VTTI's Smart Road test track in Blacksburg, VA
- Phase B. Closed-Course Alpha Testing and Passenger Motion Testing
  - Develop test scripts for collision avoidance maneuvers
  - Equip first bus with collision avoidance system
  - Test collision avoidance system on test track
  - Test collision avoidance system under rain and fog on test track
  - Develop passenger motion testing methodology
- Phase C. In-Service Engineering and Data Collection Testing
  - Develop on-board video processing for detection of false positives and false negatives
  - Install three systems for initial systems testing and engineering modifications at Pierce Transit
  - Develop driver survey questionnaires
  - Return first bus to Pierce Transit
- Phase D. Revenue Service Field Demonstration
  - Develop data collection, storage, and analysis systems
  - Install collision avoidance systems on 26 additional buses for a total of 30
  - Operate buses in revenue service in data collection mode only (stealth mode)
  - Train and survey drivers

  - Operate buses in active mode and collect data
- Phase E. Project Reporting and Evaluation
  - Report on driver acceptance and system performance
  - Report on economic return on investment
  - Undertake knowledge transfer and outreach activities
  - Prepare interim and final reports

System Being Tested

"The Pedestrian Avoidance Safety System (PASS) was developed initially as a NHTSA Level 1 system. It automatically decelerates the vehicle when an imminent pedestrian collision is detected by a suitable detection and warning system. The system provides active (automatic deceleration) assistance to the driver in avoiding or reducing the severity of a collision. It uses a standalone microprocessor based controller with proprietary sensor fusion algorithms to integrate pedestrian detection and warning sensor systems with the vehicle powertrain and brake systems. Monitoring the CAWS warning data and vehicle dynamics (speed, direction, throttle and brake position, etc.), the system determines within a fraction of a second if automatic action is required."[6]

The vendor developed a pedestrian and forward vehicle detection sensor package to detect and calculate the potential for imminent collisions with the bus. It uses an array of three light detection and ranging (lidar) sensors attached to the front of the bus as shown in Figure 2. The sensors are attached to a mounting bracket immediately below the foldable bicycle rack. The sensor array had been tested on several types of vehicles but had not been deployed on a bus. Consequently the decision was made to conduct closed-course testing, "alpha testing," at the VTTI Smart Road facility to characterize the system's capabilities and fine tune it.

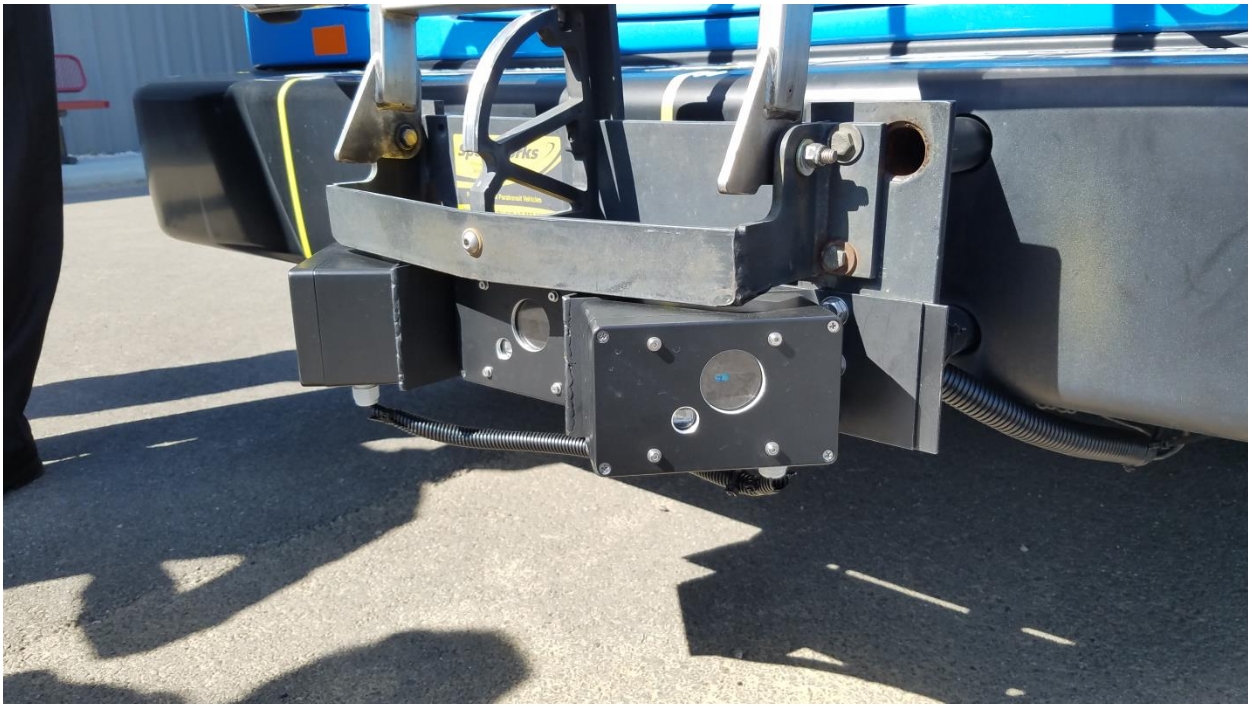

Figure 2 Lidar sensor package for collision avoidance Photo credit: Jerome Lutin

Alpha Testing

VTTI and the vendor jointly developed a test plan for simulating collisions with pedestrians and bicyclists, “vulnerable road users” (VRU’s) and forward collisions with vehicles[7]. For collision avoidance with VRU’s a simulated intersection was constructed to represent one that Pierce Transit buses regularly traverse. The simulated intersection includes lane markings and stop lines, a streetlight, a bus stop pad and shelter, a curb parking lane in which a vehicle can be parked to occlude vision of a pedestrian stepping from the curb, and a crosswalk equipped with a computer-controlled belt that can propel a VRU manikin across he crosswalk at walking or running speed. Figure 3 shows a drone view of the test track intersection. Figure 4 shows the bus braking automatically for the VRU at the simulated intersection during a test.

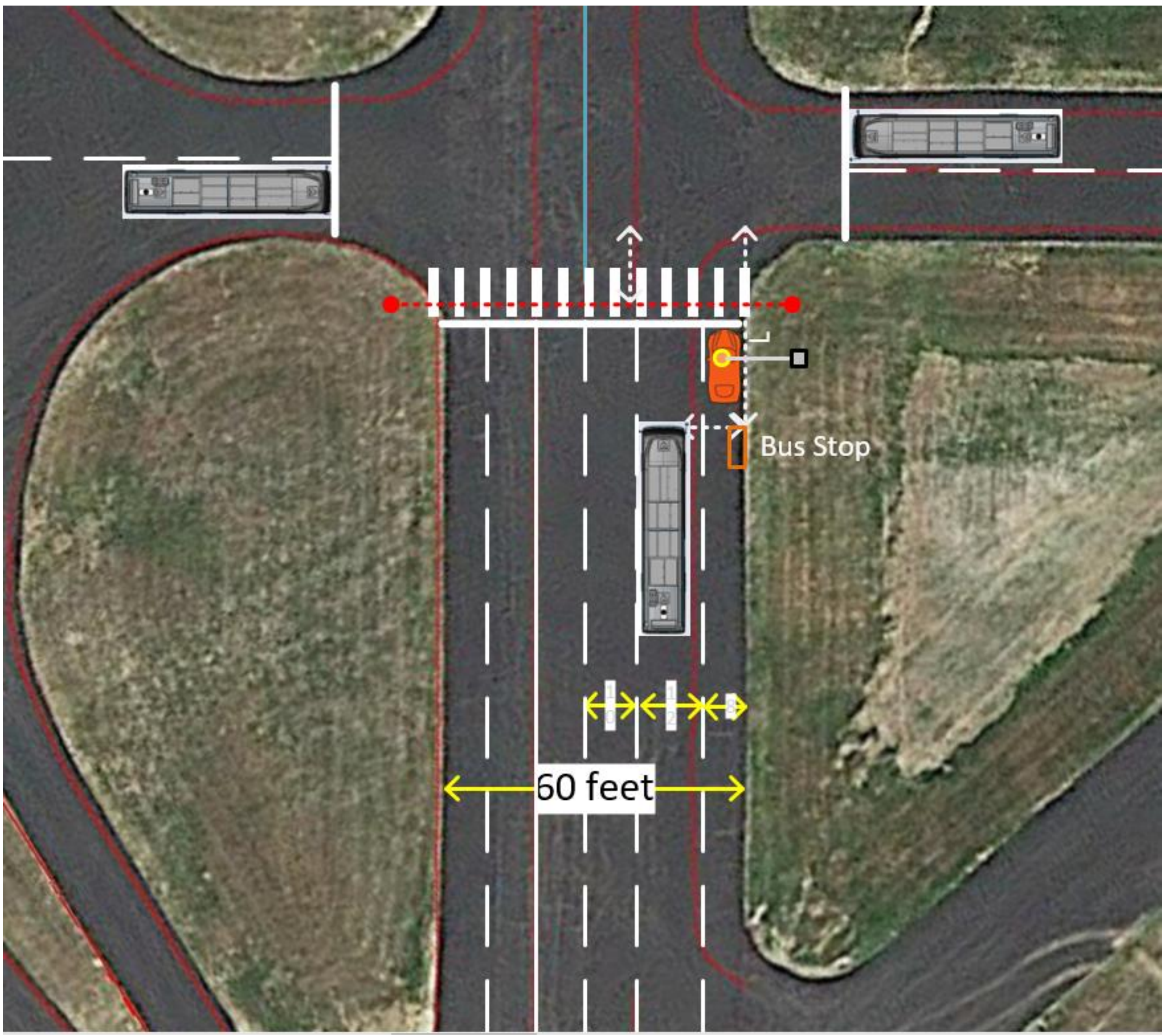

Figure 3 Drone View of Test Track Intersection Photo credit: VTTI

Most of the alpha testing was conducted during two vendor site visits to VTTI, one in mid-March and the second in late April, 2019. More than 400 test runs were conducted including collision avoidance bus runs at various speeds with static VRUs, walking and running VRU's, occluded VRUs, and forward collision avoidance with simulated moving vehicles. Both day and night testing was conducted for both VRUs and vehicles. Weather testing under simulated rain and fog conditions was conducted on April 30, 2019 and May 7, 2019. The technology was fine-tuned during the testing sessions and performance was deemed satisfactory for deployment in the next project phase.

Figure 4 VRU Collision Avoidance Test Photo credit: VTTI

Passenger Motion Testing

While collision avoidance and emergency braking systems have been successfully developed for trucks and autos and are in widespread use, none has yet been deployed for transit buses. Unlike autos and truck passengers, transit bus passengers are unrestrained and may be standing. Consequently, automated braking for transit buses must be designed to avoid injuring passengers during deceleration. Deceleration, which is the rate at which speed is reduced, and jerk, which is the rate of change in deceleration, must be closely controlled. Research in this area is limited.[8] Only one study, conducted in 1932 for streetcars, has been found that tested the effects of braking on standing passengers.[9] McGean provides braking limits for standees of 0.25g for deceleration and 0.1g per second for jerk, but cites no reference.[10]

VTTI was tasked to develop a methodology to measure and evaluate the effects of manual and automated braking on bus passengers in order to draft a standard for autonomous braking for buses. Data will be collected to compare manual braking with automated braking and determine passenger tolerance. VTTI has completed engineering of a passenger motion capture system that records the forces acting on passengers, signals from the PASS system via the bus's controller area network, (CAN bus) and captures videos of passenger motion. Images are blurred to protect individual privacy. VTTI's institutional research board will review the protocol for approval.

The system uses software developed by VTTI running on a Neuosys Technologies Nuvo in-vehicle edge computer using an Nvidia graphics card. The Nuvo will collect the following data elements for two field buses on 2TB hard-drives: passenger motion stereo-vision measures, blurred interior camera (for motion verification), blurred forward camera (braking event context: vehicle or pedestrian), vehicle CAN (e.g., brake, speed), vehicle motion (i.e., accelerometers, GPS 5 Hz), PASS on vehicle CAN (i.e., warning and caution signals).

False Positive and False Negative Processing

False positives are defined as events in which the collision avoidance system triggers a warning or activates emergency braking when there is no imminent collision. False negatives are defined as events in which a collision is imminent but the system neither warns the driver nor activates braking. False positives can produce an uncomfortable ride and irritate drivers. False negatives are more serious because they can lead to a collision. False positives and false negatives both can erode confidence in the technology.

University of Washington's Smart Transportation Applications and Research Laboratory (STAR Lab) is developing an on-board video processor, the Transit Event Logging System (TELS) to detect false positives and false negatives. The video processor uses an NVIDIA Jetson module to receive a continuous feed from a forward-facing camera whenever the bus engine is running. Figure 5 shows an example of the processor categorizing objects as persons and cars. Video clips will be stored continuously in a buffer for immediate retrieval. The video feed will be processed through an object detector that can categorize objects as VRUs or vehicles and measures their closing rate and trajectory with respect to the bus. If the trajectory and closing rate appear to lead to an imminent collision, the processor will record a video clip. In addition, the PASS system will signal the processor if its lidar detectors identify an imminent collision, and TELS will store a video clip.

When PASS signals an imminent collision, TELS will retrieve a video clip for several seconds before and after the signal and check the video for the presence of a VRU or vehicle. If none is found, the clip will be saved for analysis and labeled as a potential false negative. TELS will be continuously searching its video feed for VRUs and vehicles. If a VRU or vehicle is estimated by TELS to be at risk of a collision, it will check to determine if PASS has sent an alert signal. If no signal is received from PASS, the video clip will be stored and labeled as a potential false negative. Video clips will be downloaded and checked manually to validate false positives and negatives. In addition, random samples of video will be downloaded and manually checked for the presence of VRUs or vehicles to verify the accuracy of TELS.

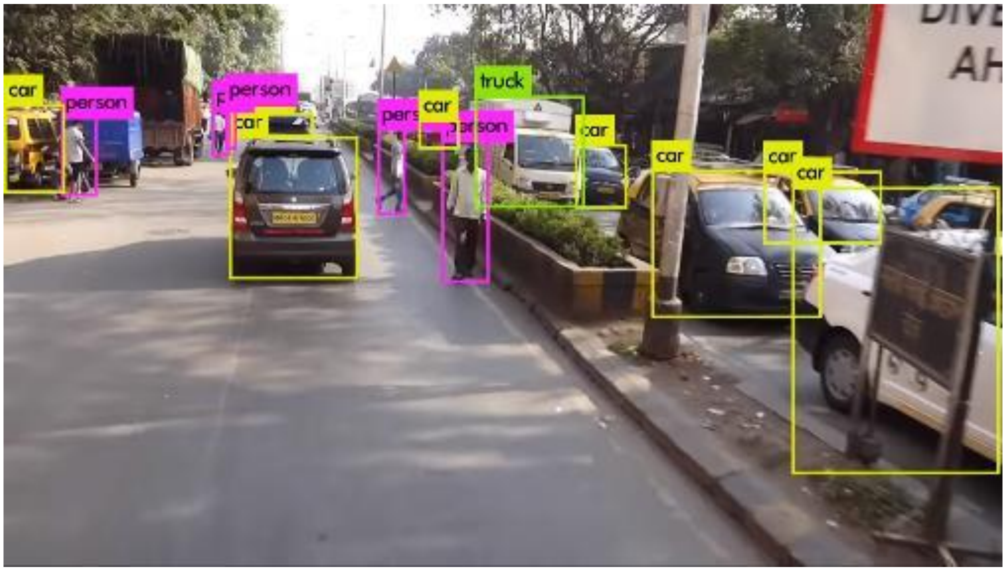

Figure 5 Video Processing of Objects Photo credit: University of Washington

System Performance Monitoring

In the IDEA project cited earlier, it was found that collisions were rare events. WSTIP transit agencies participating in the pilot averaged one reportable collision per 812,335 miles and one injury per 344,964 miles. None of the CAWS-equipped buses in that study experienced collisions during the data collection period. Although none of the CAWS-equipped pilot project buses was involved in a reportable incident, the probability was that they might not have experienced a collision or injury had they not been equipped with CAWS, simply due to the limited test period.[11] Consequently this project is increasing the number of buses and the number of miles travelled. However, it is still possible that during the test period there may be insufficient numbers of collisions to calculate system effectiveness with statistical certainty, so other metrics are being used.

CAWS activations occur when a pedestrian or vehicle is calculated to be on a closing trajectory leading toward an imminent collision with the bus. If no collision takes place, we term these events “near misses.” The previous study found that bus drivers who received warnings from the CAWS experienced fewer near misses per 1000 miles than drivers on buses which had CAWS installed and collecting data but not set up to provide warnings. Those CAWS-equipped buses not issuing warnings were said to be operating in “stealth mode.”

The rate of near misses was used as a proxy measure for system effectiveness. This project will test that hypothesis. This project will test the frequency of near misses during a period of stealth mode operation and a subsequent period in which CAWS/AEB is active. The before-and-after data will be used to compare samples of CAWS/AEB-equipped buses with buses that are not so equipped. It will also examine changes in the rates of near misses experienced by drivers as they gain experience with CAWS/AEB.

DATA COLLECTION PROCESS

Under terms of the FTA grant, data collection and sharing constitute a significant part of the project scope. Three aspects of the project will collect significant amounts of data on a daily basis: PASS system performance data from 30 buses, false positive and false negative data from four of those buses, and passenger motion data from two of the 30 buses. Passenger motion data will be downloaded by manually exchanging the 2 TB on-board drives periodically and transferring the files to a secure server. False negative and false positive data and PASS system performance data will be downloaded wirelessly to a secure server. Pierce Transit is providing access to its cellular data plan for wireless downloads from the buses. Figure 6 diagrammatically illustrates the data communications model.

In Figure 6, items shown in the blue outlined rectangle labeled 1 represent data generation systems existing on the bus. Items in the red outlined rectangle labeled 2 represent new data generating systems being installed for this project. Items in the blue outlined rectangle labeled 3 represent the existing Wi-Fi and cellular communications hub on the bus. Items in green outlined rectangles aligned vertically with label 4 represent existing servers for collecting data, and the rectangle outlined in purple and labeled 5 represents the new server being set up by the University of Washington for this project.

To enable data analysis at a granular level for each bus and each driver, data will be extracted from Pierce Transit's existing computer aided dispatch/automatic vehicle locator (CAD/AVL) system shown at the top. The CAD/AVL data includes identification numbers for each: bus, driver, route, trip, time point, and schedule on-time performance.

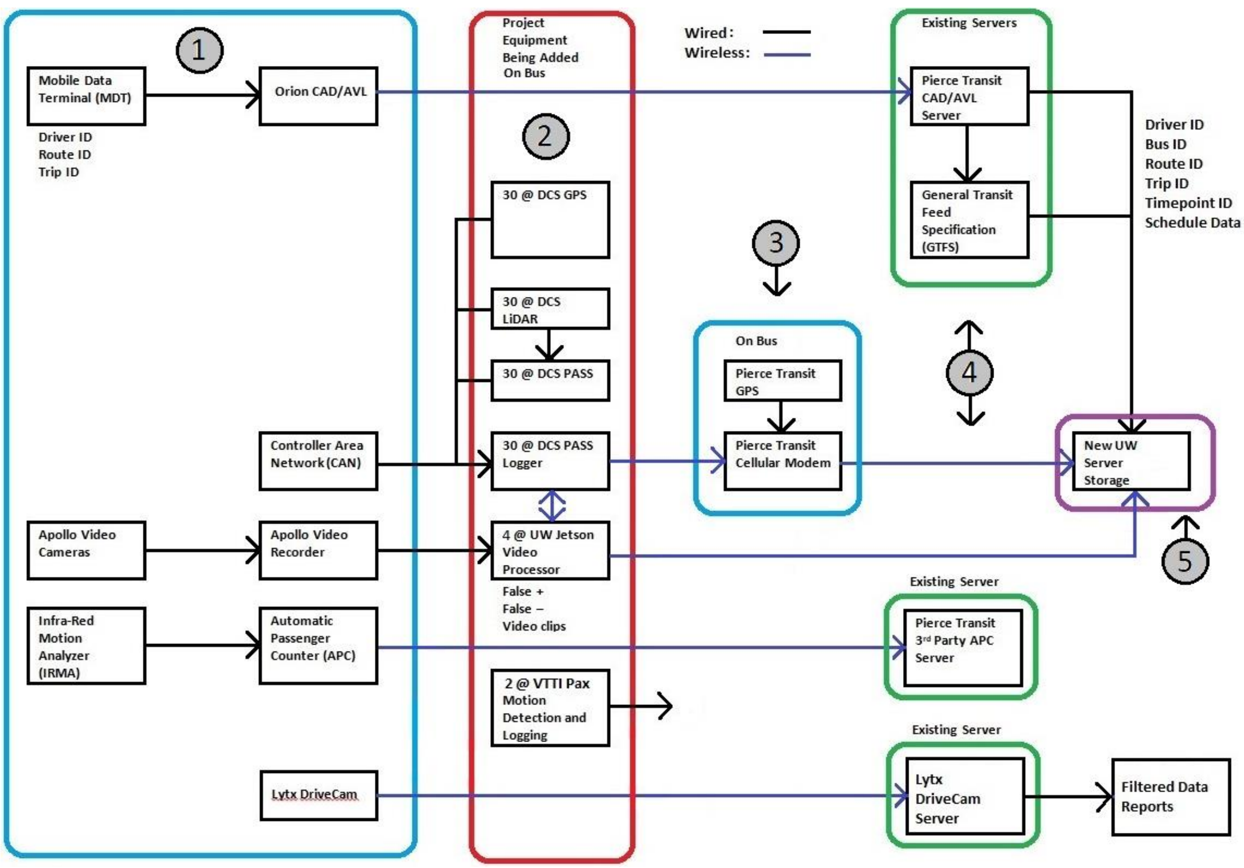

Figure 6 Data Communications Model

PROJECT EVALUATION CRITERIA AND METRICS

The project has well-defined performance metrics that will be documented at key milestones and in the interim and final reports. The metrics include:

- Accuracy of CAWS in terms of false positives and false negatives per 1,000 miles
- Reductions in collision near-misses by comparison of CAWS warnings per 1,000 miles before and after driver warning displays are activated.
- Long-term driver performance changes measured in CAWS warnings per 1,000 miles for individual drivers over the duration of the data collection period.
- Reduction in stopping distance due to CAWS/AEB.
- Reductions in collisions, injuries, and fatalities, measured over the data collection period and compared with historical data for prior years.
- Reductions in insurance claims expenses measured by the monetary value of claims incurred over the data collection period compared with historical data for prior years.
- Net future benefit measured by estimated reductions in claims and internal costs not reimbursed by insurance less the installation and maintenance costs for CAWS/AEB, and extrapolated to other WSTIP members.
- Driver acceptance of CAWS/AEB measured through questionnaire surveys of drivers during the project.

Tables 1 through 3 show performance evaluation metrics: system effectiveness, safety, and return on investment. For each category several criteria are presented together with the metrics used, instrumentation or records collected, and frequency of collection.

Table 1 Project Performance Evaluation Metrics – System Effectiveness

Criterion	Metrics	Instrumentation/ Measurement	Frequency of Data Collection
System Accuracy	False Positives and False Negatives	Buses will be equipped by the vendor with telematics that reports each warning generated by the CAWS. Four buses will be equipped with on-board video processors to log video clips of false negatives and false positives.	Telematics is downloaded to a server in real time. Video will be sampled daily.
Change in Driver Performance	Change in rate of near miss warnings with vehicles and pedestrians per 1,000 miles over the test period	Warnings are captured by telematics and matched with driver, route and trip data from CAD/AVL system	Telematics data will be captured in real time and matched with CAD/AVL data daily.
Reduction in Stopping Forces, Reaction Time, and Effect on Bus Passengers	Change in stopping characteristics for buses equipped with AEB as compared with buses with CAWS only and buses with no automated driver assist	Two buses will be equipped by VTTI with g-force deceleration monitoring, LIDAR, and video to record passenger reactions	Data will be sampled over a six-month test period for specified test scenarios
Driver Acceptance	Driver responses to questionnaire and comments from drivers	Survey instruments and meetings with drivers	Drivers will be surveyed at three intervals during the testing period

Table 2 Project Performance Evaluation Metrics – Safety

Criterion	Metrics	Instrumentation/ Measurement	Frequency of Data Collection
Collisions	Number of collisions and rate of collisions per million vehicle miles experienced during test period and compared with collisions for prior year periods	Collision reports logged by drivers. Records of collisions in prior year periods will be obtained from agency files	Collision reports will be collected as they occur throughout the demonstration period. Comparisons with historic data will be made for interim report and final evaluation report
Injuries	Number of injuries and rate of injuries per million vehicle miles resulting from collisions and sudden stops during the test period compared with injuries for prior year periods	Injuries will be obtained from NTD S&S reporting during the demonstration and personal injury claims. Historical records of injuries will be obtained from insurer.	Collision reports will be collected throughout the demonstration period. Comparisons will be made for interim report and final evaluation report
Fatalities	Number of fatalities resulting from collisions and sudden stops and rate of fatalities per million vehicle miles during the test period compared with fatalities for prior year periods.	Fatalities will be obtained from NTD S&S reporting during the demonstration and personal injury claims. Historical records of fatalities will be obtained from insurer.	Fatality reports will be collected throughout the demonstration period. Comparisons will be made for the interim report and final evaluation report

Table 3 Project Performance Evaluation Metrics - Return on Investment

Criterion	Metrics	Instrumentation/ Measurement	Frequency of Data Collection
Insurance Claims	Gross costs of insurance claims paid for personal injury and property loss and comparison with claims paid in prior years	Insurance claims will be provided by WSTIP which insures Pierce Transit	Claims data generated during the project will be collected at the mid-point of the test period and the end of the test period
Internal Costs	Internal costs of collisions, not reimbursed by insurance	During the test period, the finance department will establish procedures to record categories of internal expenses incurred by collisions	Internal expenses incurred due to collisions will be recorded as they are entered into the Pierce financial reporting systems during the test period.
Equipment Life Cycle Costs	Initial equipment cost, installation cost, annual maintenance costs, and expected life of components.	Vendor invoices show system and installation costs. System failures will be reported during driver checks and inspections	Drivers report defects at the end of each run. Vendors will be required to log time and parts required for each repair and report monthly.
Net Benefits	The ratio of collision cost reductions to the acquisition and maintenance life cycle costs per bus, and years to recover initial expense for installing CAWS and AEB	Agency and vendor records	Data will be collected during the operating test period and reported at the project midpoint and final evaluation report.

LESSONS LEARNED SO FAR

Lessons learned so far fall into two main categories, doing research in the transit environment and retrofitting buses with advanced technology.

Doing Research in the Transit Environment

The primary mission of transit agencies is to provide safe and reliable transportation to the public. Transit agencies are highly visible and responsible for providing consistent, good service day after day with no interruptions or disruptions. On average, fares pay for only about 25 percent of the cost to transport a passenger. For agency staff, resources are highly constrained. Most transit agencies are governed by public boards or other governmental bodies. The responsibility for funding and operating transit ultimately rests with state and local governments that are sensitive to safety, costs, and customer complaints. These constraints frame the background for the collaboration needed for a successful project. Research into technology to improve safety involves many unknowns in terms of resource requirements and potential outcomes, creating a scenario diametrically in conflict with normal transit operations.

The lesson we learned is that champions for transit research projects are needed in the highest levels of the agency. They are the ones who can allocate the resources needed and can get things done. We also learned that vendors and researchers need to learn about and be sensitive to what a transit agency needs in order to succeed in its mission.

We also learned that because of the risk elements inherent in adopting new safety technology, involvement of insurers can help smooth the way. WSTIP, which serves as insurer for Pierce Transit and 24 other transit agencies in the state of Washington, championed this project and contributed funding as part of its loss prevention program. WSTIP is managing the research partners and will encourage sharing of the data and information produced by this project with its members. In addition, Munich Reinsurance America, Inc., which provides reinsurance to WSTIP, also is contributing funding to the project.

We underestimated the time needed for contract negotiations

There were lengthy negotiations with one vendor involving intellectual property and integration with equipment supplied by a second vendor. The negotiations did not lead to contract execution and the first vendor did not participate in the project. That necessitated modification to the scopes of work and reallocation of resources among other partners which delayed the project. The lesson learned is to confirm early in the proposal stage that all partners agree on data sharing and integration of components.

We underestimated the time needed for board approvals

Transit agency boards typically meet monthly. Several weeks prior to each board meeting are needed for staff work, preparation of resolutions and supporting documentation, and internal approvals. In this project actions were needed by the Pierce Transit board and the WSTIP board that had to be sequenced one after the other. The lesson learned is to understand the needs and time requirements for agency approval processes when building the project schedule.

Scope changes led to the need for additional expertise and testing facilities

When we no longer had a proven sensor available to trigger the PASS AEB system, it was necessary to develop an alternative solution which needed to be tested under closed course conditions. The lessons we learned were that having a creative engineering team can save a project, and that access to a testing facility and experienced technical staff should have been a priority in preparing the proposal. We were fortunate to have partners on the team who could meet those needs

Retrofitting Buses with Advanced Technology

Building hardware and software systems for retrofit and use in a legacy bus presents different challenges than building stationary systems or integrating systems into new automotive designs.

If Federal funding is used for bus purchases, buses must remain in service for at least 12 years. Most agencies seek to keep buses in service even longer, typically from 15 to 18 years. In order to reap the benefits of advanced safety technology as soon as possible, retrofits are needed.

Most buses in use now were not designed to anticipate installation of sensors, additional heat-producing electrical equipment, additional antennae, and additional sources of electromagnetic interference. Nor were the electrical systems designed to power numerous electronic components that would be sensitive to fluctuations in voltage. As a result, we learned several lessons.

Locating sensors on the front of the bus was a challenge

Lidar sensors needed unobstructed fields of view and could not be located inside behind the windshield. Folding bicycle racks took up much of the prime sensor real estate on the front of the buses. The vendor overcame this challenge by attaching the sensors to a bracket under the bicycle rack as shown in Figure 2. The lesson learned here is the need for flexibility in sensor placement requirements, and a bit of engineering creativity.

Equipment space is at a premium

In addition to the sensor package, space was required for the PASS data logger, the actuation unit, and connections to the CANbus. In addition, space is needed on four of the buses for the Jetson video processors and on two of the buses space is needed for the Neuosys Nuvo passenger motion processor. Additional space in other locations is needed for GPS antennas and cameras associated with the Jetson and Nuvo processors.

Most of the equipment can be installed in an existing locally-fabricated electrical cabinet above the left front wheel well immediately behind the driver. Space in the cabinet is already taken up for the Orion CAD/AVL equipment, Orca fare collection equipment, Apollo video system and recorder, and the bus radio system. Pierce Transit granted permission to reposition some of the existing equipment within the cabinet to accommodate some new components. The lesson learned is to size new retrofit equipment as compactly as possible and look for opportunities to relocate existing equipment to accommodate new stuff.

Bus electrical power can be unstable

DC Voltage on test buses was found to vary widely, in one example from 9 Volts to 34 Volts. In addition, power on the direct battery circuit, from which most of the electronics are powered, can be “knifed” or cut off unexpectedly in the middle of data and software uploads and downloads. The lessons learned are to use ruggedized automotive grade power regulators and to build robust operating systems that can reboot and restore automatically.

CONCLUSION

Although we are still in the early phases, there is much information that can be transferred to the research community from this project. Project phasing, data collection, evaluation methodology, and lessons learned have relevance to other safety research projects and can help other researchers avoid some of the challenges we had to overcome. The research team is happy to answer questions and share information. Feel free to reach out to us.

ACKNOWLEDGMENTS

Funding for this project was provided through a grant from the FTA administered by the Office of Research, Demonstration, and Innovation. Additional funding was provided by Pierce Transit, the Washington State Transit Insurance Pool, and Munich Reinsurance America, Inc. In particular we wish to thank Mr. Vincent Valdes, Associate Administrator and Mr. Roy Wei Shun Chen, Safety Research Program Manager of the FTA. We wish to thank Ms. Tracey Christianson, Executive Director and Mr. Matthew Branson, Member Services Manager of WSTIP. We also extend our gratitude to Dr. Sisinnio Concas, Director Autonomous and Connected Mobility Evaluation (ACME) Program, Ms. Lisa Staes, Director Transit Safety and Workforce Development Programs, and Jodi Godfrey, Senior Research Associate, Center for Urban Transportation Research, University of South Florida. We also wish to thank Mr. Michael Scrudato, Senior Vice President, Strategic Innovation Leader, and Mr. Bruce Weisgerber, Mobility Solutions Center Leader, Munich Reinsurance America, Inc. We also wish to extend our gratitude to the staff at the Virginia Smart Road facility and Pierce Transit who have made invaluable contributions to the project.

REFERENCES

[1] "National Transportation Statistics," Bureau of Transportation Statistics, Office of the Assistant Secretary for Research and Technology (OST-R), U.S. Department of Transportation (US DOT), 1200 New Jersey Avenue, SE, Washington, DC 20590, accessed July 18, 2015 http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/index.html#chapter_2

[2] FTA National Transit Database https://www.transit.dot.gov/ntd/ntd-data

[3] Spears, M. J., J. M. Lutin, Y. Wang, R. Ke, S. M. Clancy, "Active Safety-Collision Warning Pilot in Washington State'" Final Report for Transit IDEA Project 82, Transportation Research Board of the National Academies of Sciences • Engineering • Medicine, May 2017, p. 19 http://onlinepubs.trb.org/onlinepubs/IDEA/FinalReports/Transit/Transit82.pdf

[4] "DEPARTMENT OF TRANSPORTATION Federal Transit Administration FY 2016 Competitive Research Funding Opportunity: Safety Research and Demonstration (SRD) Program," Federal Register /Vol. 81, No. 157/Monday, August 15, 2016 / Notices, p. 54181-54187

[5] Spears, et al., op. cit., p. 18

[6] "Pedestrian Avoidance Safety System (PASS)," DCS Technologies, Inc. https://indd.adobe.com/view/3e0a09aa-80d1-47e0-a474-a2794aafddc9 (accessed July 24, 2019)

[7] DCS Technologies, Inc. and VTTI, "FTA-Pierce Transit Collision Avoidance and Mitigation SRD Project Alpha Test Quicklook Report," March 18, 2019

[8] J. M. Lutin, A. L. Kornhauser, J. Spears, L. F. Sanders, "A Research Roadmap for Substantially Improving Safety for Transit Buses through Autonomous Braking Assistance for Operators," Compendium of Papers, Paper Number 16-1246, 95th Annual Meeting of the Transportation Research Board, Washington, DC, January 12, 2016

[9] Hirshfield, G.F., "Disturbing Effects of Horizontal Acceleration." Electric Railway Presidents' Conference Committee, Bulletin No. 3, New York, NY, September 1932, 32 pages

[10] T. McGean, "Urban Transportation Technology," D. C. Heath and Company, Lexington, MA, 1976, p. 76.

[11] Spears, et al., op. cit., p. 22