Innovations Deserving Exploratory Analysis Programs

Transit IDEA Program

Active Safety-Collision Warning Pilot in Washington State

Final Report for
Transit IDEA Project 82

Prepared by:
Jerry Spears
Jerome M. Lutin
Yinhai Wang
Ruimin Ke
Steven M. Clancy
Washington State Transit Insurance Pool (WSTIP)

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IDEA Programs
Transportation Research Board
500 Fifth Street, NW
Washington, DC 20001

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ACKNOWLEDGEMENTS

This project has been a collaborative effort involving a number of entities and individuals. We would like to acknowledge their participation and roles in the project.

Washington State Transit Insurance Pool	Allen F. Hatten Jerry Spears	Executive Director Principal Investigator
Ben Franklin Transit	James R. Thoelke	Safety & Training Supervisor
Community Transit	Mike Burress	Risk Manager
C-Tran	Terry Lohnes	Senior Manager of Safety & Training
Intercity Transit	Paul Koleber	Maintenance Manager
King County Metro	David C. Hull	Special Projects Manager
Kitsap Transit	Jeff Dimmen	Vehicle Maintenance Manager
Pierce Transit	Jerry Blades Rob Huyck	Assistant Fleet Manager Risk Manager
Spokane Transit	Mike Toole	Manager, Safety & Security
Alliant Insurance Services, Inc.	Brian A. White	First Vice President, Specialty Group
Geneva Financial Services, Inc.	Steven M. Clancy Janet Gates	Principal Project Assistant
Government Entities Mutual, Inc.	Andrew Halsall	President & CEO
Jerome M. Lutin, PhD, LLC	Jerome M. Lutin, PhD, PE	Co-Principal Investigator
Munich Re America Inc.	Michael J. Scrudato, CPCU, ARe Jeffrey M. Myers, CPCU, ARe	SVP, Strategic Innovation Leader Vice President, Specialty Markets
Rosco Vision Systems, Inc.	Benjamin Englander Mike Cacic Gus Franjul	Vice President, Engineering Program Manager for Safety Systems Field Service Engineer
University of Washington	Professor Yinhai Wang, PhD Ruimin Ke, MSCE Wenhui Zhang PhD	Co-Principal Investigator Graduate Research Assistant Visiting Scholar
Veritas Forensic Accounting & Economics	Steve Roberts, CPA/CFF, Luke Fischer, MBA	Principal Financial Analyst

EXECUTIVE SUMMARY

The Rosco/Mobileye Shield+ system is a collision avoidance warning system (CAWS) specifically designed for transit buses. This project involved field testing and evaluation of the CAWS in revenue service over a three-month period. The system provides alerts and warnings to the bus driver for the following conditions that could lead to a collision: 1) changing lanes without activating a turn signal (lane departure warning was disabled for this pilot), 2) exceeding posted speed limit, 3) monitoring headway with the vehicle leading the bus, 4) forward vehicle collision warning, and 5) pedestrian or cyclist collision warning in front of, or alongside the bus. Alerts and warnings are displayed to the driver by visual indicators located on the windshield and front pillars. Audible warnings are issued when collisions are imminent.

The project was conducted under the auspices of the Washington State Transit Insurance Pool (WSTIP). In addition to funding from TRB's IDEA Program, funding was provided by WSTIP, Alliant Insurance Services, Inc., Government Entities Mutual, Inc., Pacific Northwest Transportation Consortium (PacTrans), and Munich Re America Inc. The contract was executed on January 19, 2016 with duration of eighteen months. Accomplishments documented in this report are based on our research objectives as stated in the IDEA contract.

Create a robust Rosco/Mobileye demonstration pilot for active/collision avoidance within the State of Washington on a minimum of 35 transit buses at seven WSTIP members – Accomplishments: CAWS were installed on 35 buses at seven WSTIP member agencies including: Ben Franklin Transit, Richland, WA, C-Tran, Vancouver, WA, Community Transit, Everett, WA, InterCity Transit, Olympia, WA, Kitsap Transit, Bremerton, WA, Pierce Transit, Tacoma, WA, Spokane Transit, Spokane, WA, and on an additional 3 buses at King County Metro Transit in Seattle, WA.

The official pilot data collection period ran from April 1, 2016 through June 30, 2016. Buses equipped with Shield+ systems logged 352,129 miles and 23,798 operating hours. No Shield+ equipped buses were involved in any collisions with bicyclists or pedestrians. During the data collection period, WSTIP's seven members participating in the pilot reported 284 events on their other fixed route buses, including six collisions with bicycles, three collisions with pedestrians, and one collision with a motorcycle. Although the project data collection period ended on June 30, 2016, three transit agencies: Ben Franklin, King County Metro, and Pierce Transit, elected to retain the Shield+ pilot systems on their buses.

Determine the ease of retrofit of the existing fleet. – Accomplishments: Our installations covered six different types of transit buses produced by three manufacturers, including high floor, low floor, Diesel, hybrid, and electric trolley buses. The target was to have a two-person team complete one bus installation in an eight-hour period. The target was met by the end of the installation phase.

Develop a methodology for estimating the full costs savings of avoided collisions for each agency. – Accomplishments: In collaboration with Veritas Forensic Accounting & Economics (Veritas), University of Washington Smart Transportation Applications and Research Laboratory (STAR Lab) analyzed 13 years of claims data provided by WSTIP and developed an analysis framework to classify claims according to the magnitude of loss and the relevant explanatory factors. Individual claims were allocated to categories that identified each claim as one that could be impacted by: 1) vehicular collision avoidance warnings, 2) pedestrian/bicyclist collision avoidance warnings, or 3) for which the collision avoidance system would have no likely impact. Of a total $53.1 million in claims for fixed route buses, $18.3 million, 35% were attributable to preventable vehicular collisions, and $16.0 million, 30% were attributable to preventable pedestrian/bicyclist collisions. These numbers established an upper bound for the potential cost savings. To estimate a lower bound to cost-savings through use of CAWS, the total costs of collisions in categories one and two were multiplied by respective vehicular and pedestrian collision reduction factors derived from changes observed in the numbers of near-misses for buses equipped with CAWS. Acquisition and maintenance costs for the CAWS were subtracted from the total claims reductions to arrive at the net benefit.

Develop a methodology and evaluation process for transit driver feedback and acceptance as well as bus passenger feedback. Accomplishments: We developed a bus driver survey and distributed it to 7 of the 8 agencies. The survey included 12 questions, was administered three times over the test period, and 277 questionnaires were submitted. Responses to two key questions are tabulated in this report: 1) was the system helpful, and 2) would they prefer to drive with it. Overall, 37 percent of the responses indicated that the system was helpful, and 63 percent indicated the system was distracting. Thirty three percent of the responses were affirmative when drivers were asked if they preferred to drive with it and 67 percent were negative. Drivers were encouraged to provide comments on the questionnaires. One hundred seventy eight (178) comments were received. The most frequent comment was the perception of false positive pedestrian indications. Warnings and alerts frequently sounded when buses were approaching stops with waiting passengers or pedestrians moving on the sidewalks.

Provide detailed data and understanding on entrance barriers to this technology (i.e. operational acceptance and rejection issues). Accomplishments: The vendor equipped buses in the test fleet with telematics monitoring and set up web access for the study team to real-time telematics data. The following events were time-stamped, geo-located, and logged by the system: 1) Exceeded Speed Limit, 2) Headway Monitoring (HMW), 3) Urban Forward Collision Warning (UFCW) - speed 0 to 19 mph, 4) Forward Collison Warning (FCW) - speed greater than 19 mph), 5) Pedestrian Collision Warning (PCW) - from each of four cameras, and 6) Pedestrian Detection Zone (PDZ) alert that triggered yellow indicator illumination but no audible warning. UFCW's, FCW's, PDZ's, and PCW's are defined as "near miss" events.

Because Shield+ cameras do not record video, the vendor installed additional recording cameras on the buses. STAR Lab developed an independent video processor to identify the presence of near-miss incidents involving pedestrians and bicyclists and determine the presence of near-miss false positives and false negatives. More than 30 hours of onboard video data from 25 buses was used to test the performance of the proposed near-miss detection method.

A false positive was defined as the presence of a pedestrian/bicyclist near-miss event in the telematics data that was not confirmed by the video. A sample of 6,070 events was examined of which 3.21% were found to be false positives. A false negative was defined as an incident in which a pedestrian with an estimated time to collision (TTC) less than a specified threshold is not detected by the CAWS. Based on the sample, the false negative rate was estimated to be 0.30%. This is likely on the lower end because there could be near-miss events missed by both the CAWS and the STAR Lab video processor.

The most significant measure of acceptance of CAWS by the transit industry is expected to be the degree to which CAWS will reduce collisions and claims. We were able to run a controlled experiment to estimate potential reductions in collisions and claims. CAWS on Spokane Transit buses were set up to collect and transmit data via telematics only and did not issue warnings to drivers. This was called operating in "stealth mode." Buses operating with systems in stealth mode served as a baseline, or control group, to help determine if CAWS resulted in changes in driver performance over time. It was hypothesized that as drivers gain experience with the Shield+ equipped buses, they may be better able to anticipate adverse driving conditions, which would be reflected in fewer events per miles logged.

For each warning type, there were fewer warnings per 1000 miles for the active fleet compared with the control group. Although data was not linked to individual drivers, it appears that drivers of buses in the active fleet triggered fewer warnings than those who drove buses in "stealth mode." Buses with active CAWS experienced 71.55% fewer forward collision warnings (UFCW's plus FCW's) per 1000 miles. The rates for PCW's and PDZ's were combined to yield 43.32% fewer pedestrian collision warnings. These rates were applied to the historic costs for claims described above. The net result was an estimated reduction in vehicular claims of $13.1 million and a reduction in pedestrian claims of $6.9 million. The total reduction of $20.0 million amounted to an estimated 58.5% potential reduction in claims due to collisions for all buses insured by WSTIP.

The upper and lower bounds for annual claims reduction per bus were estimated at $2,514 and $1,471 respectively for an annual average of 1,058 buses insured by WSTIP. Annual benefits were estimated by subtracting the cost of the CAWS (estimated at $7,375) from the claims reductions for service periods ranging from 5 to 14 years. Upper bound annual net benefits from collision claims reduction for all WSTIP members were estimated to start at $1,099,262 in year 5 and increase to $2,102,473 in year 14. For the lower bound, benefits were estimated to be negative by $4,232 in year 5 but become positive in year six and increase to $998,979 by year 14.

The pilot test showed that although driver acceptance was mixed, there were large reductions in near-miss events for CAWS-equipped buses. Consequently, achieving driver acceptance will be a key factor in continued development and deployment of CAWS. As a result of comments received from the drivers, the vendor has begun a program to incorporate desired modifications to the system including reducing false positives. The study also showed that supervisors, drivers and maintenance personnel should be involved in product development, trained in how to use CAWS, and educated in how CAWS can directly benefit them by reducing their risk of collisions.

A second major factor in achieving industry acceptance is to demonstrate the business case for CAWS to both transit agencies and system developers. Transit is a niche market compared with autos and trucks. Consequently, it is necessary to demonstrate the profit potential within the transit market to attract developers and capital. Part of this effort should be to stimulate and support the necessary research and development. Although the pilot project produced encouraging results, collisions, injuries and fatalities can be considered "rare events." A much larger in-service test will be needed to demonstrate actual cost-savings.

Early findings from this pilot led Pierce Transit to obtain a $1.66 million research and development grant from the Federal Transit Administration (FTA) to equip all 176 of its 40-foot transit buses with CAWS and to run extended testing and data collection. Starting in mid-2017 Pierce plans to conduct a full-year of testing, data collection, analysis, and evaluation during an estimated 4.4 million miles of revenue service.

IDEA PRODUCT

OVERVIEW OF THE PROBLEM

A serious problem is facing the bus transit industry. As shown in Table 1, buses and vanpools have been involved in 85,391 collisions, experienced 1,340 fatalities, 201,382 injuries, and created expenditures for casualty and liability expenses of $5.7 billion.[1] The annual numbers of collisions, injuries, and fatalities are reported in the Federal Transit Administration (FTA) National Transit Database (NTD) "Safety & Security Time Series Data". Reportable events include the following: fatalities, injuries requiring transport away from the scene for medical attention, total property damage greater than $25,000, and newly added, tow away of any motor vehicle, evacuations, derailments, collisions (at grade crossings, with an individual, or with another rail vehicle.)

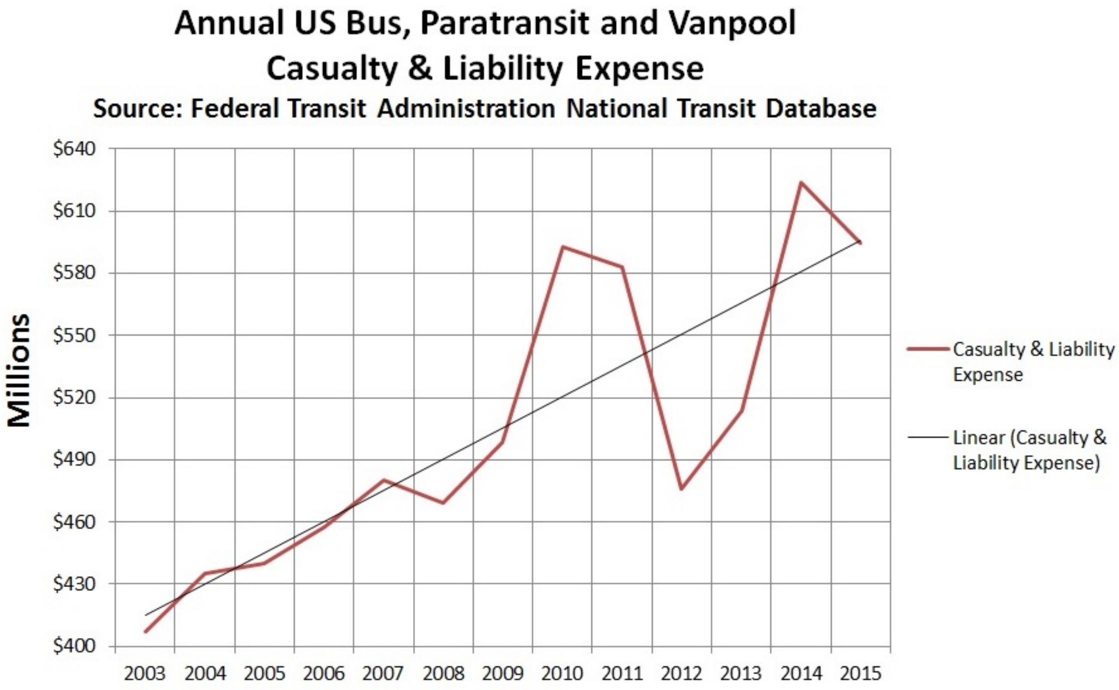
Casualty and liability expenses are reported on an annual basis to the FTA NTD as part of the Operating Expense report.[2] According to the manual, casualty and liability expenses "are the expenses a transit agency incurs for loss protection."[3] Expenses are broken out by mode code for each agency and categorized as either: general administration, vehicle maintenance, or non-vehicle maintenance. Figure 1 shows sharp fluctuations in casualty and liability expenses with a significant upward trend over the period 2002-2015.

TABLE 1 Collisions, Fatalities, Injuries, Casualty and Liability Expenses by Transit Mode 2002-2014

Mode	Reporting Period 2002-2014 Except as Noted			Reporting Period 2002-2013 Except as Noted		
	Collisions	Fatalities	Injuries	Total Casualty and Liability Expenses by Mode	Average Annual Vehicle Fleet	Average Annual Cost of Casualty and Liability Expenses per Vehicle
Commuter Bus (CB)[a]	94	3	390	$34,599,730[a]	2357	$4,894
Demand Responsive (DR)	14,513	120	19,833	$668,245,896	28,449	$1,957
Demand Responsive Taxi (DT)[b]	144	3	262	$2,123,284[b]	3,960	$134
Motor Bus (MB)	69,722	1,185	177,931	$4,908,851,572	62,307	$6,565
Bus Rapid Transit (RB)[a]	55	0	358	$2,752,895[a]	137	$6,714
Trolley Bus (TB)	486	10	2,096	$57,539,948	581	$8,257
Van Pool (VP)	377	19	512	$79,677,613	9,581	$693
Total Bus, Demand Responsive and Van Pool	85,391	1,340	201,382	$5,753,790,938	N/A	N/A
Total Rail[c,d]	6,118	1,303	89,806	$3,174,067,800	N/A	N/A

Source: FTA National Transit Database (NTD) for all reporting US transit agencies
[a] Data reporting started in 2012, included in Motor Bus (MB) for prior years
[b] Data reporting started in 2011, included in Demand Responsive (DR) for prior years
[c] Rail includes Automated Guideway (AG), Cable Car (CC), Commuter Rail (CR), Heavy Rail (HR), Light Rail (LR), Monorail/Guideway (MG), Monorail (MO), Streetcar Rail (SR), Hybrid Rail (YR);
[d] Collisions, fatalities, and injuries are not reported for Commuter Rail (CR).; casualty and liability expenses are included for Commuter Rail (CR).;

FIGURE 1 US Bus and Paratransit Casualty and Liability Expenses



PROJECT OBJECTIVES

The primary research objectives as stated in the IDEA contract are the following:

- Create a robust Rosco/Mobileye demonstration pilot for active safety/collision avoidance within the State of Washington on a minimum of 35 transit buses at 7 WSTIP members.
- Determine the ease of retrofit of the existing fleet.
- Develop a methodology for estimating cost savings of avoided collisions for each agency.
- Develop a methodology and evaluation process for transit driver feedback and acceptance as well as bus passenger feedback.
- Provide detailed data and understanding on entrance barriers to this technology (i.e. operational acceptance and rejection issues).

PROJECT TASKS

The project was divided into five tasks and two stages:

Stage 1 Acquisition and Installation of Equipment Including Data Collection and Historical Crash Data Research

Task 1: Acquire and install the Rosco/Mobileye equipment (Duration 3 months)
Task 2: Investigation and data collection (Duration 5 months)
Task 3: Stage I Report (Duration 3 months)

Stage 2 Data Analysis, Conclusion and Final Report

Task 4: Analysis and Conclusion (Duration 3 months)
Task 5: Final Report Preparation and approval (Duration 4 months)

CONCEPT AND INNOVATION

DESCRIPTION OF THE COLLISION AVOIDANCE WARNING SYSTEM (CAWS)

The Rosco VQS4560 Mobileye Shield+ System is a Collision Avoidance Warning System (CAWS) specifically developed for use on transit buses.[4] The CAWS includes four cameras: a master attached to the center of the inside windshield, a camera attached to the inside windshield positioned to cover the blind zone on the left front created by the "A" pillar, and one external forward-facing camera on each side of the bus towards the rear, to cover blind zones behind the driver. The rear external cameras are encased in ruggedized, heated enclosures mounted 78 to 82 inches (198-208 cm) above the ground. Figure 2 illustrates the locations of the system components on a typical bus.

The system provides coverage of blind zones where vulnerable road users may be hidden from the driver's view, and by alerting the driver to avoid potential collisions. The Mobileye Shield+ system illuminates one of three indicators located on the windshield to draw the driver's attention towards a potential pedestrian collision. The indicator shows a yellow light if a pedestrian or bicyclist is calculated to be within 2.5 seconds or less of colliding with the bus. The indicator flashes red and an alarm sounds if a pedestrian or bicyclist are within one second or less of colliding with the bus. An indicator mounted in the center of the windshield also provides forward collision warning, headway monitoring and following time, lane departure warning, and speed limit violation warning. Because buses routinely change lanes in low speed operation while pulling into and out of stops, the lane departure feature was disabled in this pilot to avoid unnecessary distraction for the driver. Rosco provided a reference guide to each agency which could be posted and reproduced for distribution to drivers. The guide, shown in Figure 3, illustrates the locations of the visual indicators and explains the functions of each indicator and what each indication means.

FIGURE 2 Diagram of typical Shield+ system component layout

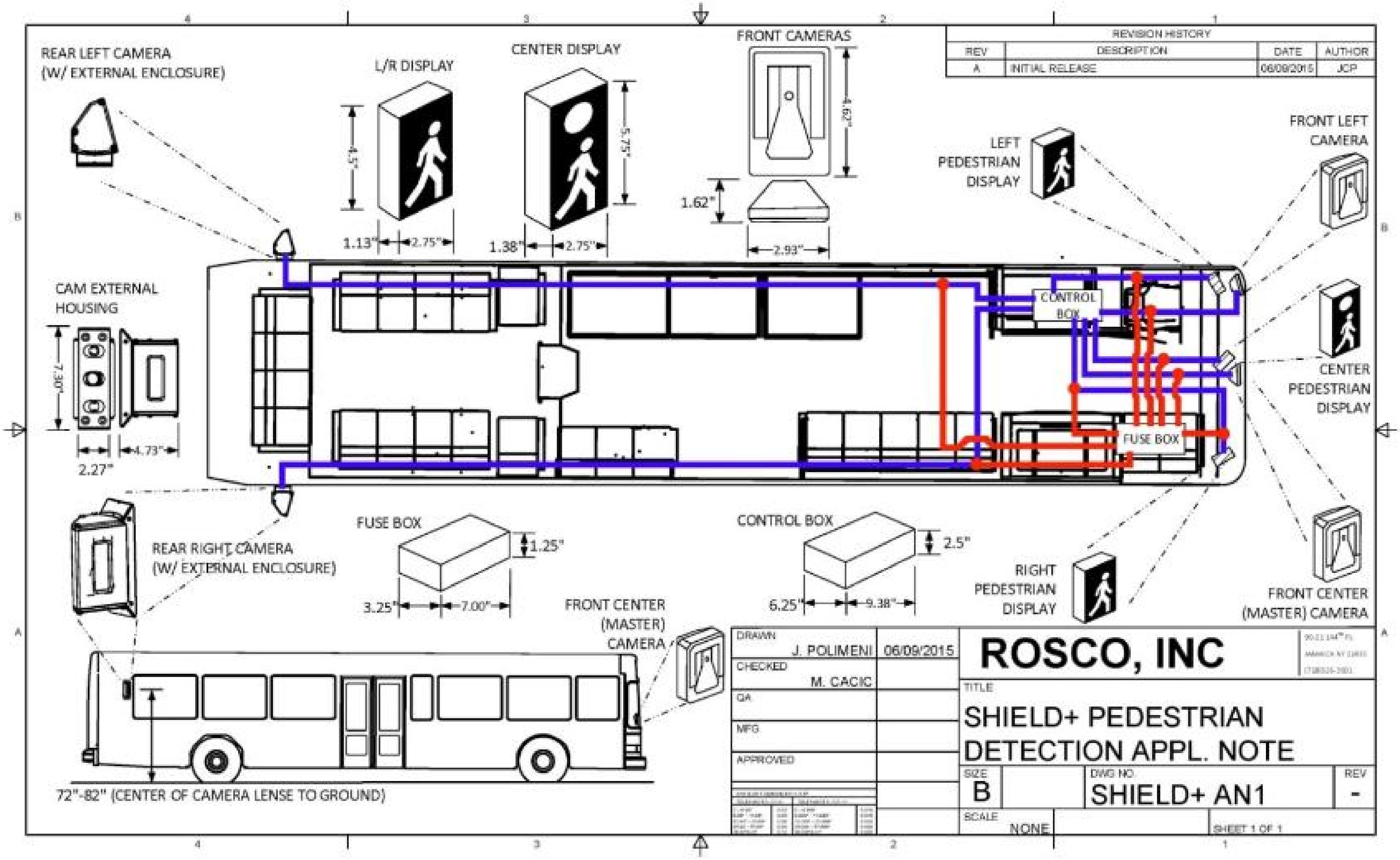
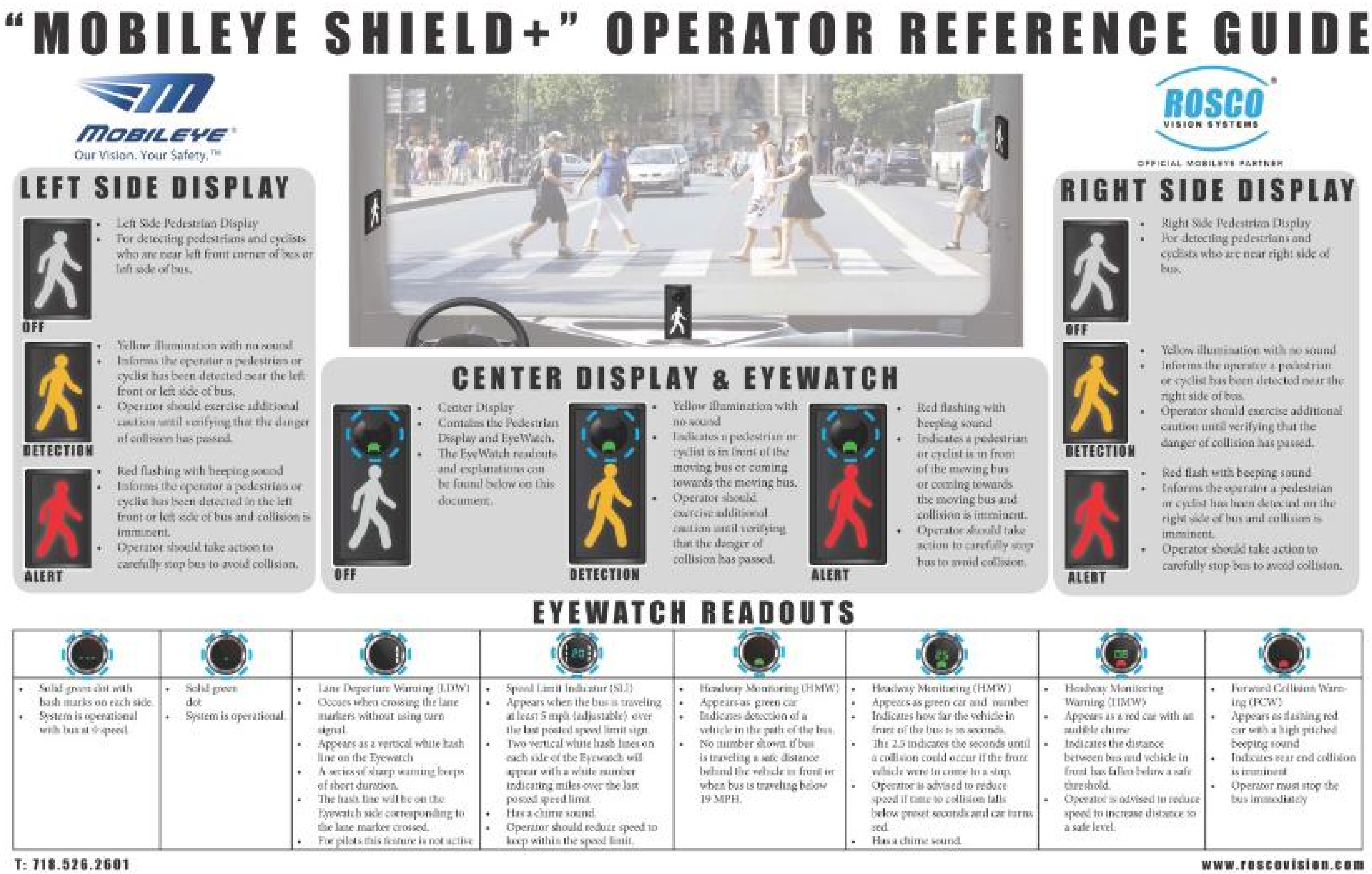


FIGURE 3 Driver Reference Guide



DESCRIPTION OF TELEMATICS DATA COLLECTION AND VIDEO RECORDING SYSTEMS

The Mobileye Shield+ system does not include video record/playback. For the pilot project, Rosco attached a smaller camera to the bottom of each Mobileye side camera housing. Rosco also mounts a Dual-Vision XC module on the windshield with both forward facing and driver facing cameras to record reactions when the Mobileye cameras detect a pedestrian or bicyclist. Video is stored in the Dual-Vision camera and can be uploaded wirelessly to an off-board server via Wi-Fi if network access is provided by the host agency. Video data was recorded for seven of the eight transit agencies, including Ben Franklin, C-Tran, Community, InterCity, King County Metro, Kitsap, Pierce, and Spokane. Video was downloaded manually by removing and replacing 32 GB SD cards, or for C-TRAN and InterCity, downloaded wirelessly.

Video is recorded in three streams as shown in Figure 4, from left to right, videos taken by the front-facing camera; by the windshield-mounted rear-facing camera; and the split-screen image shows those taken by the external rear left and right side-mounted forward-facing cameras.

FIGURE 4 Left to Right - Images captured by Rosco Dual-Vision Cameras from left to right: forward-facing, interior rear-facing, and split-screen left and right external side cameras

Each bus was equipped with an Ituran 3G telematics system which can transmit a message whenever the collision warning system is triggered by an event. Each event message includes a specific event code, bus identification, heading, miles traveled, speed, and location. Interspersed with the event messages, the Ituran system monitors "G" forces along three axes which provides readings on speed, turning and braking rates. Each telematics unit communicated directly with a server and uploaded event data in real time. Four of the 38 buses in the project (KCM #4342, Kitsap #752, Pierce #9203, and Spokane #10701) experienced communications failures due to faults in the telematics units and did not report data during the test period. Six other buses experienced partial communications failures, resulting in data reported for 29 buses in April, 31 buses in May, and 33 buses in June. The following event data were logged from the Shield+ system:

- HMW (Headway Monitoring)
- UFCW (Urban Forward Collision Warning; speed 0 to 19 mph)
- FCW (Forward Collison Warning; speed > 19 mph)
- Mobileye Pedestrian Collision Warning Right (PCWR)
- Mobileye Pedestrian Collision Warning Left (PCWL)
- Mobileye Pedestrian Collision Warning Left Front (PCWLF)
- Mobileye Pedestrian Collision Warning Forward (PCW)
- Total Audible alerts
- Total Audible alerts related to forward facing events
- Total Visual Only - Pedestrian Detections resulting in yellow indicator illumination but no audible alerts (PDZs)

Pedestrian collision warnings are active only in daylight. The other warnings are active both in daylight and at night.

INVESTIGATION

SYSTEM INSTALLATIONS

Systems were installed on 38 buses spanning a period from August 28, 2015 to March 17, 2016. Table 2 lists the transit agencies, buses and installation dates. Figure 5 shows the tools and kits set up for an installation on a Gillig bus at C-TRAN in Vancouver, WA. Procurement of the collision warning systems was funded locally and was not part of the IDEA contract. Consequently, installation was able to start in advance of the IDEA grant.

Each agency designated a key staff member to coordinate installations and training. Drivers were asked to participate in the initial installations as indicators needed to be placed in clear view of the driver, and components needed to be located to avoid obstructing the driver's vision. Since different bus types had different windshield and driver station configurations, the process had to be repeated for each type. Care was taken to insure that the system configuration would work for large and small drivers. Each agency handled training to conform to its own standard operating procedures and labor agreements. Each system was calibrated and tested in non-revenue operation prior to being placed in revenue service. Figure 5 shows testing in progress. A pedestrian crosses in front of a moving bus and triggers an alert illuminating the center indicator.

FIGURE 5 Shield+ system being installed on Gillig bus at C-Tran in Vancouver, WA

FIGURE 6 Center indicator illuminates as pedestrian crosses in front of moving bus

TABLE 2 : Installation of Shield+ Bus Collision Warning Systems

Agency	Location	Bus #	Manufacturer	Model	Year	Shield+ Install Date
Ben Franklin Transit	Richland, WA	5322	Gillig	Low Floor	2015	1/12/2016
Ben Franklin Transit	Richland, WA	5323	Gillig	Low Floor	2015	1/13/2016
Ben Franklin Transit	Richland, WA	5324	Gillig	Low Floor	2015	1/14/2016
Ben Franklin Transit	Richland, WA	5325	Gillig	Low Floor	2015	1/15/2016
Ben Franklin Transit	Richland, WA	5326	Gillig	Low Floor	2015	1/20/2016
Community Transit	Everett, WA	11100	New Flyer	XD40	2011	10/5/2015
Community Transit	Everett, WA	11101	New Flyer	XD40	2011	9/9/2015
Community Transit	Everett, WA	11102	New Flyer	XD40	2011	10/5/2015
Community Transit	Everett, WA	11103	New Flyer	XD40	2011	9/10/2015
Community Transit	Everett, WA	11104	New Flyer	XD40	2011	10/6/2015
C-Tran	Vancouver, WA	2204	Gillig	Phantom	1999	10/8/2015
C-Tran	Vancouver, WA	2215	Gillig	Phantom	2002	10/12/2015
C-Tran	Vancouver, WA	2272	Gillig	Low Floor	2008	11/12/2015
C-Tran	Vancouver, WA	2285	Gillig	Low Floor	2009	10/14/2015
C-Tran	Vancouver, WA	2401	Gillig	Low Floor	2010	10/6/2015
InterCity Transit	Olympia, WA	400	Gillig	Low Floor Hybrid	2010	11/20/2015
InterCity Transit	Olympia, WA	402	Gillig	Low Floor Hybrid	2010	11/20/2015
InterCity Transit	Olympia, WA	411	Gillig	Low Floor Hybrid	2012	11/20/2015
InterCity Transit	Olympia, WA	416	Gillig	Low Floor Hybrid	2012	11/17/2015
InterCity Transit	Olympia, WA	427	Gillig	Low Floor Hybrid	2014	11/17/2015
King County Metro	Seattle, WA	4342	New Flyer	Xcelsior XT40	2015	12/2/2015
King County Metro	Seattle, WA	4346	New Flyer	Xcelsior XT40	2015	12/2/2015
King County Metro	Seattle, WA	7028	Orion	VII	2010	1/6/2016
Kitsap Transit	Bremerton, WA	752	Gillig	Low Floor	2004	1/27/2016
Kitsap Transit	Bremerton, WA	753	Gillig	Low Floor	2004	1/18/2016
Kitsap Transit	Bremerton, WA	754	Gillig	Low Floor	2004	1/12/2016
Kitsap Transit	Bremerton, WA	755	Gillig	Low Floor	2004	1/20/2016
Kitsap Transit	Bremerton, WA	756	Gillig	Low Floor	2004	1/26/2016
Pierce Transit	Tacoma, WA	501	Gillig	G30D102N4	2010	8/28/2015
Pierce Transit	Tacoma, WA	516	Gillig	G30D102N4	2010	8/28/2015
Pierce Transit	Tacoma, WA	517	Gillig	G30D102N4	2010	8/28/2015
Pierce Transit	Tacoma, WA	9201	Gillig	G30D102N4	2012	2/24/2016
Pierce Transit	Tacoma, WA	9202	Gillig	G30D102N4	2012	9/1/2015
Pierce Transit	Tacoma, WA	9203	Gillig	G30D102N4	2012	9/1/2015
Pierce Transit	Tacoma, WA	9204	Gillig	G30D102N4	2012	2/25/2016
Spokane Transit	Spokane, WA	1401	Gillig	40’ Low Floor	2014	11/15/2015
Spokane Transit	Spokane, WA	10701	Gillig	40’ Low Floor HEV	2010	11/13/2015
Spokane Transit	Spokane, WA	12702	Gillig	40’ Low Floor	2012	3/17/2016

TESTING AND OPERATIONS

The data collection period ran from April1, 2016 through June 30, 2016. During this period, WSTIP and KC Metro Transit buses equipped with Shield+ systems logged 352,129 miles and 23,798 operating hours. Table 3 below shows all reported incidents involving Shield+ equipped buses for the test period. None of the events resulted in injuries. None of the incident types would have generated Shield+ alerts.

Maintenance during the pilot was provided by the vendor. A “trouble ticket” process was established to provide uniform reporting of maintenance issues by each transit agency. The project administration team created a spreadsheet to keep track of all tickets and resolutions. Seventeen trouble tickets were logged.

TABLE 3 Incidents Involving Shield+ Equipped Buses during Data Collection Period

Agency	Bus #	Date	Incident #	Description	Additional Detail
Community	11103	4/27	16-001566	Collision with: Other	Hit construction cones
Community	11103	5/02	16-001617	Collision with: Fixed object	Hit curbside obstruction damaged Shield+ camera
C-Tran	2204	4/18	16-001286	Mirror strike	Hit parked car mirror with rear of bus
C-Tran	2215	4/25	16-001517	Collision with: Fixed object	Hit curbing - severe scuff marks on right side of bus
C-Tran	2204	6/20	16-002433	Mirror strike	Hit mirror of another bus
Intercity	411	5/26	16-001947	Collision with: Fixed object	Hit construction fence Shield+ camera knocked off
Intercity	411	6/18	16-002265	Collision with: Other vehicle	Bus hit by turning car
Kitsap	752	6/23	16-002311	Collision with: Other vehicle	Hit parked car mirror
Spokane	10701	5/31	16-002020	Mirror strike	Hit parked car
Spokane	12702	6/17	16-002321	Collision with: Other vehicle	Hit parked car while pulling away from curb

During the test period, for comparison, we also accumulated incident and claims data on all buses not equipped with Shield+ at each of the WSTIP member agencies participating in the pilot. We found the following:

- There were no fatal accidents between 4/1/16 and 6/30/16 involving a WSTIP bus and a 3rd party person or vehicle.
- WSTIP has 25 members. Between 4/1/16 and 6/30/16 WSTIP members reported 395 events involving fixed route buses. There were 39 possible injuries from those 395 events.
- WSTIP members reported 44 collision or sudden stop events which resulted in 22 possible injury claims.
- WSTIP's seven members participating in the pilot reported 284 events on their fixed route buses during this time period, including six collisions with pedal cycles, three collisions with pedestrians, and one collision with a motorcycle. There were 34 possible injuries from those 284 events, including two pedal bicyclists. **No Shield+ equipped buses were involved in any collisions with bicyclists or pedestrians.**
- WSTIP's seven participating members reported 32 collision or sudden stop events which resulted in 19 possible injury claims.

The Ituran telematics system is capable of reporting vehicle/driver performance in terms of numbers of events per miles traveled for each vehicle. Due to agency concerns about driver reactions, Shield+ systems on Spokane Transit buses were set up to collect and transmit data via telematics only and did not issue warnings to drivers. This was called operating in "stealth mode." Buses operating with systems in stealth mode served as a baseline, or control group, to help determine if installing Shield+ systems with functioning visual and audible alerts and warnings, resulted in changes in driver performance over time. Two of the Spokane Transit buses provided data for 17,070 miles of service.

DRIVER SURVEYS

During field testing in revenue service, it was determined that passengers did not interact with the collision warning systems. Indicators are not very visible to passengers and audible warnings may not be distinguishable by passengers from other normal bus sounds such as stop requests and fare card validators. On some runs, depending on conditions, there may be no noticeable activations. Consequently, it was decided not to conduct a survey to obtain passenger feedback but to rely on reports from the drivers

Driver survey instruments were developed for administration through distribution of paper surveys and for direct entry via computer. The survey included 12 questions, four about the conditions for the run, four about the frequency of warnings, and four about the driver's assessment of system performance. The survey was administered three times, to determine if driver reactions would change over time. We did not see a discernable pattern of change in responses over time. The following numbers of responses were received: April – 117, May – 85, and June – 75. Because their Shield+ systems operated in stealth mode, Spokane Transit did not administer the survey to its drivers.

Table 4 provides a summary of two key questions asked of drivers about Shield+: was it helpful, and would they prefer to drive with it. Overall, 37 percent of the responses indicated that the system was helpful, and 63 percent indicated the system was distracting. Thirty-three percent of the responses were affirmative when drivers were asked if they preferred to drive with it and 67 percent were negative. The largest percentage of positive responses was from King County Metro. The smallest percentage of positive responses was from Kitsap Transit. Drivers were encouraged to provide comments on the survey. One hundred seventy-eight (178) comments were received.

TABLE 4 Summary Results from Bus Driver Survey Responses

Question in Driver Survey:		As a Driver of a transit bus in revenue service, please rate how helpful you found the collision avoidance system.		As a Driver of a transit bus in revenue service, how much would you like to drive with this system full-time?	
Questionnaire Responses and Summary Categories in this Table:		"Helpful" = Very Helpful, Helpful, Somewhat Helpful. "Distracting" = Somewhat Distracting, Distracting, Very Distracting.		"Affirmative" = Always, Very Often, Sometimes. "Negative"= Rarely, Very Rarely, Never.	
Pilot Transit Agency	Month Survey was Administered	Helpful	Distracting	Affirmative	Negative
Ben Franklin	April	7	8	6	9
Ben Franklin	May	6	2	4	4
Ben Franklin	June	6	10	7	10
Ben Franklin – Total Response %		48%	52%	43%	57%
Community	April	8	16	5	16
Community	May	4	15	2	16
Community	June	8	9	7	10
Community – Total Response %		33%	67%	25%	75%
C-Tran	April	2	3	1	4
C-Tran	May	4	6	4	6
C-Tran	June	2	5	2	5
C-Tran – Total Response %		36%	64%	32%	68%
Intercity	April	5	19	3	20
Intercity	May	10	19	6	11
Intercity	June	N/A	N/A	N/A	N/A
Intercity – Total Response %		28%	72%	23%	77%
King County	April	19	8	20	6
King County	May	N/A	N/A	N/A	N/A
King County	June	N/A	N/A	N/A	N/A
King County – Total Response %		70%	30%	77%	23%
Kitsap	April	0	9	0	9
Kitsap	May	1	12	1	12
Kitsap	June	2	9	1	10
Kitsap – Total Response %		9%	91%	6%	94%
Pierce	April	6	7	5	7
Pierce	May	1	0	1	0
Pierce	June	8	12	8	12
Pierce – Total Response %		44%	56%	42%	58%
Total Responses Tabulated		99	169	83	167
Total Response %		37%	63%	33%	67%

ISSUES NOTED IN DRIVER COMMENTS

- False positive pedestrian Indications – Warnings and alerts frequently sounded when buses were approaching stops with waiting passengers or pedestrians moving on the sidewalks. This appeared to be the most frequently cited issue. However, according to the vendor, some false positives reported by drivers may have been their interpretations of situations where there is a risky activity by a road user or by a vehicle and the alert happens at the exact same time the driver perceives the risk and also slows down.
- False speed limit violation indications – The Shield+ system determines speed limits by recognizing speed limit signs detected by the front camera. Buses merging onto freeway lanes frequently experienced speeding indications due to the system continuing to reference ramp speed limit signs when no freeway speed limit signs were seen by the system. Buses passing through school zones also frequently experienced speeding indications during periods when the school speed limit was not in force.
- Audio indications too loud – Many drivers commented that the beeps emanating from the system were too loud. Some commented that the audio indications were annoying because they added to the beeps generated by existing systems on the bus, including fare boxes and stop request annunciators.
- System does not function in darkness – The vendor stated that the pedestrian detection functions of system are intended for daylight use only. Some drivers may not have been made aware of that limitation.
- System inoperative – Some drivers commented that they received no alerts or warnings from the system during a run. In some instances, maintenance was required to restore systems to operation.
- Pedestrian warning indications appearing in a direction opposed to drivers' perception of a pending collision – Some drivers commented that they received a warning of a pending pedestrian collision on one side of the bus when they could see a pedestrian on the other side of the bus.
- Headway warnings – Some drivers commented that headway warnings appeared when they pulled in behind parked cars or when cars pulled into their lane.
- Inaccurate speed limit warnings – Some drivers commented that they received speed warnings that differed from the readings on the bus speedometer.

TESTING FOR FALSE POSITIVES AND FALSE NEGATIVES

A key task for the pilot was to evaluate the accuracy of the CAWS in correctly identifying incidents involving near-misses with pedestrians and filtering out incidents which posed no imminent risk of collision with pedestrians. Evaluating this aspect of CAWS performance involved reviewing video and telematics data to detect false positives and false negatives. A false positive (FP) is defined as the presence of pedestrian/bicyclist near-miss event in the telematics data that is not confirmed by the video. A false negative (FN) is defined as an incident in which a pedestrian with an estimated time to collision (TTC) less than a specified threshold is not detected by the CAWS. False positives generate warnings that can annoy drivers and divert their attention from the driving task. False negatives are potentially more serious because they could place pedestrians at risk.

University of Washington Smart Transportation Applications and Research Laboratory (STAR Lab) developed a program for automatically checking the front-facing videos and filtering out most of the frames without events. Another round of manual checking was conducted to further verify the detection results. The STAR Lab detection framework excludes complex background information and attempts to locate the pedestrian directly.[5] Distance calculation to the pedestrian is calculated in 3D real-world coordinates. The process has four main stages: 1) pedestrian detection in onboard video, 2) motion estimation in image coordinates, 3) relative position and speed calculation in real-world coordinates, and 4) near-miss detection.

Figure 7 illustrates the process. In the first stage, a Histogram of Oriented Gradients (HOG) pedestrian detector is used to detect pedestrians within the camera vision.[6] In the second stage, interest points inside the detected rectangle representing the pedestrian are tracked with a Kanade-Lucas-Tomasi *(*KLT) tracker to estimate pedestrian motion in image coordinates.[7] In stage three, a camera model is used to find the correspondence between image coordinates and real-world coordinates. The pedestrian's position and speed relative to the bus are calculated in 3D real-world coordinates. In stage four, thresholds for time to collision (TTC) are calculated to detect near-miss events which can be extracted from video clips. In order to set an appropriate TTC threshold for evaluation, we use a detection overlap rate (*OR*) to find the TTC threshold that would maximize *OR*. *OR* is defined in Equation (1)

$$OR = \frac{A \cap B}{A \cup B} \quad (1)$$

where A is the set of detections identified by STAR Lab and B is the set of detections identified by Shield+. OR ranges from 0 to 1 and a larger OR indicates a TTC threshold that more closely approximates the detection performance of Shield+. All events with TTC less than 2.5s detected by the STAR Lab program were identified for manual checking.

To identify FPs, the STAR Lab video processor is run on video clips labeled with events. If the processor detects the event in the video, it is considered a true-positive ($A \cap B$). However, if no event is detected by the processor in the video clip, further checking is required. Audio alerts can be heard when the clips are played on the Rosco viewer. Manual checking process for FPs runs as follows: 1) find the time of audio alert; 2) check both the front facing video and side videos to see if there is a conflict; 3) if there is no conflict observed such as no appearance of vulnerable road users or no obvious aggressive movement around the time of alert, the event would be considered a FP (FP $\in A \cup B - A$).

The identification of FNs is much more challenging and time consuming. The STAR Lab method aims to minimize checking time and maximize the probability of finding all FNs. The first step in identifying FNs is to run the video processor on the whole video dataset to mark all near-miss events. A manual checking process on all marked events follows as step two. False detections of road users are filtered out in this manual checking process. For example, a tree mistakenly recognized as a pedestrian will be discarded immediately. The remaining detected events are considered true events that could be found given the time and budget constraints. The last step for FN detection is to identify the events detected by STAR Lab's video processor but not Shield+, i.e. FN $\in A \cup B - B$. Although the KLT based estimation process performs well, it cannot guarantee all near-miss events are detected. Thus, the FN rate produced by this method is likely at the lower end.

Two typical FP patterns were found during the testing period as seen in Figure 8. The first pattern was false detection of road users, in which a PCW was generated by movement of the bus toward an object similar in shape to a pedestrian. For example, a standalone stop sign did not generate a warning, but for some Ben Franklin buses during April and May, a stop sign with other objects around it did. The second typical pattern for false positives involved pedestrians/bicyclists moving parallel to and on the left of the bus either in the same or opposite direction. In some instances, pedestrians were on sidewalks at some distance and not on a trajectory to collide with the bus. The second pattern did not generate FP's for all buses, and may be caused by individual installation or parameter settings.

Very few FN's were identified and no strong patterns emerged. Late detections were defined as FN's. Two example false-negatives identified by the STAR Lab processor are shown in Figure 9. Both (a) and (b) were detected by the Shield+ system but the warnings were late. In (b), the warning was generated after the bus had passed the pedestrian.

Table 5 shows summary statistics based on the sample of videos that had been fully processed prior to this publication. The total FP rate is about 3.21% and the FN rate is about 0.30%. In summary, the Shield+ system rarely missed potential conflicts and was found to be robust in challenging scenarios such as adverse weather, low lighting condition, direct sunlight, and shadows.

TABLE 5 Summary Statistics for Identification of False Positives and False Negatives

	Ben Franklin Transit	Community Transit	King County Metro	Kitsap Transit	Pierce Transit	Total
Events	1640	1062	430	1477	1461	6070
FP	111	24	7	39	14	195
FN	3	4	4	2	5	18
FP Rate	6.77%	2.26%	1.63%	2.64%	0.96%	3.21%
FN Rate	0.18%	0.38%	0.93%	0.14%	0.34%	0.30%

FIGURE 7 Vehicle-Pedestrian Near-Miss Detection through Onboard Monocular Vision

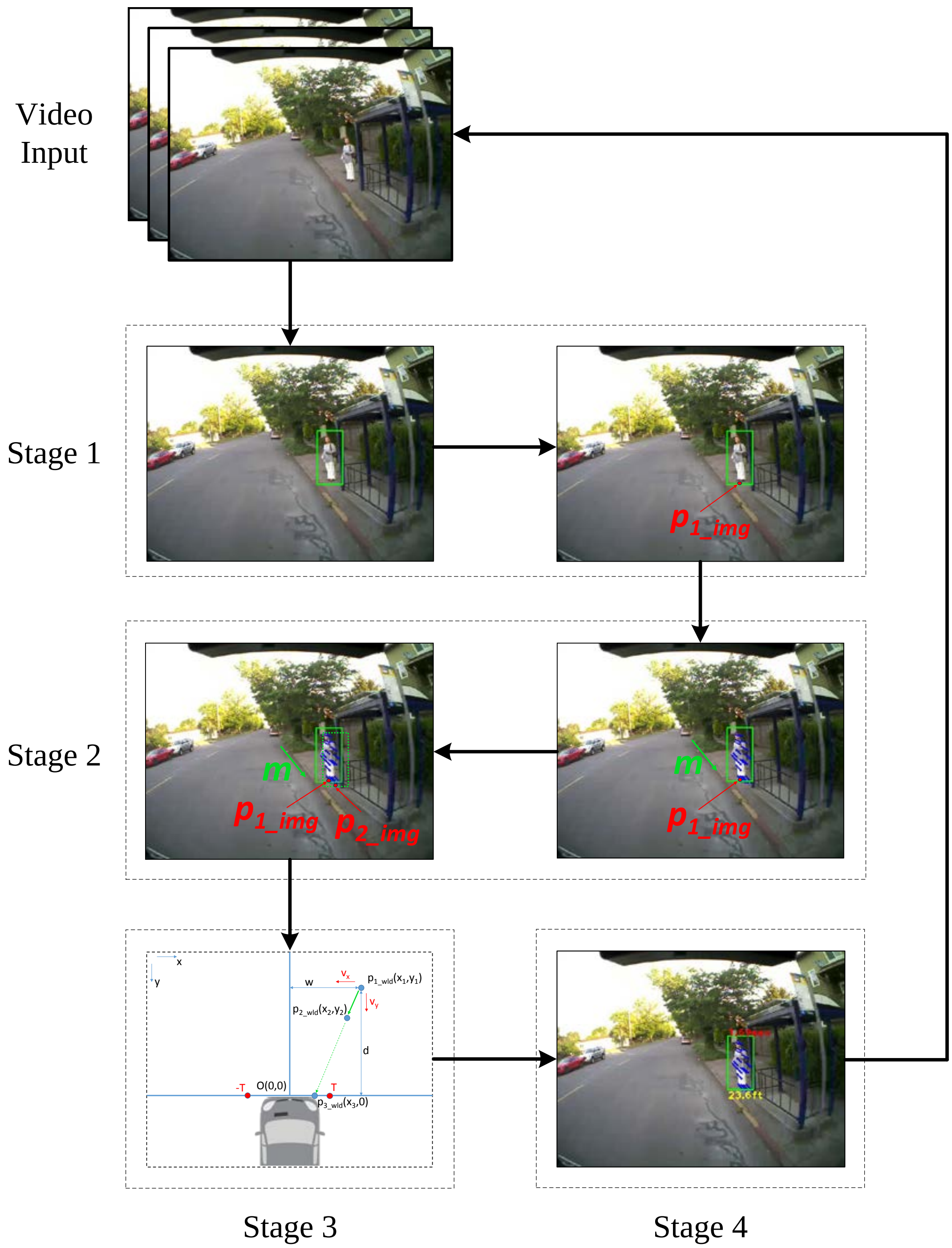


FIGURE 8 Typical Patterns for False Positives

FIGURE 9 Examples of Late Detections Identified as False Negatives

COLLISION AVOIDANCE PERFORMANCE MEASUREMENT

As discussed earlier, Shield+ systems on Spokane Transit buses were set up to collect and transmit data via telematics only and did not issue warnings to drivers. Buses operating with systems in "stealth mode" served as a baseline, or control group, to help determine if installing Shield+ systems with functioning visual and audible alerts and warnings, resulted in changes in driver performance over time. As drivers gain experience with the Shield+ equipped buses, they may be better able to anticipate adverse driving conditions, which would be reflected in fewer events per miles logged.

The rate of warning per 1000 miles was recorded for each bus. It was therefore possible to compare the performance of buses that broadcast the warnings to drivers with buses that did not. Table 6 shows the comparison for each type of warning. Headway Monitoring (HM) indications were not considered to be "near-misses," or a significant indicator of driver performance, due to the normal traffic conditions experienced in urban bus operations. There were fewer collision warnings per 1000 miles for the active fleet. Although the data was not linked to individual drivers, it appears that drivers of buses in the active fleet triggered fewer warnings than those who drove buses in "stealth mode."

Compared with the Spokane buses in the control group, buses with active CAWS experienced 71.55% fewer forward collision warnings per 1000 miles. Estimation of pedestrian collision prevention required combining the rates for PCW's and PDZ's because they are not equivalent measures. There were 43.32% fewer combined pedestrian collision warnings per 1000 miles. It is hypothesized that the CAWS equipped buses made the drivers more sensitive to conditions that triggered warnings, and they were able to anticipate those conditions and avoid triggering the CAWS indicators. Thus the CAWS may be able to reduce collisions by increasing driver awareness of potential conditions that might lead to a crash. The percent reductions in warnings seen by comparing the active fleet with the control group will be used to develop a lower bound to the potential reduction in the cost of claims attributable to collisions.

TABLE 6 Comparison of CAWS Warnings per 1,000 Miles for Active Fleet and Control Group

Performance Measures	Spokane Buses (Control Group Operating in "Stealth Mode")	Buses with CAWS System Active Excluding KCM Trolleys*	Percent Difference in Warnings per 1k Miles for the Active Fleet
Total Mileage (mi)	17,070.62	336,913.51	N/A
HMW (Headway Monitoring)	285	5,281	N/A
HMW (Headway Monitoring) Per 1k Miles	16.69	15.67	-6.11
UFCW (Urban Forward Collision Warning; speed 0 to 19 mph))	5,408	29,271	N/A
UFCW (Urban Forward Collision Warning; speed 0 to 19 mph)) Per 1k Miles	316.8	86.88	-72.58
FCW (Forward Collison Warning; speed > 19 mph)	187	2,143	N/A
FCW (Forward Collison Warning; speed > 19 mph) Per 1k Miles	10.95	6.36	-41.91
Total Forward Collision Warnings (UFCW+FCW)	5,595	31,414	N/A
Total Forward Collision Warnings (UFCW+FCW) Per 1k Miles	327.76	93.24	-71.55
Total PCW (Pedestrian Collision Warning)	471	5,853	N/A
Total PCW Per 1k Miles	27.59	17.37	-37.03
Total Visual Only (PDZs)	23,790	242,849	N/A
Total Visual Only (PDZs) Per 1k Miles	1,393.62	720.80	-48.28
Total PCW + PDZ (by converting PDZ to equivalent PCW) Per 1k Miles	61.66	34.95	-43.32
* KCM trolley buses were not included. Trolley buses comprise a separate mode in FTA's National Transit Database and may have different operating characteristics than Diesel buses.			

ANALYSIS OF HISTORICAL CLAIMS

WSTIP is an organization providing risk management and insurance services to 25 public transportation providers in the state of Washington. It has been monitoring transit industry claims for 25 years, insures 5,000 vehicles, and handles about 1,000 claims per year. WSTIP maintains complete records of all claims incurred by its members. For this pilot, records of all claims greater than $2,900 between 2004 and 2016 for fixed route service were tabulated.

In collaboration with Veritas Forensic Accounting & Economics (Veritas), University of Washington Smart Transportation Applications and Research Laboratory (STAR Lab) analyzed 13 years of claims data provided by WSTIP and developed an analysis framework to classify claims according to the magnitude of loss and the relevant explanatory factors. Each claim record includes a brief description which was used as the basis for assigning one of 17 loss category labels. Individual claims greater than $2,900 were allocated to categories that identified each claim as one that could be impacted by: vehicular collision avoidance warnings, pedestrian/bicyclist collision avoidance warnings, or for which the collision avoidance system would have no likely impact. Of a total $53.1 million in claims for fixed route buses, $18.3 million, 35% were attributable to preventable vehicular collisions, and $16.0 million, 30% were attributable to preventable pedestrian/bicyclist collisions. Table 7 shows the results of the historical claims analysis. Table 7 includes all WSTIP Fixed Route bus service, but not paratransit or vanpool.

The study did not address other costs not necessarily included in insurance payments such as: accident investigation, drug and alcohol testing, emergency services response, hearings and discipline, in-house legal services, in-house collision repair, lost fare revenue, overtime, passenger and service delays, sick time, spare vehicles and replacements, vehicle towing and recovery, and worker's compensation.

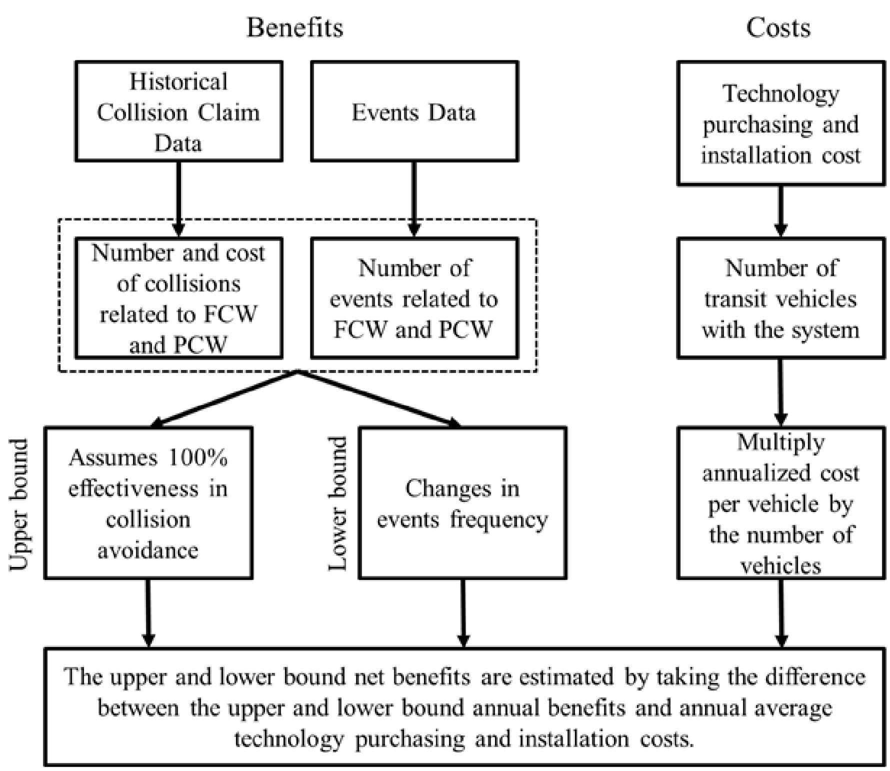
TABLE 7 WSTIP Fixed Route Liability Claims History 2004-2016

WSTIP Fixed Route Liability Claims History 2004-2016 – Claims >$2,900						
Claim Type – Loss Indicator	Legal Expense $	Bodily Injury $	Property Damage $	Incurred Expense $	Indemnity Other Expense $	Total $
Hit Structure	-	-	87,305	6,563	-	93,867
Hit Pole	16,778	43,180	123,691	8,656	-	192,305
Loss of Control	17,902	46,585	13,492	12,942	-	90,921
Loss of Control - Ice	29,722	584,036	330,815	60,108	-	1,004,681
Malfunction	36,063	1,406,599	658,217	40,572	-	2,141,451
Medical Issue	21,062	442,020	122,067	81,561	717	667,426
Other Vehicle Collided	587,736	3,287,173	903,025	394,899	-	5,172,832
Passenger Altercation	50,444	11,500	-	1,452	-	63,395
Side Swipe	235,934	383,349	77,919	112,166	-	809,368
Slip & Fall	1,533,014	5,280,490	16,179	725,662	734	7,556,080
Vehicle Fire	-	-	273,326	7,300	-	280,626
(blank)	95,500	248,500	108,071	60,058	-	512,129
Claims not Impacted by CAWS (35.0%)						**18,585,081**
Hit Parked Vehicle	-	-	224,659	25,866	-	250,525
Intersection (Broadside/T-Bone)	269,710	4,745,079	466,444	278,255	987	5,760,475
Multi Vehicle Collision	60,112	441,000	21,178	65,486	-	587,776
Rear End Collision	1,009,738	7,815,356	912,223	654,678	9,176	10,401,172
Vehicle on Vehicle Collision	91,613	634,783	674,342	192,349	-	1,593,087
Claims Impacted by Forward Vehicle CAWS (35.0%)						**18,593,035**
Vehicle on Pedestrian/Cyclist	954,104	14,108,090	7,852	886,506	25,000	15,981,552
Claims Impacted by Pedestrian CAWS (30.1%)						**15,981,552**
Total Claims Impacted by Forward Vehicle and Pedestrian CAWS (65.1%)						**34,574,587**
Grand Total	**5,009,431**	**39,477,742**	**5,020,804**	**3,615,079**	**36,614**	**53,159,668**

ESTIMATION OF SYSTEM COST-EFFECTIVENESS

From the historical analysis of $53.2 million in fixed route bus claims, $18.6 million, 35%, were attributable to preventable vehicular collisions, and $16.0 million, 30%, were attributable to preventable pedestrian/bicyclist collisions. Figure 10 shows the methodology used to estimate benefits by combining historical collision claims data with driver performance data. The total claims established an upper bound for potential cost savings. To estimate a lower bound to cost-savings through use of CAWS, the total costs of vehicular collisions and pedestrian/bicyclist collisions were multiplied by collision reduction factors derived from changes observed in the numbers of near-misses for buses equipped with CAWS. Those reductions are documented in the previous section on Collision Avoidance Performance Measurement.

FIGURE 10 Framework for Estimating Benefits and Costs



The values used to calculate upper and lower boundaries for claims reductions are shown in Table 8 and the following equations. Total claims were divided by the number of years (13) in the historical period to calculate an average annual claims cost. The upper bound annual claims reduction per bus was calculated by dividing the annual claim cost by the average number of buses insured by WSTIP each year (1,058). The lower bound annual claims reduction per bus was calculated by multiplying the annual claims cost by the appropriate reduction factor and dividing by the number of buses. The net benefits calculations multiplied the average annual claims reduction by the service life and subtracted the cost of the CAWS ($7,375 per bus, the contracted price for the pilot). The net result was divided by the service life to arrive at net annual benefits. Values for service life were varied from 5 years, a typical period for amortizing technology, to 14 years, a nominal period for the useful life of a transit bus. Table 9 shows the net benefits. The changes in benefits over the service life are shown in Figure 11.

As shown in Table 9, the upper bound annual net benefits from collision claims reduction for all WSTIP members increase from $1,099,262 in year 5 to $2,102,473 in year 14. For the lower bound, benefits are negative by -$4,232 in year 5 but become positive in year six and increase to $998,979 by year 14.

TABLE 8 Variables Used in Estimating CAWS Cost-Effectiveness Boundaries

Total cost of vehicular collisions for fixed route buses 2004-2016	$18,593,036
Annual average cost of vehicular collisions for fixed route buses 2004-2016	$1,430,234
Total cost of pedestrian/bicyclist collisions for fixed route buses 2004-2016	$15,981,522
Annual average cost of pedestrian/bicyclist collisions for fixed route buses 2004-2016	$1,229,348
Average Annual Number of Fixed Route Buses in WSTIP Inventory	1,058
Cost of installed Shield+ system (2017 dollars)	$7,375
Lower bound reduction factor for vehicular claims for CAWS	71.55%
Lower bound reduction factor for pedestrian/bicyclist claims for CAWS	43.32%

Upper bound annual claims reduction per vehicle (*UBB)* is calculated as:

$$UBB = \frac{UBFC + UBPC}{NV} = \frac{\$1{,}430{,}234 + \$1{,}229{,}348}{1{,}058} = \$\mathbf{2,514}$$

Lower bound annual claims reduction per vehicle (*LBB)* is calculated as:

$$LBB = \frac{LBFC + LBPC}{NV} = \frac{\$1{,}430{,}234 \times 71.55\% + \$1{,}229{,}348 \times 43.32\%}{1{,}058} = \$\mathbf{1,471}$$

Upper bound annual net benefit per vehicle (UBV) is calculated as:

$$UBV = \frac{UBB \times YSL - \$7{,}375}{YSL}$$

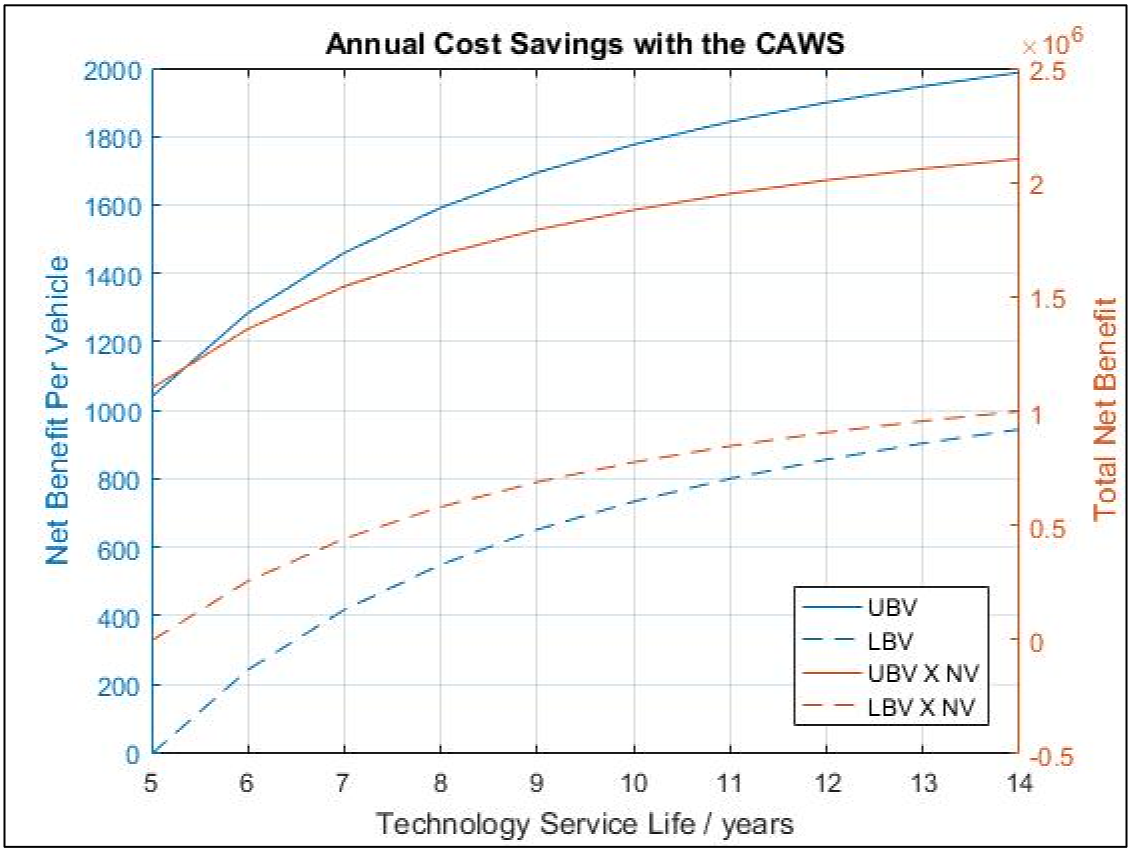
Lower bound annual net benefit per vehicle (LBV) is calculated as:

$$LBV = \frac{LBB \times YSL - \$7{,}375}{YSL}$$

TABLE 9 Estimated Annualized Net Benefit Boundaries for CAWS

Years of Service Life (YSL)	Lower Bound of Annual Net Benefit Per Vehicle ($) (LBV)	Lower Bound of Annual Total Net Benefit ($) LBV X NV	Upper Bound of Annual Net Benefit Per Vehicle ($) (UBV)	Upper Bound of Annual Total Net Benefit ($) UBV X NV
5	-4	-4,232	1,039	1,099,262
6	242	255,860	1,285	1,359,354
7	417	441,639	1,460	1,545,133
8	549	580,974	1,592	1,684,468
9	652	689,346	1,695	1,792,840
10	734	776,043	1,777	1,879,537
11	801	846,977	1,844	1,950,471
12	856	906,089	1,899	2,009,583
13	904	956,106	1,947	2,059,600
14	944	998,979	1,987	2,102,473

FIGURE 11 Net Benefits of CAWS per Vehicle by Service Life



PLANS FOR IMPLEMENTATION

NEED FOR FURTHER TESTING

Although the pilot project produced encouraging results, collisions, injuries and fatalities can be considered "rare events." A much larger in-service test will be needed to demonstrate actual cost-savings. Table 10 shows the numbers of collisions, injuries, fatalities and revenue vehicle miles reported by the eight transit agencies in the pilot for 2015. Table 10 also shows the average vehicle revenue miles between reportable collisions, fatalities, and injuries. The WSTIP transit agencies participating in the pilot average one reportable collision per 812,335 miles and one injury per 344,964 miles. 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. It is clear that more buses need to be tested for a longer period to see if CAWS can significantly reduce collisions.

TABLE 10 Numbers and Frequency of 2015 Bus Collisions, Fatalities, and Injuries for Pilot Transit Agencies

	Vehicle Revenue Miles (VRM)	Collisions	VRM/ Collision	Fatalities	VRM/ Fatality	Injuries	VRM/ Injury
Ben Franklin	2,148,656	2	1,074,328	0	-	1	2,148,656
Community	4,953,326	9	550,370	0	-	24	206,389
C-Tran	3,864,255	4	966,064	0	-	12	322,021
Intercity	2,342,410	2	1,171,205	0	-	6	390,402
Kitsap	1,981,899	2	990,950	0	-	4	495,475
Pierce	4,411,207	6	735,201	0	-	12	367,601
Spokane	5,480,629	6	913,438	1	5,480,629	14	391,474
	25,182,382	31	812,335	1	25,182,382	73	344,964
King County	31,651,853	38	458,723	2	15,825,927	135	234,458
	56,634,235	69	820,786	3	18.878,078	208	272,280

FUTURE PRODUCT DEVELOPMENT

As a result of comments received from the drivers, the vendor has begun a program to incorporate desired modifications to the system. The following modifications are in the product development pipeline at various stages:

- Adjust system sensitivity to reduce false positives when coming to a stop at a traffic signal, on approaches to bus stops, and on the opposite side of the bus when turning (being included in upgrade for systems retained after pilot)
- Install switch to allow “stealth mode” operation to store video and transmit telematics data without providing warnings and alerts to driver
- Regulate audio alert volume to improve driver acceptance
- Improve pedestrian detection in low light (testing in progress)
- Provide external warnings to pedestrians triggering Shield+ (testing in progress)
- Provide haptic feedback (seat vibration)

Rosco has advised us that the junction box and harnessing has been changed to be a plug-n-play system, which will simplify installation. Mobileye has advised us that a new chipset, EyeQ4 will succeed the current EyeQ2 chipset in 2018. Shield+ with EyeQ4 will include 3D vehicle detection and capabilities to provide collision warnings for stationary objects, sideswipes, and animals.

PIERCE TRANSIT RESEARCH, DEMONSTRATION, AND DEPLOYMENT PROJECT

The findings from the pilot study led Pierce Transit to apply for a competitive research and development grant from the Federal Transit Administration (FTA) to equip all 176 of its 40 foot transit buses with CAWS and to run extended testing and data collection for a full year. The expectation is that Pierce would be able conduct a full-year of testing, data collection, analysis, and evaluation during an estimated 4.4 million miles of revenue service for its entire fixed-route fleet. In addition to the installation of CAWS, the grant will fund research and demonstration to link CAWS with autonomous emergency braking (AEB). Pierce received notice that the FTA awarded $1.66 million for the project and work is expected to begin in mid-2017.

CONCLUSIONS

OVERALL FINDINGS

The pilot test met all of the objectives included in the contract. The vendor equipped 38 buses with Shield+ CAWS. Buses equipped with Shield+ systems logged 352,129 miles and 23,798 operating hours during the official pilot data collection period from April 1, 2016 through June 30, 2016. No Shield+ equipped buses were involved in any collisions with bicyclists or pedestrians. Because Spokane Transit decided to operate its buses in stealth mode, the pilot included the unanticipated benefit of having a control group as well as an active fleet.

The pilot test showed that although driver acceptance was mixed, there were large reductions in near-miss events for CAWS-equipped buses. Consequently, achieving driver acceptance will be a key factor in continued development and deployment of CAWS. As a result of comments received from the drivers, the vendor has begun a program to incorporate desired modifications to the system including reducing false positives. The study also showed that supervisors, drivers and maintenance personnel should be involved in product development, trained in how to use CAWS, and educated in how CAWS can directly benefit them by reducing their risk of collisions.

A second major factor in achieving industry acceptance is to demonstrate the business case for CAWS to both transit agencies and system developers. Transit is a niche market compared with autos and trucks. Consequently it is necessary to demonstrate the profit potential within the transit market to attract developers and capital. Part of this effort should be to stimulate and support the necessary research and development. Although the pilot project produced encouraging results, collisions, injuries and fatalities can be considered "rare events." A much larger in-service test will be needed to demonstrate actual cost-savings.

LESSONS LEARNED

Testing of the pedestrian detection and warning features involved individuals walking toward the bus while it is in motion. This involved significant risk of injury. A better testing procedure is urgently needed, along with a set of specifications for a more robust system testing mode to simulate both bus movement and turning.

WSTIP greatly facilitated the historical claims research by opening its claims database and obtaining claims data for other transit agencies. Without access to detailed claims data it would have been extremely difficult to estimate cost-effectiveness for the CAWS. However, working with the claims data proved challenging, first due to the volume, second due to the fact that most claim descriptions required the researcher to make a subjective interpretation of whether the claim could be prevented by CAWS, and third because claims were not always entered into the expected categories. Careful review of historical claims and the data acquisition and entry process is needed.

Gaining driver acceptance of new technologies and seeking their participation in testing new products is a challenge. Driving a bus requires skill and concentration. Warning indicators that divert attention from the driving tasks at hand are viewed as distracting and annoying. After initial development and testing in non-revenue operation, the path to deployment of CAWS requires testing in revenue service. Drivers need to be thoroughly trained on the technology and be able to have input to product development. In addition, drivers should be made aware of the potential positive benefits of CAWS to them.

Bus drivers who are involved in collisions are at risk not only of being injured but of having their careers disrupted and losing income. When collisions occur, the driver may feel that he or she "is guilty until proven innocent." Drivers are escorted under supervision to drug and alcohol testing and may fear being out of service due to injury or disciplinary action. Technology can have a positive impact on drivers by reducing the potential for them to be involved in collisions.

OVERCOMING BARRIERS TO DEPLOYMENT OF CAWS

The ability of the transit industry to foster private sector innovation in safety technology such as CAWS hinges on the ability of a vendor to bring a new product to market, recover development costs, and make a profit. Without favorable economic prospects, vendors will not have a business case to invest in the transit market. The pilot pointed towards three critical issues: 1. reducing product development costs, 2. determining the cost-effectiveness of the product to potential customers, and 3. providing efficient paths to reduce the cost of the installation.

For this pilot, the vendor was responsible for all expenses above the $2,000.00 per installation subsidy and was at risk for claims that could arise. Each installation required custom fitting for different bus types, increasing the time and expense. Agency scheduling pressures to limit out-of-service time for buses also impacted the ability of the team to efficiently use labor.

To reduce product development costs, this pilot demonstrated two key factors: the ability to absorb risks, and the ability of transit agencies to cooperate with vendors in facilitating pilots. In this instance, leadership by the transit insurance pool enabled the project to move forward. The pool defrayed a portion of the cost as a loss-prevention activity. The insurance pool also provided leadership in working with transit risk managers and agency executives to promote testing of new technology that agencies might otherwise be reluctant to undertake.

It will be necessary to make a business case for acquiring the product to transit managers and the boards of directors that normally approve capital spending. Most transit agencies are public bodies subject to strict procurement and budgeting policies. Spending for capital items such as new technology is budgeted on an annual basis and may be approved in open public meetings. Procurements are often done through competitive bidding. Agency managers and boards generally are required to document in public records the justification for acquisition of new technology. Consequently, there is a need for the pilots to provide a compelling case to demonstrate the potential of the technology to improve safety, cost-effectiveness, and customer service.

Providing efficient paths to reduce the cost of installing the systems leads in two directions: first, retrofitting the system to existing buses and second making it possible to acquire the system installed at the factory for new buses. For efficient bus retrofits, having a trained and skilled team is absolutely essential. There should not be a long time interval between the pilots and fleet installations that would allow skills and knowledge to erode. Specialized tools and parts layout templates can speed the installation process. For this pilot, the CAWS were augmented by telematics systems and video recording systems. Many buses are already equipped with video recording systems and automatic vehicle locators. Developing data interfaces between the CAWS and other systems would eliminate the added expense of installing redundant equipment. Additional documentation of installation and calibration procedures will be needed to train agency personnel on installation and maintenance. Ultimately, CAWS developers should be encouraged to work with bus manufacturers to enable factory installation of CAWS on new buses, especially through development of specifications for locating cameras and displays.

GLOSSARY

AEB	Autonomous Emergency Braking
CAWS	Collision Avoidance Warning System
FCW	Forward Collison Warning; speed > 19 mph
FN	False Negative – a pedestrian seen on video with a TTC of 2.5 seconds, with no CAWS warning
FP	False Positive – a warning sent by the CAWS with no imminent pedestrian collision seen on video
FTA	Federal Transit Administration
HMW	Headway Monitoring – alerts and warnings displayed when a vehicle is present ahead of the bus
HOG	Histogram of Oriented Gradients – an algorithm for identifying pedestrians on video
IDEA	Innovations Deserving Exploratory Analysis
Near-Miss	A pedestrian or vehicle with a TTC of 2.5 seconds or less that does not collide with the bus
NTD	National Transit Database – an on-line FTA data repository for individual US transit operators
PCW	Pedestrian Collision Warning – warning of a pedestrian with TTC of 1.0 second or less
PDZ	Pedestrian Detection Zone - TTC between 1.0 and 2.5 with yellow indicator but no audible alert

STAR Lab	University of Washington Smart Transportation Applications and Research Laboratory
Stealth Mode	CAWS operating mode to collect data while not generating warnings to driver
Telematics	Transmission of data from vehicle via 3G cellular telephone
TRB	Transportation Research Board
TTC	Time To Collision
UFCW	Urban Forward Collision Warning; speed 0 to 19 mph
WSTIP	Washington State Transit Insurance Pool

EXPERT REVIEW PANEL

EXPERT REVIEW PANEL MEMBERS

John Toone, ITS Program Manager, King County Metro Transit (Chair)
Mike Burress, Risk Manager, Community Transit
Jessie Harris, Esq., Managing Director, Williams Kastner
Rob Huyck, Risk Manager, Pierce Transit
Danielle Julien, Recording Secretary/Safety Officer, Amalgamated Transit Union, Local 1576
Terry Lohnes, Senior Manager of Safety & Training, C-Tran
Louis F. Sanders, Senior Director Engineering Services, American Public Transportation Association
Paul Shinners, Finance Director, Kitsap Transit
Jim Thoelke, Safety and Training Supervisor, Ben Franklin Transit

COMMENTS

A teleconference was held on May 5, 2017 to receive comments from the panel members. The panel members had several comments on items that required clarification and typos or errors in numbers that needed correction. The panel commented that they were uncomfortable with one sentence by the author that was editorial in nature. All noted errors have been corrected and all comments by the panel have been addressed in this draft.

The panel chair, John Toone, provided the following overall comment: "I wanted to reiterate what I said at the beginning of this meeting. I am very pleased with this report. It is very professional. You achieved very good results that have practical applications which is great to see. I appreciate everyone's work that was on the team. I see contribution across the board."

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