

COLLISION AVOIDANCE SYSTEM FOR BUSES, MANAGING PEDESTRIAN DETECTION AND ALERTS NEAR BUS STOPS

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ABSTRACT

The Mobileye Shield+ Collision Avoidance System has been implemented in numerous pilot projects and installations at various Transit Authorities throughout North America. The system uses sophisticated driver scene interpretation to assess the potential for collisions with vulnerable road users. The system can alert the driver about an impending collision. In the area around bus stops, statistics have shown a high rate of injuries and fatalities during bus operations. The FTA National Transit Database shows that between 2008 and 2015, 10.8% of all bus-crash related fatalities and 22.3% of all injuries happened to “People Waiting or Leaving” the bus. The geometry and geography of bus stop areas present challenges as the rate and angle of approach of the bus and the density of waiting passengers can lead to high rates of alerts for drivers as they approach. Higher rates of alerts can lead to drivers ignoring the alerts. The objective of this project is to use data and video to create filtering and improved system performance.

INTRODUCTION

The following paper shows the results of the development that has been done to test warnings of Mobileye Shield+ in various scenarios including bus stops, intersections and other high density locations. The analysis is based on real time testing in certain scenarios in order to improve system performance levels and filter unwanted alerts - aka false warnings or false positives/false negatives.

MOBILEYE SHIELD+ SYSTEM

Mobileye Shield+ is an intelligent blind spot detection system for buses, trucks and heavy goods vehicles (HGV). The system utilizes multiple smart vision sensors and smart angle detection. The combination of the two technologies provides an informational assistance system to the drivers and is activated with sufficient time for the driver to avoid dangerous situations. The Mobileye Shield+ artificial vision is trained to identify vehicles and all vulnerable road users (VRUs) while ignoring inanimate objects. Furthermore, the artificial vision

Sensors of Shield+ are connected to a G-Force system to ensure that the proper parameter combinations are detected (lateral time-to-collision) based on the real time vehicle and VRU trajectories.

The Shield+ system delivers two kinds of alerts based on the severity of the risk of collision and adaptive sensitivity levels.

Danger Zone Detection (Yellow visual only) - indicating that a VRU is present in one of the blind spot zones of the vehicle alerting the driver to act with caution.

Collision Warning (red flashing visual and audio) - indicating that a VRU and the vehicle are on an imminent collision course, triggered when the time to collision (TTC) between the VRU and the vehicle shortens to a critical time, alerting the driver to take immediate action to prevent the collision.

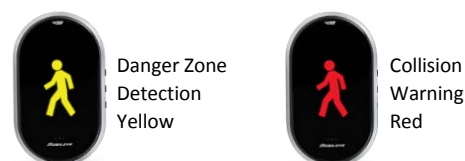


Figure 1. Driver Alert Displays

BUS STOP AND SIMILAR SCENARIOS

Bus Stop Approach

In this scenario, the vehicle is turning obliquely towards the bus stop and straightening quickly. This maneuver contains three distinct scenarios: Driving straight, partial turning and straightening parallel to the bus stop.

As seen in the figure above, the vehicle is approaching the bus stop (position 1), making an oblique right turn (position 2) and straightening away (position 3).

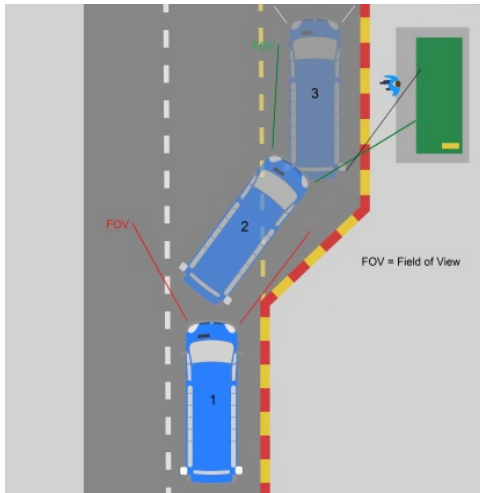


Figure 2. Bus Stop Approach Scenario

Figures 3, 4 and 5 show the scene as the bus approaches a pedestrian waiting at the bus stop. The Field Of View (FOV) is changing accordingly with each position. When about to reach the bus stop (Position 1 as seen in Figure 3), the system recognizes the pedestrian but does not alert as the pedestrian is not at a critical TTC. When approaching the bus stop (Position 2 as seen in Figure 4), the system detects the pedestrian and the TTC reaches the critical threshold due to the bus speed, direction and proximity to the detected pedestrian (Note the red cross is very close to the pedestrian indicating the system sees that pedestrian as being at risk to a direct collision). However, as the vehicle straightens (Position 3 as seen in Figure 5), the TTC drops as there is diminishing danger of collision (Note the red cross is now much further away from the pedestrian).

The same scenario can be seen graphically in Figure 6 below. The graph shows the criticality of the TTC at each position of the vehicle over time.

As the vehicle's position and angle quickly change, the instantaneous TTC criticality becomes irrelevant as the pedestrian is in a danger zone only momentarily.



Figure 3. Waiting Pedestrian as seen while bus is in position 1



Figure 4. Waiting Pedestrian as seen while bus is in position 2



Figure 5. Waiting Pedestrian as seen while bus is in position 3

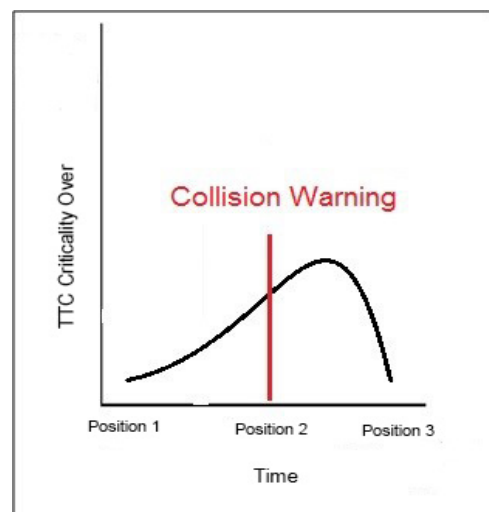


Figure 6. Bus Stop Approach Graph

Left + Right Turns Scenario

This maneuver is very similar to a bus stop scenario but in the opposite direction. As seen in Figure 7, the vehicle starts its journey at position 1, makes a slight left turn at position 2 and then amidst the left turn, the driver changes the course of the vehicle and makes a right turn (turning point) in order to arrive at position 3. Just before the turning point, the Shield+ system detects the pedestrian and determines that, given the current course of the vehicle and the pedestrian, the time to collision (TTC) is shortening critically and consequently alerts the driver with a collision warning. Figure 8 graphically shows the criticality TTC at the different positions within the scenario. (In the same fashion as the bus stop scenario with respect to TTC) The driver in this case as well, does not view the pedestrian as a potential risk since he intends to change course quickly and turn right. Therefore, he interprets the collision warning as a subjectively sensitive warning. The Shield+ System detects a true risk based on the current course while the driver doesn't consider it as a risk.

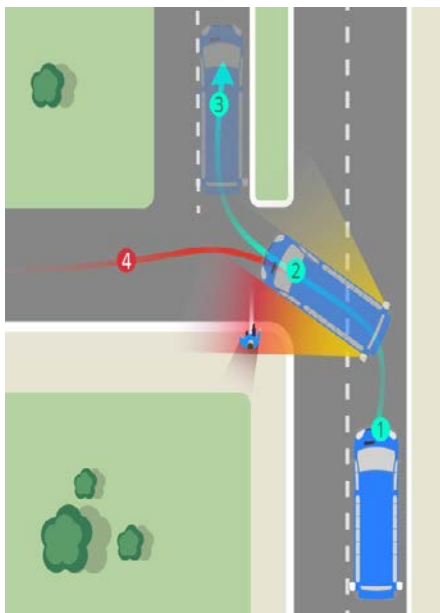


Figure 7. Left + Right Scenario

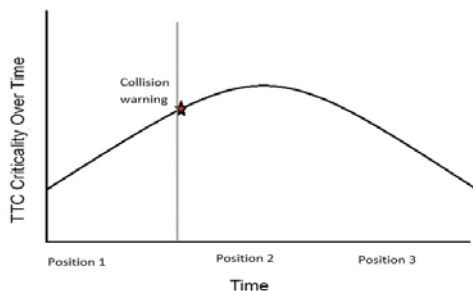


Figure 8. Left + Right Scenario Graph

Cross Walks

Vehicle approaches the crosswalk as pedestrians are crossing. Vehicles may approach with too much speed when approaching the cross walk, thereby creating alerts, sometimes subjectively deemed overly sensitive by drivers.

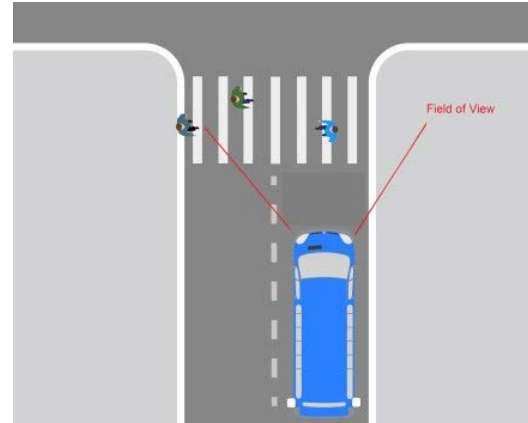


Figure 9. Crosswalk Scenario

Parallel Scenarios

Detection of VRUs when moving parallel to the bus – cyclists may pull up alongside the bus waiting at an intersection. Filtering must be done to provide detection for the driver without providing a warning unless the driver begins a turn. Pedestrians moving parallel to the bus along the sidewalk shall not create a collision warning unless the pedestrian changes direction suddenly.

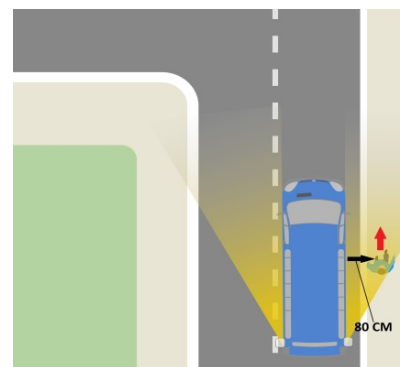


Figure 10. Parallel Pedestrian Scenario



Figure 11. Parallel Bicyclist Scenario

Turns

The Shield+ system must be configured to alert the driver only when the VRU is determined to be on a collision course below the TTC threshold. See Figure 12. Figure 13 illustrates the type of filtration that allows the Shield+ system to ignore pedestrians seen by the system either moving away or parallel to the vehicle but alert on pedestrians moving towards the vehicle.

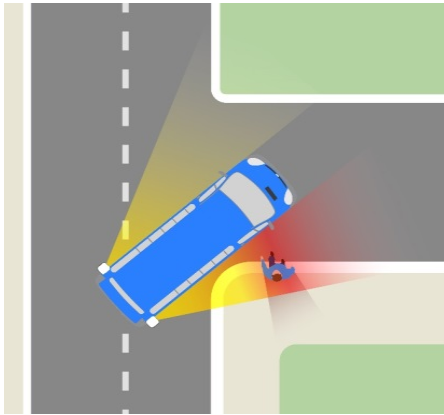


Figure 12. Turn w/ Pedestrian Alert

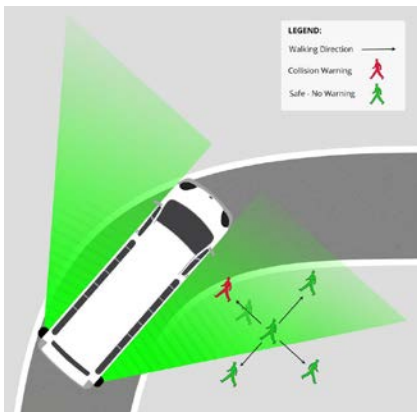


Figure 13. Turn w/ Filtration

PROCEDURE

1. Installation of Shield+ systems together with FMS (Fleet Management System) units in order to capture and retrieve the alerts from the Mobileye Shield+ systems
2. Installation of video recording systems to record and assess the actual scenarios
3. Comparison of results from the FMS unit and real time video
4. Labeling (marking) false alerts
5. Finding a balance by using the adaptive sensitivity levels in order to maximize performance and filter very low risk or irrelevant alerts

ALERT ANALYSIS

Alerts

Accuracy is a key factor in any driver assistance system that is based on detection and warnings to the driver. Such systems should have a low threshold of false alerts assuring that: a) all imminent collisions are truly detected; and b) drivers will not become numb to the warnings and ignore them.

When referring to alerts, the following types should be considered:

Definition

- **Appropriate Alert** – An appropriate alert as described in detail above occurs when the system detects a vehicle or VRU on a collision course with the subject vehicle/bus. If the TTC falls below the pre-determined threshold, the system will alert.
- **False Negative Alert**– A false negative alert is an incident where no collision warning was given although there was an imminent collision course between a VRU and the vehicle (the time to collision between the VRU and the vehicle critically shortens). This type of false warning is due to a failure of the system to detect the collision.
- **False Positive Alert**– A false positive alert is an incident where a collision warning was given although there was no imminent collision course between a VRU and the vehicle (the time to collision between the VRU and the vehicle did not critically shorten or no VRU was present).
- **Subjective Sensitivity Positive Alert** – a subjective sensitivity positive alert is the case when there is a collision course between a VRU and the vehicle, and the time to collision shortens, but due to conservative system definitions regarding possible collisions, the system is set to observe a potential imminent danger in a more sensitive way than the attentive driver perceives or at the same time that the driver perceives the danger. Thus while the system detects and gives a warning of a collision the driver will subjectively not interpret the situation as an imminent collision risk. This disparity must also balance the need for alerts with an inattentive driver.

Analysis

The focus of the analysis in this paper is on driver behavior and driver experience as a user of the system and therefore the main issue for analysis is different types of positive alerts. As described earlier, a false positive alert is an incident where a collision alert was given although there was no imminent collision course between a VRU and the vehicle (the time to collision between the VRU and the vehicle did not critically shorten or there was no VRU present). A low threshold of false positive or subjective alerts is vital to any driver assistance system, in order to assure drivers' confidence and reliance on the system and to avoid drivers becoming numb to the alerts and ignoring them. From analysis of videos and alerts it is apparent that almost none of the false positive alerts that were reported in Shield+ pilots were true false positive alerts; that is to say, that there were a very small number of incidents that a collision warning was provided while there was no VRU in a possible collision course with the vehicle. (less than 1%)

Therefore, the focus of this report are the

Subjective Sensitivity Positive Alerts; meaning that there is a gap in the interpretation of the risk between the driver and the Shield+ system. This gap is mostly due to conservative system definitions regarding possible collisions, setting the system to observe a potential imminent danger in a more severe way than the driver. It is still important to refine the filtering in a way that does not compromise safety in the event the driver is inattentive or distracted.

The Results of the Study

The following table shows the accumulated data of one pilot study in Washington State, indicating for each vehicle the total distance travelled and the number of warnings, their type and from which camera they originate. It should be noted that the trial was done in an urban area, dense with pedestrians, bus stops, cyclists and motorcycles; therefore, the probability of false warnings is higher than on highways or country roads.

Vehicle	Total Mileage	Mobileye PCWRR	Subjective PCWRR	Mobileye PCWLR	Subjective PCWLR	Mobileye PCWLF	Subjective PCWLF	Mobileye PCWF	Subjective PCWF
1	13744.85	18	3	16	1			247	177
2	22044.87	54	2	49	3	2		390	100
3	24644.08	21	1	10	1	1		293	41
4	19801.85	6		5	0			390	97
5	20884.59	3	0	11	1	2		536	132
6	19965.09	42	4	35	2	1		227	28
7	41867.36	2		17	0	1		183	27
8	39578.9	45	5	49	6	2		616	47
9	35495.69	3		87	0			309	39
10	34656.16	25	4	24	0	5		179	63
11	12203.48	30	6	93	14	14		241	80
12	30967.09	15		42	0	1		633	109
13	28806.94	15	1	35	2	18		219	78
14	7635.47	28	1	75	4			202	37
15	5961.19	60	1	5	0			143	16
16	20062.08	2		81	7	7		449	93
17	20099.05	22	2	53	15	5		345	100
18	9364.8	9		150	7			536	168
19	10703.3	35	1	239	13	32		491	134
20	19225.96	29	2	76	11	23		458	161
Total	437712.8	464	33	1152	87	114	0	7087	1727

Table 1. Data from Washington State Pilot

PCWRR	Pedestrian Collision Warning - Right Rear
PCWLR	Pedestrian Collision Warning - Left Rear
PCWLF	Pedestrian Collision Warning - Left Front
PCW	Pedestrian Collision Warning - Front

	Mobileye PCWRR	Subjective PCWRR	Mobileye PCWLR	Subjective PCWLR	Mobileye PCWLF	Subjective PCWLF	Mobileye PCWF	Subjective PCWF	Total Warnings	Total Subjective Warnings
Total Number of Warnings	464	33	1152	87	114	0	7087	1727	8817	1847
Warnings per 1000 Miles	1.06	0.07	2.63	0.2	0.26	0.00	16.2	3.94	20.1	4.21

Table 2. Total & Averages Per 1,000 Miles for the Above Table

The data shows that the total number of collision warnings over the trial period was 8,817. The total number of subjective sensitivity alerts over the trial period was 1,847. The subjective alert rate over the trial period was 20.9%.

The number of collision warnings per 1,000 miles was 20.1.

The number of subjective alerts per 1,000 miles was 4.21.

The following pie charts represent the percentages as described in the tables above:

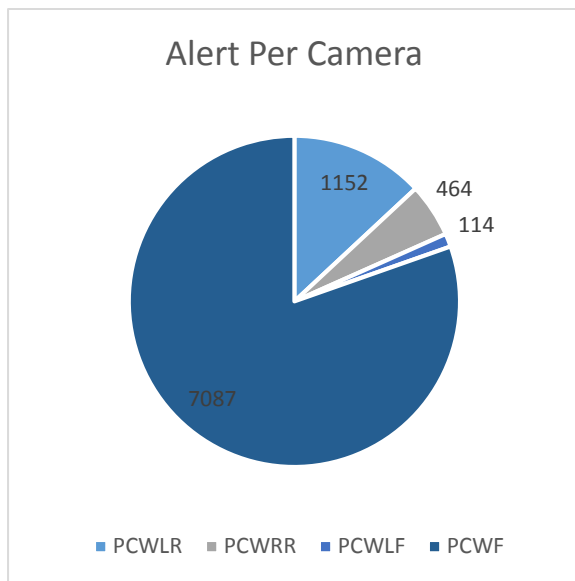


Figure 14. Alerts Per Camera

According to the table and as described in this pie chart, we can see that most of the alerts have been generated by the master camera (PCWF).

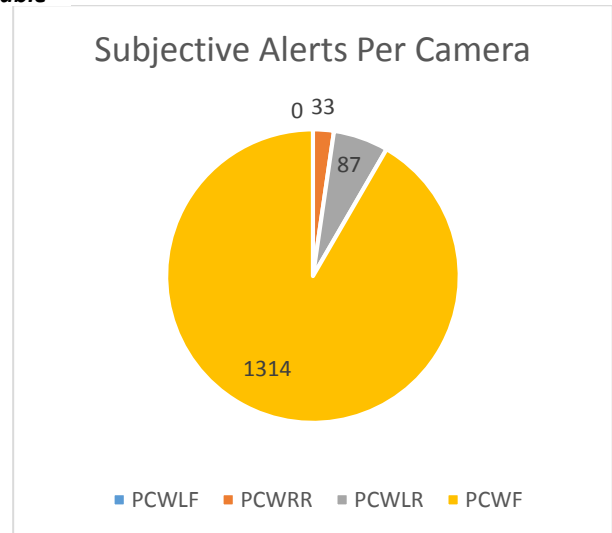


Figure 15. Subjective Alerts Per Camera

This Pie chart indicates that most of the subjective alerts have also been generated by the master camera. This corresponds to the preeminence of bus stop and crosswalk activity in the operation of a transit bus.

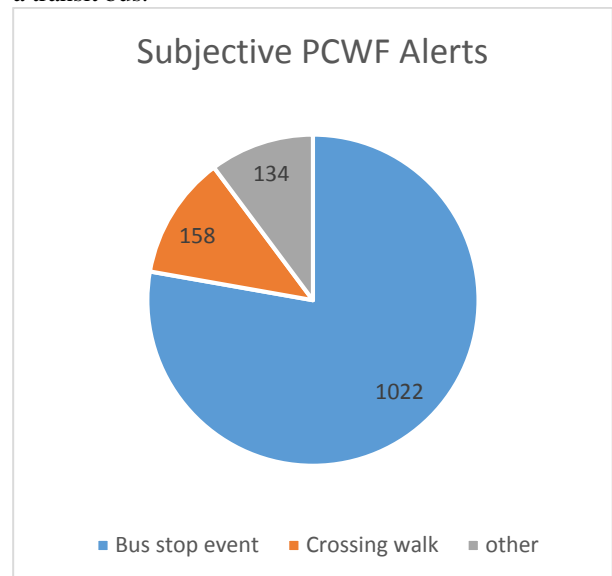


Figure 16. Subjective PCWF Alerts

By reviewing the video data from vehicles in the pilot, we determined that most of the subjective sensitivity alerts have been generated in the bus

stop scenario with the second largest amount coming from cross walk approaches.

RESULTS

Using the above data, we were able to determine that most of the subjective sensitivity alerts were coming from the front camera in bus stop scenarios. When approaching a bus stop, the bus may make a right turn in the range of 45 degrees maximum, and then quickly turn left to come parallel to the bus stop. This pattern together with a dramatic slowdown and the resulting G-forces became a signature to recognize a form for filtration of subjective alerts. We were able to “teach” the system how to filter scenarios by using parameters of view and sensor configuration. We improved performance and detection levels at the bus stop scenario and significantly reduced the pedestrian sensitivity during the maneuver and filtered irrelevant pedestrian detections and warnings. By finding the correct balance the system generates alerts only when appropriate. As a result subjective sensitivity PCWs have been reduced. In most cases those PCWs have been replaced with

PDZ alerts thereby maintaining driver awareness of pedestrians without nuisance audio.

In Table 3 and Figure 17, data is shown from two transit properties in Washington State where the improved algorithm was applied. The resulting reduction in PCWF type alerts was indicative of reduced sensitivity based on the bus stop maneuver filtration.

Transit	Status	Before Algorithm Change	After Algorithm Change	Improvement
Transit A	PCWRR	3.4	1.7	50.00%
	PCWLR	12	2.3	80.83%
	PCWF	51.8	27.1	47.68%
Transit B	PCWRR	6.8	3.3	51.47%
	PCWLR	37.8	22	41.80%
	PCWF	111.4	48.2	56.73%

Table 3. Data from (2) transit properties before & after the bus stop algorithm change.

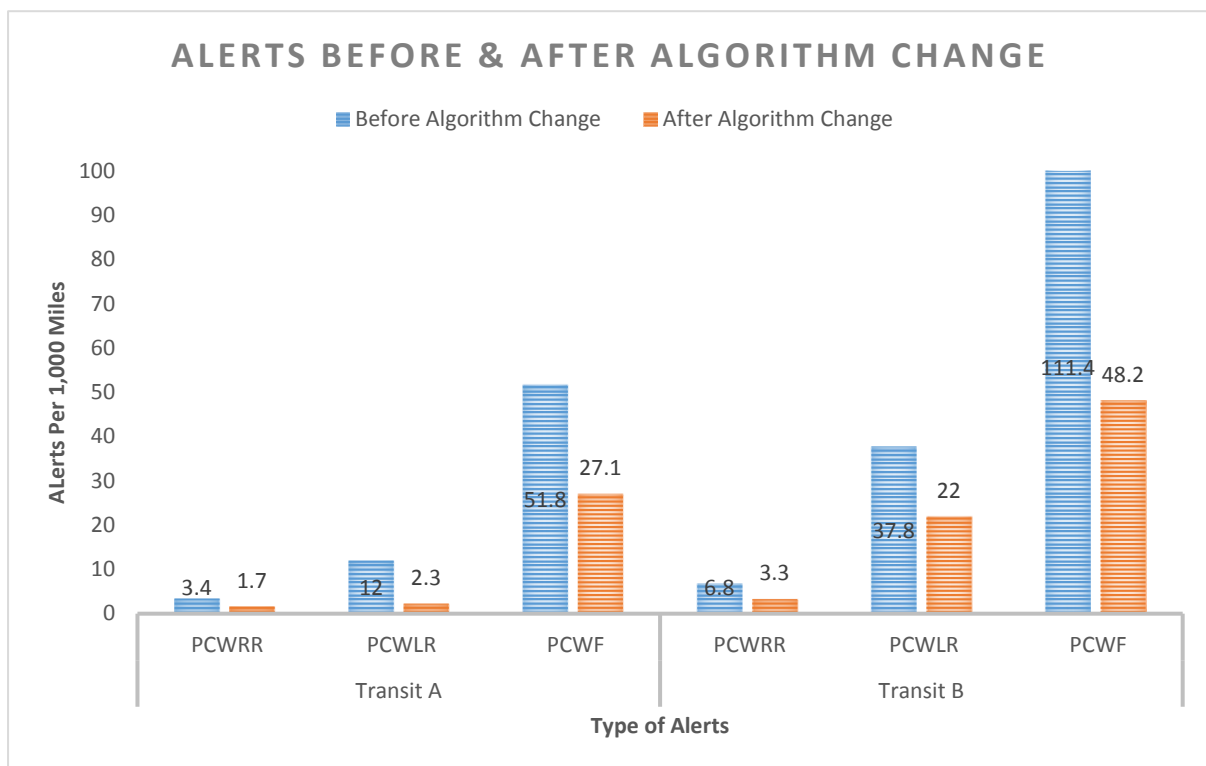


Figure 17. Graphical data from (2) transit properties before & after the bus stop algorithm change.

Figures 18 & 19 show screen shots of video playback before and after the algorithm changes at a specific Washington State transit authority. In the exact same locations with pedestrians standing at

the same bus stop, and with similar approach speeds and angles, the Shield+ system generated a PCWF alert before the change (Figure 18) and a PDZ (Detection alert) after the change (Figure 19).

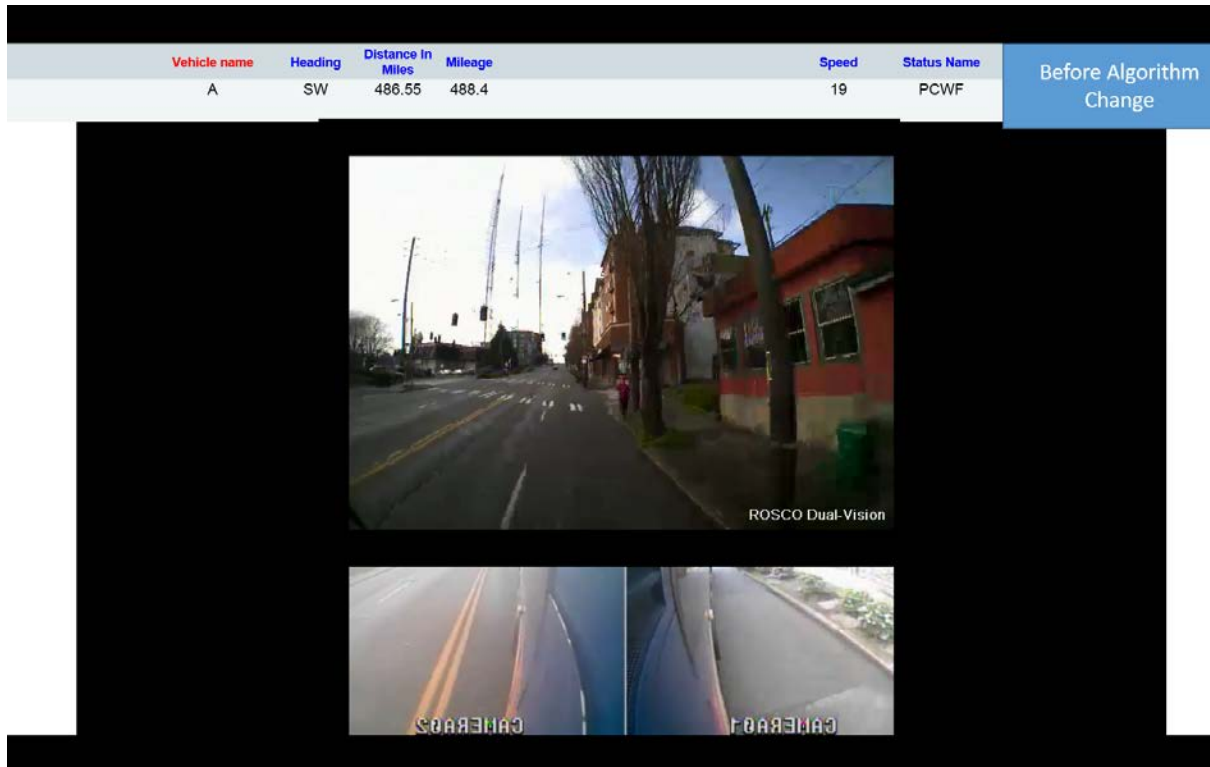


Figure 18. Vehicle A shows PCWF before algorithm change.

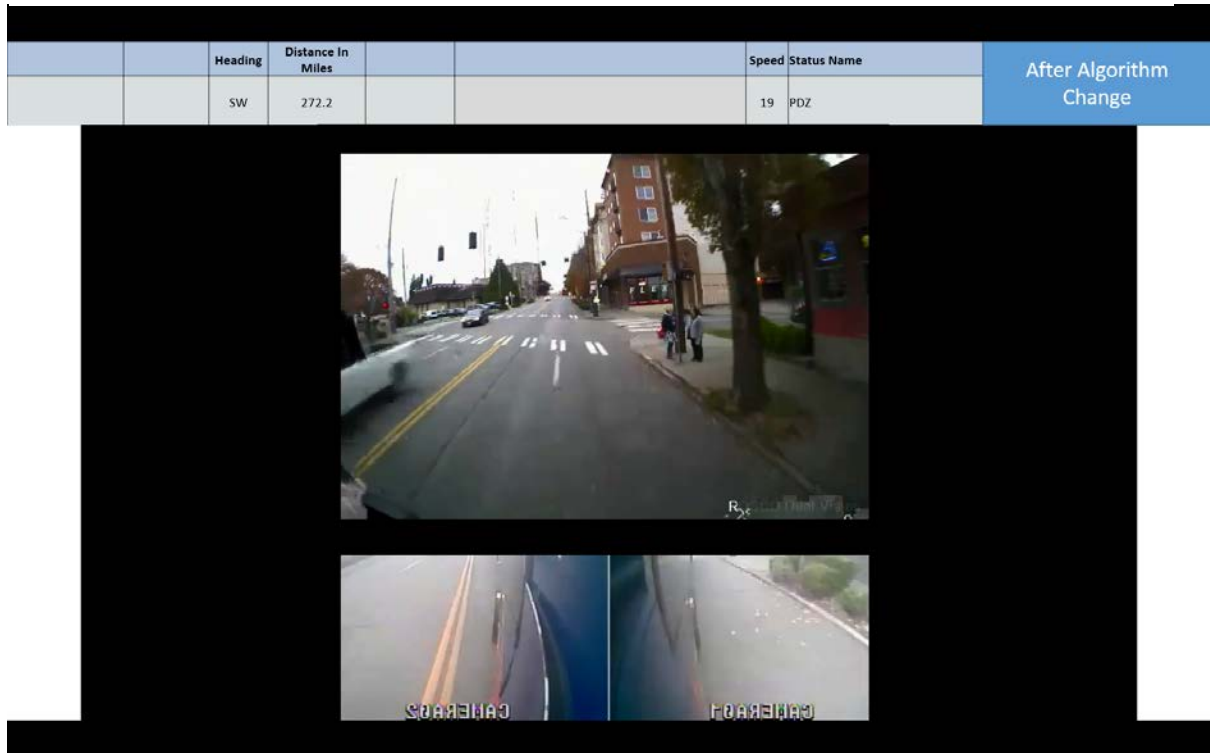


Figure 19. Vehicle A shows PDZ after algorithm change.

The second set of screen shots show the algorithm improvements as they were applied to cross walk approaches. Similarly, the first screen shot (Figure 20) shows a pedestrian crossing in front of an approaching bus at a crosswalk. This situation

generated a PCWF alert before the algorithm change. The second screen shot (Figure 21) shows nearly the exact scenario after the algorithm change. In the second case, the system generated a PDZ (Detection alert).

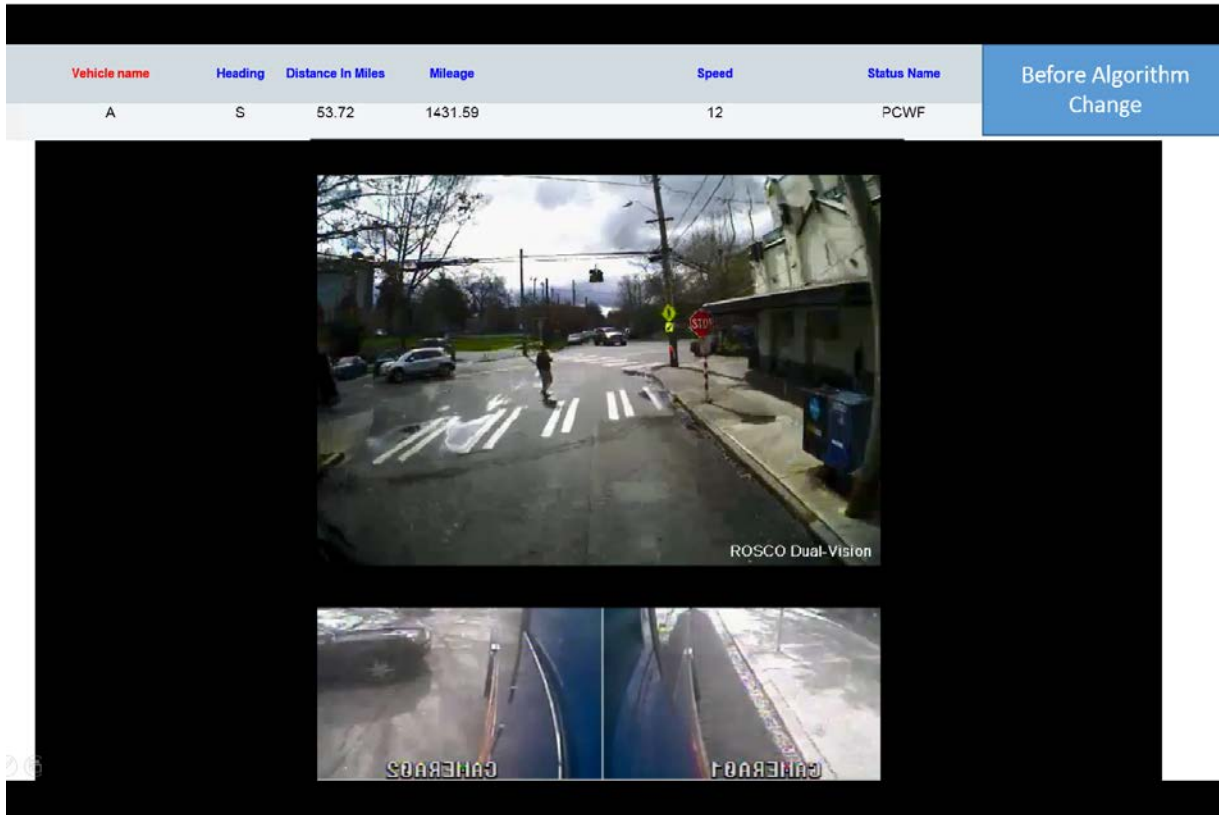


Figure 20. Vehicle A shows PCWF before algorithm change.

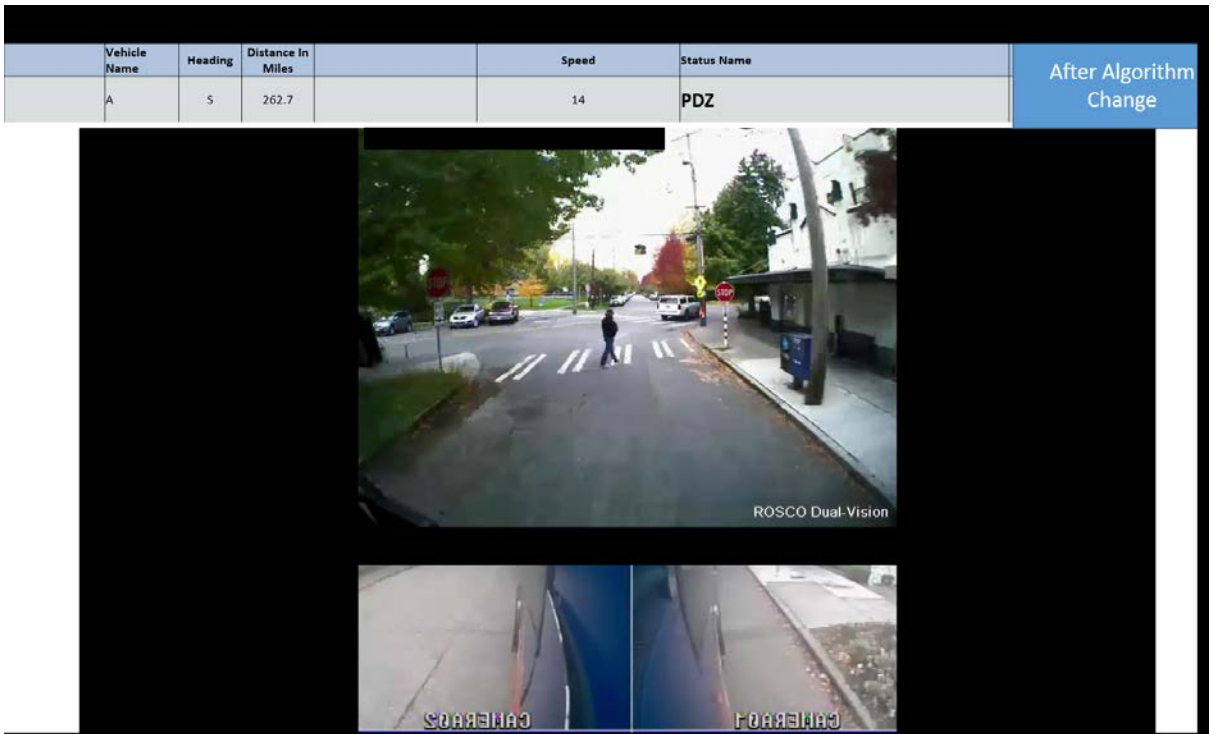


Figure 21. Vehicle A shows PDZ after algorithm change.

CONCLUSION

By analyzing the details of these pilots, we were able to determine that most of the false alerts were subjective sensitivity alerts generated by the master camera when entering a bus stop or approaching a crosswalk.

After filtering, buses that continued operating were found to experience in the range of 50% fewer front PCW collision warnings and as much as a 90% reduction in subjective sensitivity alerts. Other ongoing pilots have borne these results out. Video and data continues to be processed and analyzed. As more video is analyzed, additional results will be provided during the oral presentation and subsequent reports.