# ACTIVE SAFETY-COLLISION WARNING PILOT IN WASHINGTON STATE

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## ABSTRACT

This paper documents a project to test bus collision avoidance warning systems being performed by Pierce Transit under the auspices of the Washington State Transit Insurance Pool (WSTIP) and the University of Washington under a grant from the Innovations Deserving Exploratory Analysis (IDEA) program of the Transportation Research Board. Commercially available collision avoidance warning systems (CAWS) were modified and adapted by a vendor for use on standard transit buses and installed on 38 buses operating at eight transit agencies, including seven buses at Pierce Transit. Each bus also was equipped with a cellular telematics unit and supplemental cameras with video recording. Buses were operated in normal service for several months, including a three month testing and data collection period**.** The paper discusses the rationale for the project, technology to be tested, operations and data collection, and some of the early findings from the pilot test**.**

## INTRODUCTION TO PIERCE TRANSIT

Pierce Transit (PT) provides public transportation services in the urbanized area of Pierce County, WA, Washington's second largest county. This area includes the City of Tacoma; and the communities of Edgewood, Fife, Fircrest, Gig Harbor, Lakewood, Milton, Puyallup, Ruston, Steilacoom, Tacoma, University Place; portions of Auburn and Pacific; and some unincorporated portions of Pierce County. The service area population is 557,069.

The service area, located 35 miles south of Seattle, provides critical connections to these employment, education, and commerce epicenters in the region: The Cities of Tacoma, Seattle and Olympia (the State Capitol); SeaTac International Airport; Joint Base Lewis-McChord; and a number of universities and hospitals. We also serve the Puyallup Tribe of Indians, providing service to the tribal healthcare center, youth center, a new business center, and the largest employment center, the Emerald Queen Casino.

PT directly operates local fixed-route service and a portion of its Americans with Disabilities Act (ADA) complementary paratransit service, known as SHUTTLE. Additional SHUTTLE service is operated under contract by First Transit. The SHUTTLE fleet is 100 vehicles, 36 operated by PT and 64 by First Transit. PT has an extensive vanpool program, using about 380 12- and 15-passenger vans and minivans. In addition, PT, acting as a contractor to Sound Transit, the regional transit provider, operates fixed-route express bus service using Sound Transit vehicles.

The fixed-route fleet is comprised of 204 vehicles of various types, including expansion vehicles due to arrive in the first quarter of 2017. The fleet mix includes these buses: 30- and 40-foot compressed natural gas (CNG), 40-foot diesel-electric hybrid, 40-foot diesel, and 25-foot CNG and gas-powered cutaway vans. PT is the recipient of a 2016 FTA Low or No Emissions grant and will order our first electric buses in 2017. The number of buses required for peak service is 119 at present.

PT operates a network of 36 local fixed routes connecting riders to the Tacoma Dome Station, a multi-modal transit center with direct connections to the City of Seattle, SeaTac International Airport, Link Light Rail, Greyhound bus and the Puget Sound Ferry System, the largest ferry system in the U.S.

Financial and operating statistics for 2015:
Unlinked Passenger Trips: Fixed Route 9,104,337, Paratransit 368,411, Vanpool 849,159.
Revenue Hours: Fixed Route 388,736, Paratransit 166,951, Vanpool 143,234.
Operating Expenses: Fixed Route $56,495,424, Paratransit $17,347,909, Vanpool $4,182,296.

Over ten years, Pierce Transit has experienced 91 incidents resulting in 109 injuries, and incurred $11.1 million in claims. WSTIP data show that 94% of claims are attributable to collisions and sudden stops. Potential savings in claims for Pierce could be up to $1 million per year.

**RATIONALE FOR THE PROJECT**

The Washington State Transit Insurance Pool (WSTIP) is an organization providing risk management 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. In this role, WSTIP is acutely aware of the magnitude of the problem of bus collisions and the ensuing losses they create. We examined 282 closed WSTIP member claims for spanning January 1, 2006 - December 31, 2015 as seen in Table 1 below. Major findings include:

- 100% of fatalities (6 total) were collision-related (vehicle, pedestrian, and bicyclist)
- 88% of injuries (335 total) resulted from collisions or sudden stops
- 94% of claims ($24.9 million total) resulted from collisions or sudden stops

WSTIP applied for, and was awarded, a grant from the TRB's transit IDEA program. Additional funding is being contributed by Munich RE America, a worldwide reinsurer, Government Entities Mutual (GEM), a captive reinsurance company for public entities throughout the United States, and Alliant Insurance Services, an insurance broker focused on public entities.

**TABLE 1.**
**Tabulations of Washington State Transit Insurance Pool (WSTIP) Closed Claims Greater Than $10,000 by Type of Claim for Eight Largest Fixed Route Operators – from January 1, 2006 to December 31, 2015 - Run March 31, 2016. – Source: WSTIP**

| | Incidents | Total Claims $ | % of Total Claims $ | Average Claim $ | Fatalities | Injuries | Fatal + Injured |
|---|---|---|---|---|---|---|---|
| Collision with Other Vehicle | 174 | 11,834,203 | 47 | 68,013 | 2 | 212 | 214 |
| Collision with Person | 18 | 6,476,442 | 26 | 359,802 | 3 | 15 | 18 |
| Collision with Bicyclist | 2 | 2,436,701 | 10 | 1,218,350 | 1 | 0 | 1 |
| Non-Collision - Sudden Stop | 30 | 1,645,612 | 7 | 54,854 | 0 | 38 | 38 |
| Non-Collision - Board/Alighting | 36 | 1,345,139 | 5 | 37,365 | 0 | 29 | 29 |
| Collision with Fixed Object | 8 | 878,405 | 4 | 109,801 | 0 | 29 | 29 |
| Non-Collision – Slip/Fall/Trip | 9 | 233,656 | <1 | 25,962 | 0 | 8 | 8 |
| Other | 5 | 90,232 | <1 | 18,046 | 0 | 4 | 4 |
| Totals | 282 | 24,940,390 | 100 | -- | 6 | 335 | 341 |

The IDEA grant and insurance company contributions funded the program to install collision avoidance warning technology on 35 buses at seven participating transit agency members of WSTIP in the state of Washington, and three additional buses at King County Metro, the major transit provider for the Seattle area. The project includes a comprehensive examination of the total costs of the most severe and costly types of collisions, frontal collisions and collisions with pedestrians and cyclists,  the potential for collision avoidance technology to reduce the frequency and severity of these types of collisions, and reduce the associated casualty and liability expenses.

**PROJECT OBJECTIVES**

The project was conceived with the following objectives in mind:

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

In addition to the stated objectives, the project team was asked by the sponsor to test the effectiveness and accuracy of the CAWS in terms of generating false positive warnings and false negative warnings. Subsequent to the initiation of the project, the vendor provided an additional unanticipated set of data analytics for logging events per mile.  That will enable the team to test the hypothesis that as drivers gain experience with the CAWS-equipped buses, they may be better able to anticipate adverse driving conditions, which would be reflected in fewer events per miles logged.

Pierce Transit has been operating seven (7) buses equipped with the Shield+ Collision Avoidance Warning System (CAWS). Five of the systems at Pierce were installed in August-September 2015 and the remaining two were installed in February 2016. A three-month data collection and reporting period

Systems were installed on 38 buses spanning a period from August 28, 2015 to March 17, 2016.  Figure 2. is a diagram that illustrates the locations of the system components on a typical bus.  Procurement of

was run from April 1, 2016 through June 30, 2016. During that period Pierce buses logged 52,000 miles with CAWS, accumulated an estimated 3,600 hours of video and logged an estimated 2,000 alerts and warnings.

**INSTALLATION AND TESTING OF EQUIPMENT**

The Rosco VQS4560 Mobileye Shield+ System provides coverage of blind zones where vulnerable road users (VRU's) may be hidden from the driver's view, and by alerting the driver to avoid potential collisions.  The system includes four cameras, one facing forward on the inside of the windshield, one covering the blind spot  created by the left front pillar, and one on each side at the rear of the bus to cover blind spots behind the driver.

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. 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.  Figure 1 shows the indicators as they appear to the driver.


***Figure 1.*** **Collision Avoidance Warning System Indicators. [1]**

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.

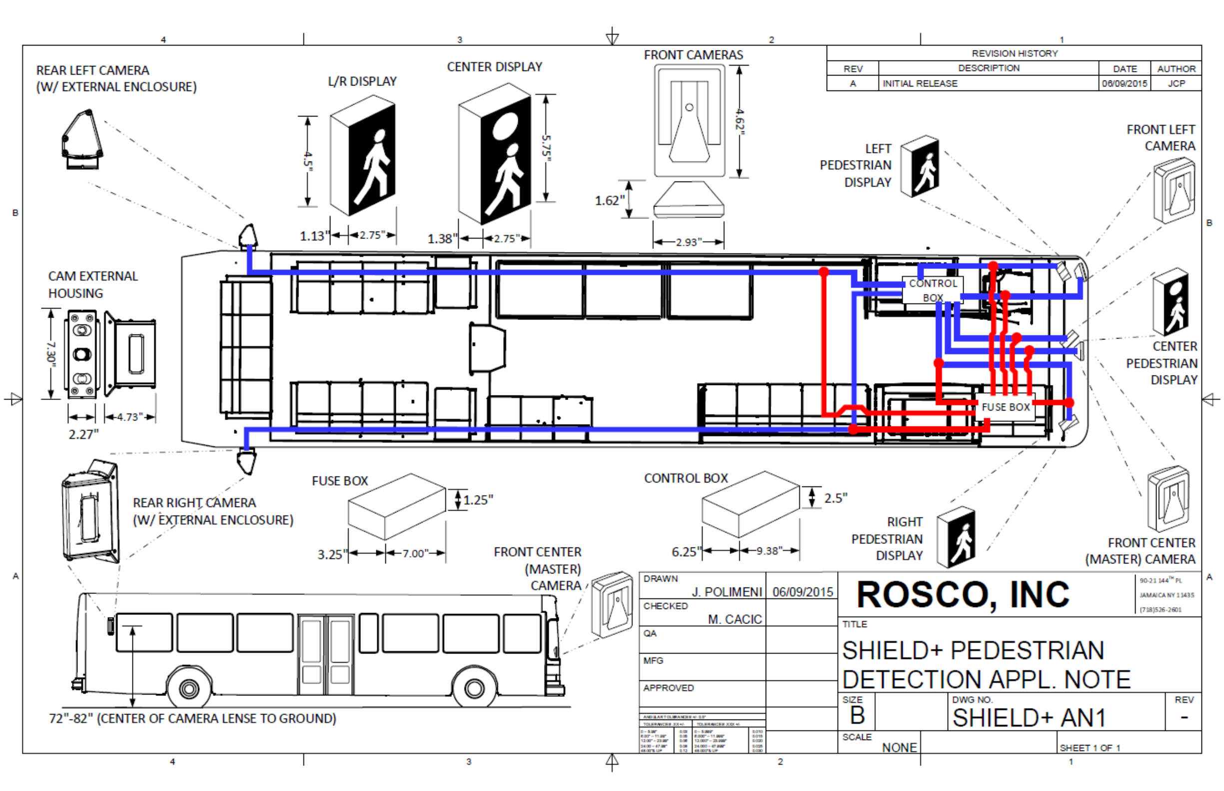


*Figure 2.* **Installation Diagram for Collision Avoidance Warning System. [2]**

Each system was calibrated and tested in non-revenue operation prior to being placed in revenue service.

**MONITORING AND DATA COLLECTION**

The Mobileye Shield+ system does not include video record/playback. For this pilot, Rosco installs Dual-Vision XC camera systems to record continuous video and Ituran telematics units to record time-stamped events triggering the Mobileye Shield+ system.

Once in service, each bus was continually monitored in real time by an Ituran telematics system which sends 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. Three of the 38 buses in the project, including one at PT, experienced communications failures due to faults in the telematics units and did not report data during the test period. The following event data for 35 buses were logged from the Shield+ system:

- Exceeded Speed Limits
- HW (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)

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. 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. This hypothesis is being tested in the pilot.

**GATHER OPERATOR, STAFF, AND PUBLIC REACTIONS TO THE WARNING SYSTEMS**

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.

Operator survey instruments were developed for administration through distribution of paper questionnaires and for direct entry via computer. 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 – 115, May – 85, and June – 75. Because their Shield+ systems operated in stealth mode, Spokane Transit did not administer the survey to its drivers.

Two of the questions that were asked of operators about Shield+ deserve note: 1) was it 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. Operators were encouraged to provide comments on the questionnaires. One hundred seventy eight (178) comments were received.

**ISSUES NOTED IN OPERATOR 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.
- 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 operators complained that the beeps emanating from the system were too loud. Some complained 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 specifically stated that the system is intended for daylight use only. Some operators may not have been made aware of that limitation.
- System inoperative – Some operators 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 operators' perception of a pending collision – Some operators 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 operators commented that headway warnings appeared when they pulled in behind parked cars or when cars pulled into their lane.
- Inaccurate speed limit warnings – Some operators commented that they received speed warnings that differed from the readings on the bus speedometer.

**VIDEO DATA SPECIFICATION AND CAPTURE**

Videos collected by the Rosco Dual-Vision system are in asd format. Rosco provided a converter to convert all videos in one SD card all at once from ".asd" to ".avi". The final .avi files are composed of videos from three channels. As shown in Figure 3, Channel 1 videos are taken by the front-facing camera; channel 2 videos are taken by the windshield-mounted rear-facing camera; and channel 3 videos are split-screen images taken by the external rear left and right side-mounted forward-facing cameras.


***Figure 3*. Left to Right - Images captured by Rosco Dual-Vision: Channel 1 forward-facing, Channel 2 interior rear-facing, Channel 3 split screen left and right external side cameras.**

Video data is downloaded from each Dual Vision camera using 32GB SD cards, which are sent to UW for processing. Video from each channel is 640 × 480 pixels (width × height). One SD card can normally hold up to 2,799 video clips. Video clip duration varies from about 45 seconds to 75 seconds. One video clip is about 10 MB. During the data collection period, 717 SD cards were processed capturing about 10,000 events totaling 16,600 hours and requiring about 19TB of storage.

**Video Processing Framework**

`UW developed a framework for automatically processing the front-facing videos and filtering out most of the frames without events. Another round of manual checking is conducted to further verify the detection results. The proposed detection framework excludes complex background information and attempts to locate the pedestrian directly. Distance calculation to the pedestrian is calculated in 3D real-world coordinates. Our framework 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 4 illustrates the process. In the first stage, a Histogram of Oriented Gradients (HOG) pedestrian detector is used to detect pedestrians within the camera vision. 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. 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, several thresholds such as time to collision (TTC) are calculated to detect near-miss events which can be extracted from video clips.

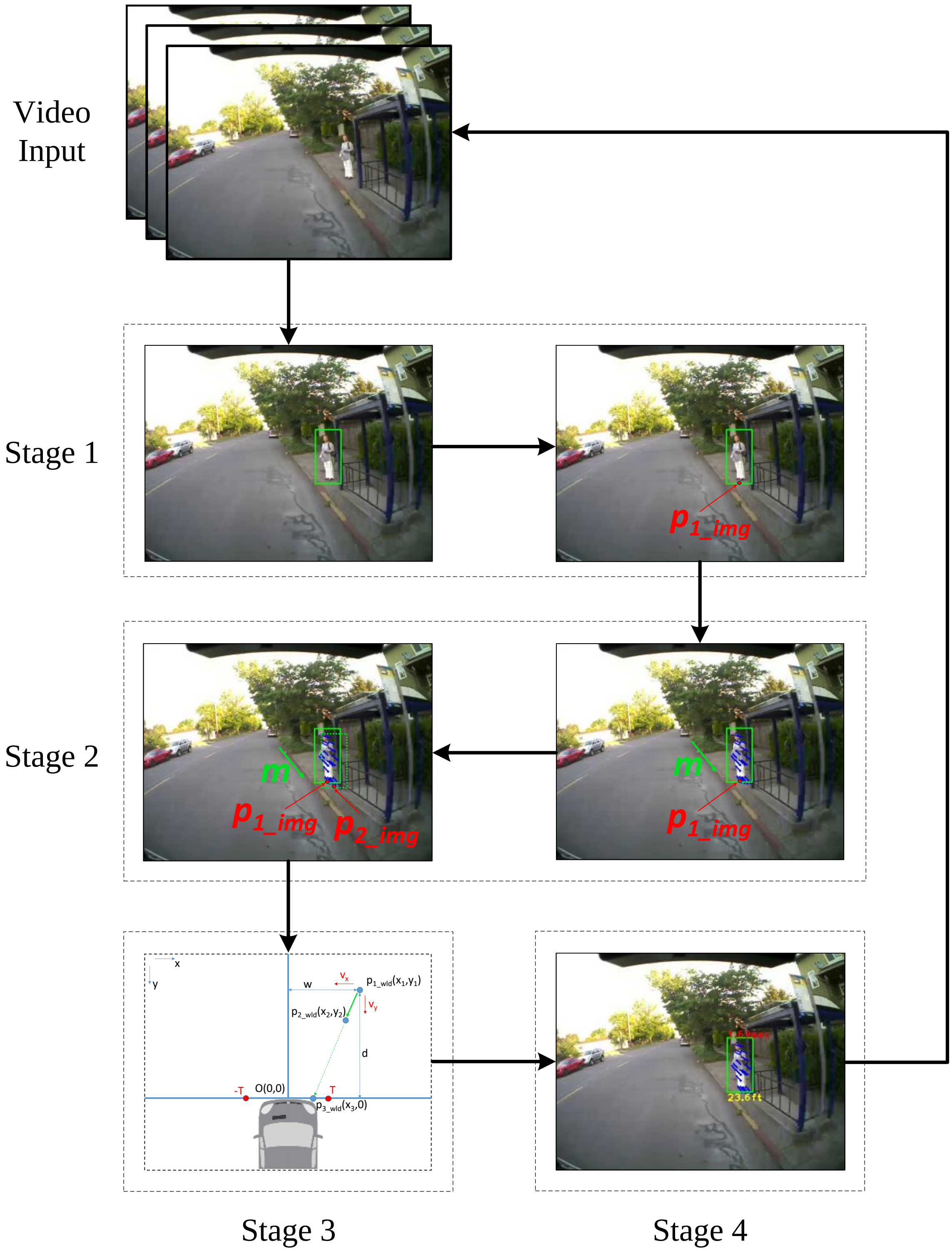


***FIGURE 4.*** **Proposed processing method for vehicle-pedestrian near-miss detection through onboard monocular vision. Four stages are pedestrian detection, motion estimation, relative position and speed estimation, and near-miss detection.**

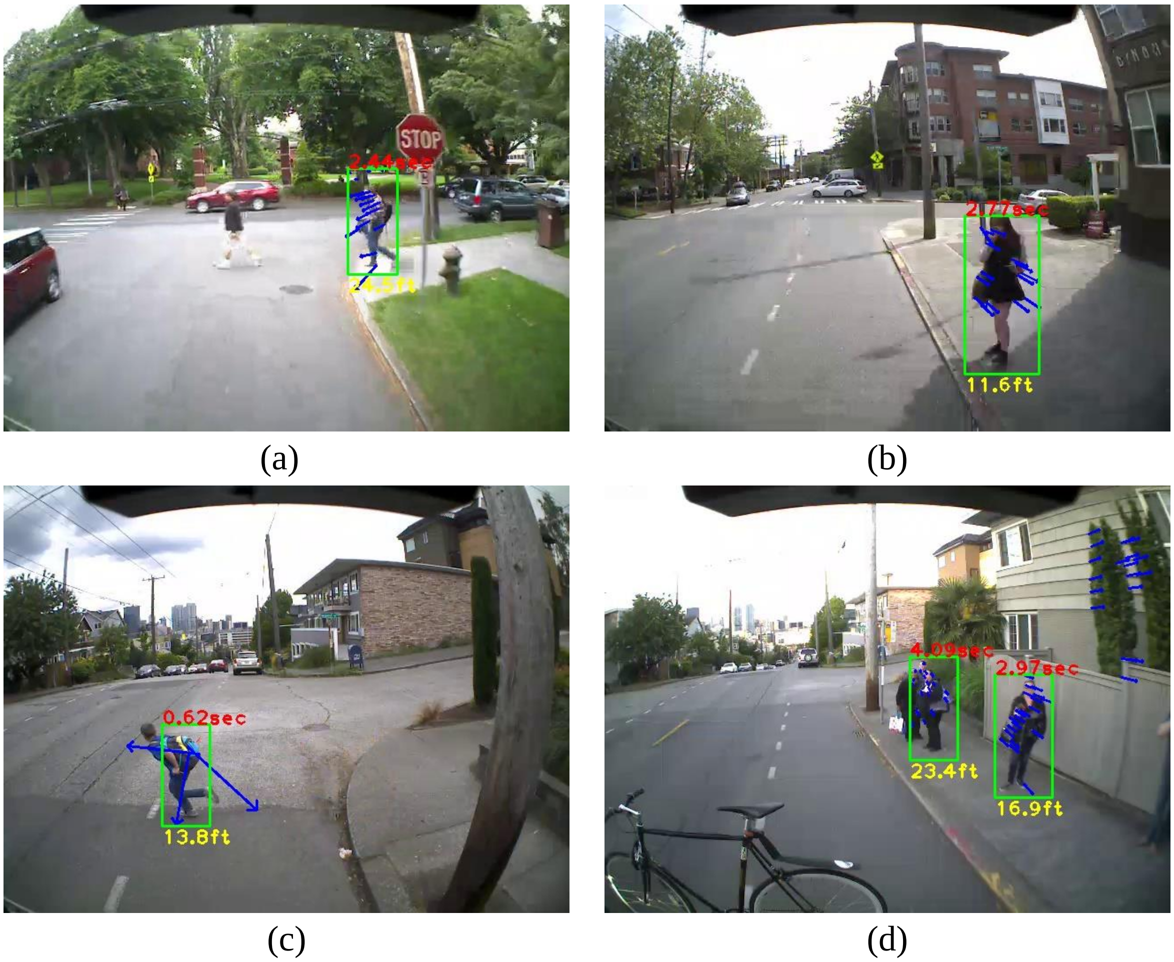


***Figure 5.*** **Sample frames showing detected near-miss events.**

**Validation**

More than 30 hours of onboard video data was used to test the performance of the proposed near-miss detection method. Figure 5 shows some sample frames identified as near-misses. In (a), the vehicle is approaching a stop sign when two pedestrians are crossing the street. One of the pedestrians is detected as having the potential to collide with the bus if no evasive action is taken. In (b), a pedestrian standing at a bus stop is detected when the bus approaches the stop and changes lanes. In (c), an event is detected when the bus approaches a non-signalized intersection and a pedestrian is running to cross the street. In (d), the system demonstrates the ability to detect multiple conflicts at the same time.

**CONCLUSIONS AND RECOMMENDATIONS**

As mentioned earlier in the section on data collection and monitoring, 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 2 shows the comparison for each type of warning.

For each type of warning, there is a discernable reduction in warnings per 1000 miles for the active fleet. Although the data was not recorded for individual drivers, it appears that drivers of buses in the active fleet triggered fewer warnings than those who drive buses in “stealth mode.”

It is possible that the CAWS equipped buses made the drivers more sensitive to conditions that triggered warnings, and they may have been 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.

| Table 2. Comparison of Control Group with Active Fleet for Warnings per 1000 miles | | | |
|---|---|---|---|
| **Warning Type** | **Warnings per 1000 miles** | | |
| | **Control Group** (2 buses 17K mi) | **Active Fleet** (33 buses, 344K mi) | **Active Fleet Reduction** |
| **Speed Limit** | 16.74 | 15.39 | **-8%** |
| **Headway (HW)** | 185.84 | 50.31 | **-73%** |
| **Forward Collision <19 mph (UFCW)** | 317.74 | 96.04 | **-25%** |
| **Forward Collision >19 mph (FCW)** | 10.99 | 6.27 | **-43%** |
| **Pedestrian Collision** | 27.67 | 18.00 | **-35%** |

In summary, key findings from the pilot test are as follows:

- None of Pierce's CAWS equipped buses were involved in any collisions with vehicles, pedestrians or cyclists during the test period.
- Telematics data provided by the vendor indicated that CAWS-equipped buses may have a positive impact on driver performance
- The initial version of the CAWS received mixed reactions in driver surveys, but demonstrated a clear path for product improvements.
- Based on evidence from the pilot test, WSTIP has committed to provide insurance and support for loss prevention activities for continued development and a full-scale deployment of CAWS on all Pierce Transit fixed-route buses.

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 PT 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 our entire fixed-route fleet. PT received notice that the FTA awarded $1.66 million to PT for the project and we are currently working with our partners to complete and submit the necessary documents to initiate the work.

**REFERENCES**

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2. "Shield+ Pedestrian Detection Appl. Note," Rosco Vision Systems, June 9, 2015