Testing of a Vision-Based Pedestrian Collision Warning System on Transit Vehicles

FDOT Project No.: BDV29 TWO 943-07

Final Report

Prepared for

Florida Department of Transportation

By

Lehman Center of Transportation Research
Florida International University

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Metric Conversion Chart

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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16. Abstract
Collision Avoidance Systems (CAS) have the potential for improving transportation system safety including the safety of transit vehicles and pedestrians. Recognizing the importance of improving the safety performance of transit services, FDOT in collaboration with the Miami-Dade County Public Work Department has initiated this research project to evaluate the effectiveness of Mobileye Collision Avoidance Systems (CAS) technologies in addressing transit vehicle-pedestrian and rear-end conflicts and the associated safety problem. The technologies have been tested on Miami-Dade County bus routes with the goal of helping agencies in Florida and around the nation in making decisions regarding investment in CAS technologies, considering the safety effectiveness of these technologies.

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EXECUTIVE SUMMARY

The Florida Department of Transportation (FDOT) has recognized that emerging vehicle technologies and applications such as those associated with connected vehicles (CV) and automated vehicles (AV) hold significant potential for improving mobility and safety in the State of Florida. Applications of these technologies to transit vehicles have always been considered as potential early applications.

One of the issues facing transit agencies is the need to reduce transit vehicle crashes. In addition to the fatality, injury, and property damage costs associated with these crashes; there are additional significant costs to transit agencies including claim payments, legal fees, workers' compensation, and lost productivity. Collisions can also impact bus services, highway traffic, and public perceptions of transit safety. Pedestrian safety is also an important transportation system issue facing transportation agencies. Collision Avoidance Systems (CAS) have the potential for improving transportation system safety including the safety of transit vehicles and pedestrians. In particular, video-based rear-end and pedestrian warning systems have been proposed as the leading technology for CAS.

Recognizing the importance of improving the safety performance of transit services, FDOT in collaboration with the Miami-Dade County Public Work Department (the County) has initiated this research project to evaluate the effectiveness of Mobileye CAS technologies in addressing transit vehicle-pedestrian and rear-end conflicts and the associated safety problem. The technologies have been tested on Miami-Dade County bus routes with the goal of helping agencies in Florida and around the nation in making decisions regarding investment in CAS technologies, considering the safety effectiveness of these technologies.

An evaluation plan was first developed for the project. Various performance measures are proposed in the evaluation plan to assess the safety effectiveness of the installed devices in addressing rear-end and pedestrian's crashes and the user acceptance of the technology. According to the plan, the system would be assessed under both before and after the installation conditions. Under the before conditions, the devices would operate in the stealth mode on all ten buses that were equipped with CAS devices in this study to collect information about the system without the

provision of the alarms to the bus drivers. Under the after conditions, the plan was for the devices on six of the 10 buses to be considered as a "treatment group" providing active alarms, and the remaining four buses to continue operating in the stealth mode, acting as the control group. However, the County moved the buses to a new route for the after conditions. This prevented the team from conducting a before-after analysis. Instead, the evaluation was conducted by comparing the performance measures between the treatment group (five buses with active alarms) and the control group (five buses in the stealth mode) for the after route change period (ARC). The analysis for the stealth mode for the before route change (BRC) was also done and some of the analysis is included in this document, as appropriate. No active mode is associated with the BRC because the buses were moved from this route before there was a chance to activate the devices, as discussed above

E.1 EVALUATION OBJECTIVE AND PERFORMANCE MEASURES

The goal of this project is to assess the safety effectiveness of the installed devices in addressing rear-end and pedestrian crashes and the user acceptance of the technology. The specific objectives and associated performance measures are listed below:

- Objective 1: Assess the system effectiveness in reducing rear-end crashes
    - Performance measure 1-1: Percentage of rear-end safety events that are reacted to by bus drivers
    - Performance measure 1-2: Time headways of participating drivers
    - Performance measure 1-3: Frequency of hard brakes
    - Performance Measure 1-4: Frequency of generated rear-end conflict alerts
    - Performance Measure 1-5: Percentage of accurate alarms
- Objective 2: Assess the system effectiveness in reducing pedestrian and bicycle crashes
    - Performance measure 2-1: Percentage of pedestrian and bicycle conflicts that are reacted to by bus drivers
    - Performance measure 2-2: Percentage of times with conflicting events that driver yields to pedestrian
    - Performance measure 2-3: Frequency of generated pedestrian and bicycle conflict alerts

- Performance Measure 2-4: Percentage of accurate alarms

The hypotheses associated with Performance Measures 1-1, 2-1, and 2-2 are that the alerts provided by the installed devices will improve the driver reactions to events that are determined to be a high risk for collision. The hypotheses associated with Performance Measure 1-2, 1-3, 1-4, 2-3, and 2-4 are that the drivers will start leaving longer time headways and be more careful when approaching leading vehicles and locations where pedestrian and cyclists are expected, as a result of the day-to-day learning with the provision of the alarms.

- Objective 3: Assess the user acceptance of the system
    - Performance measure 3-1: Operator's perception of ease of use
    - Performance measure 3-2: Operator's perception of overall usefulness
    - Performance measure 3-3: Operator's perception of rear-end collision warning effectiveness
    - Performance measure 3-4: Operator's perception of pedestrian collision warning effectiveness
    - Performance measure 3-5: Operator's perception of accuracy
- Objective 4: Assess the ease of the installations and operations of the devices
    - Performance measure 4-1: Issues associated with the installation and operations of the system
- Objective 5: Assess the cost-effectiveness of the technology
    - Performance measure 5-1: the present worth of the technology considering the estimated benefits and costs

E.2 SYSTEM EFFECTIVENESS IN REDUCING REAR-END CRASHES

This section presents a comparison of the performance of the active and stealth mode for reaction to the three rear-end crash warning types given by the tested system, which are:

- **Headway** Warning (HW) indicates that the spacing to the front vehicle has dropped below the safe limit and that the bus operator is advised to reduce the speed and increase the space distance/headway to the leading vehicle.

- Forward Collision Warning (**FCW**) indicates that a rear-end collision is imminent and that the bus operator must stop the vehicle immediately.
- **Urban FCW (UFCW)** are given when there is a very close stopped vehicle in the front and the speed of the subject bus is higher than 0.6 mph.

E.2.1 Percentage of Rear-End Safety Events Reacted to by Bus Drivers

The hypotheses associated with this performance measure is that when the installed devices are active, the number of the bus drivers' reactions to potential threats will increase. Under the stealth mode, the bus drivers are not aware of the alarms, but the researchers are able to obtain the alarm times via the telematics data. The results presented in this section is only for ARC since there is no active mode for the BRC. The driver's reactions were observed from the video clips. The results indicate that there is a minor difference in the reaction between the active and stealth modes with regard to the HW and FCW. However, there was a significant improvement in the reaction to Urban FCW threats with the active mode. When considering all rear-end crash warnings, there was an improvement of 13%, from 67% reaction to 80% reaction, as shown in Figure E- 1. Hypothesis testing indicates that this difference in proportion is significant at the 95% significance level.

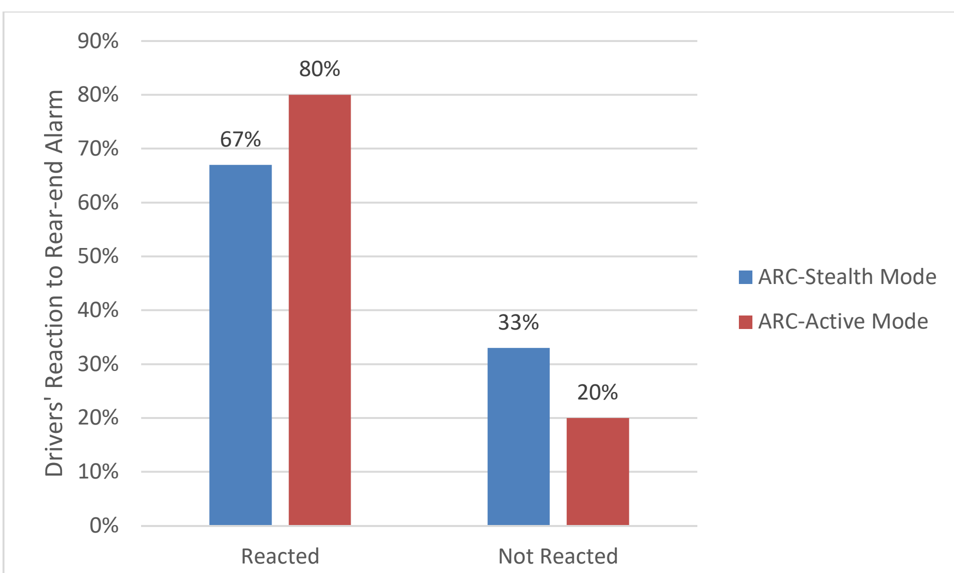

Figure E- 1: Drivers' Reaction to Overall Rear-End Collision Threats

E.2.2 Time Headways and Hard Brakes of Participating Drivers

The hypotheses associated with these performance measure is that when the installed devices are active, the drivers tend to drive in a safer manner as a result of being informed on safer driving behaviors and to avoid getting the alarms. Figure E- 2 shows that the drivers tend to leave longer headways on average with the active mode (1.968 seconds vs. 1.896 seconds, which is 3.8% improvement). Please, note that the system records the headway data only around the time that the warnings are issued. Figure E- 3 shows that the drivers tend to perform the hard brake less frequently with the assistance of the Mobileye system (166 miles per hard brake vs. 105 miles per hard brake, which is 37% improvement).

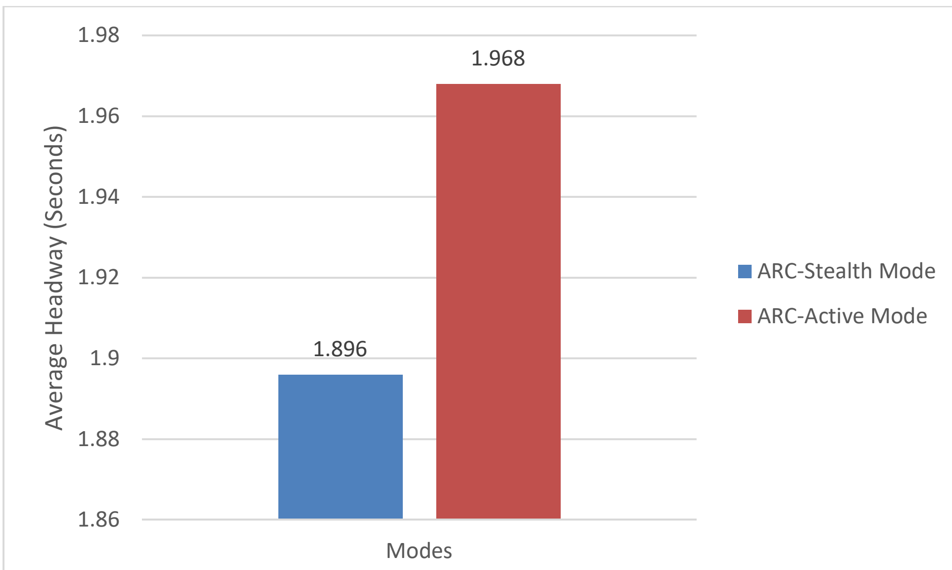

Figure E- 2: Average Headway Comparison between Stealth and Active Modes

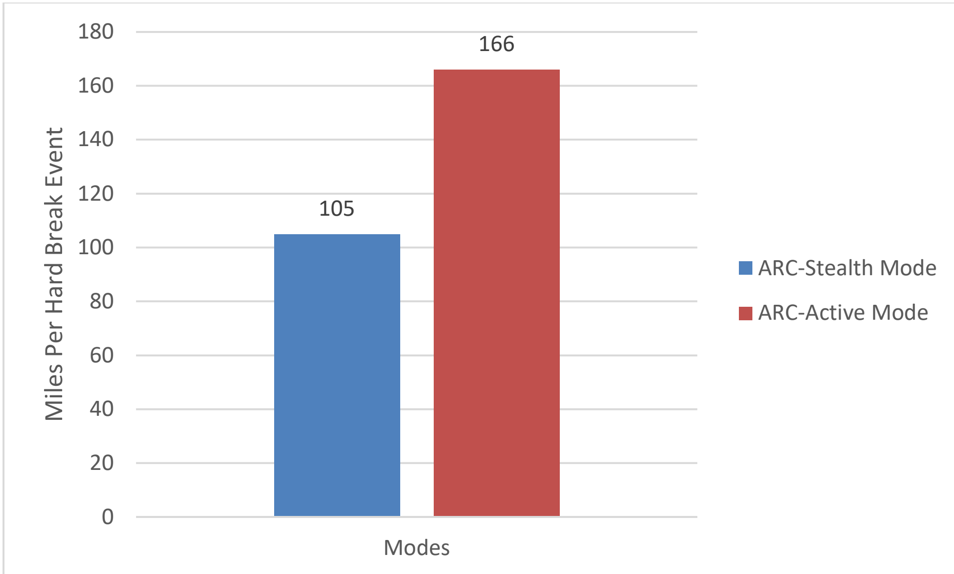

Figure E- 3: Frequency of Hard Brakes in Miles per Hard Brake Event

E.2.3 Frequency of Generated Rear-End Conflict Alerts

The hypotheses associated with this performance measure is also that the drivers will tend to drive in a safer manner as a result of being informed on safer driving behaviors and to avoid the alarms. Figure E- 4 and Figure E- 5 show a significant reduction in the warning with the active mode of all three types of threats. For example, when measured in mile per warning the reduction ranges from 28% (13.6 miles per warning vs. 9.8 miles per warning) to 34% improvement (70.6 miles per warning vs. 46.0 miles per warning), depending on the warning type. The lower number of warning with the active mode indicates more conservative driving.

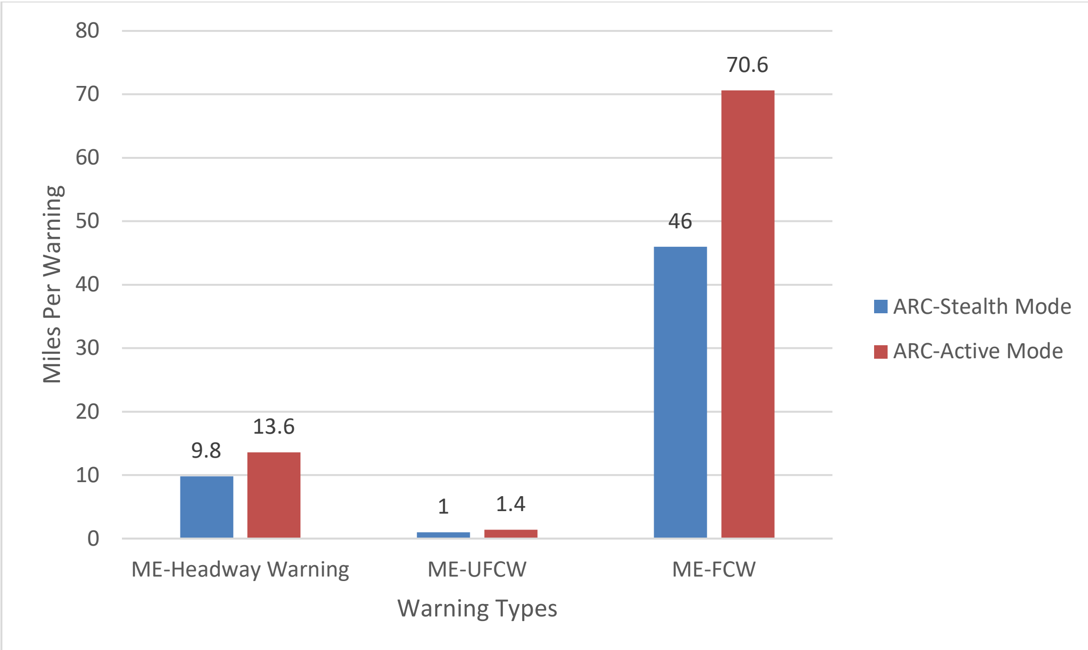

Figure E- 4: Frequency of Rear-End Warning in Miles per Warning

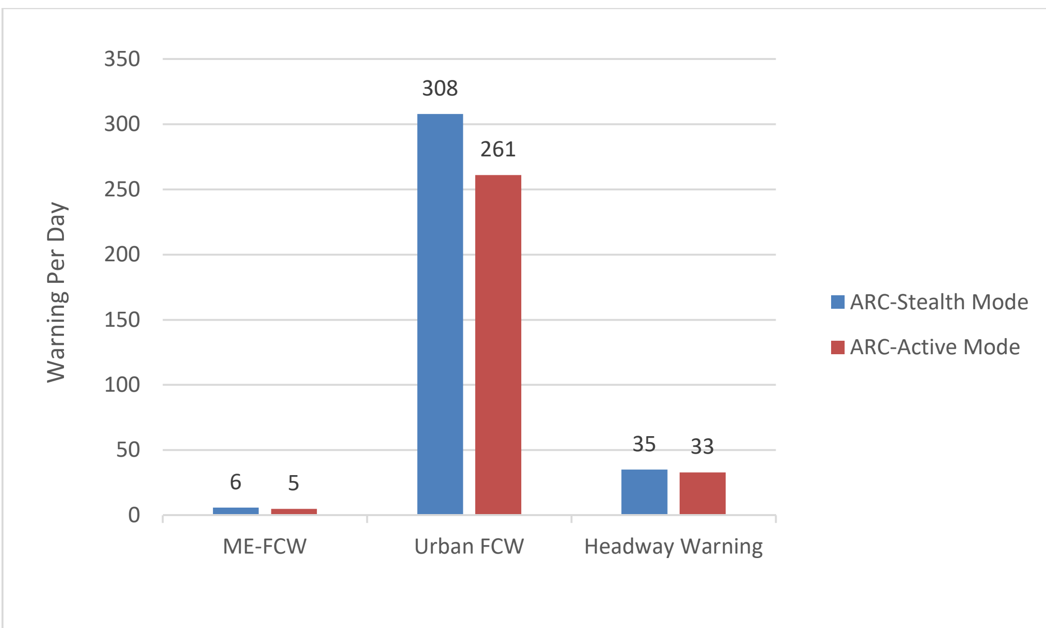

Figure E- 5: Frequency of Rear-End Alarms in Warning per Day per Bus

E.2.4 Alert Accuracy

To estimate the accuracy of the rear-end alarms, 60 videos were downloaded and observed for each of the three alarm types (HW, UFCW, and FCW) for the before changing the route and after changing the route condition. If there was no observed vehicle in front of the bus or the front vehicle was too far from the bus at the alarm time, then the alarm was regarded as a false alarm. Figure E- 6 to Figure E- 8 show the percentage of and false alarms for headway warnings, Urban FCW, and FCW, respectively. After route changing, it can be seen that the percentage of the true alarm is 98%, 98%, and 92% for the three warnings, respectively; indicating a very high accuracy. Before route changing, the corresponding true alarms were 80%, 62%, and 82%; respectively.

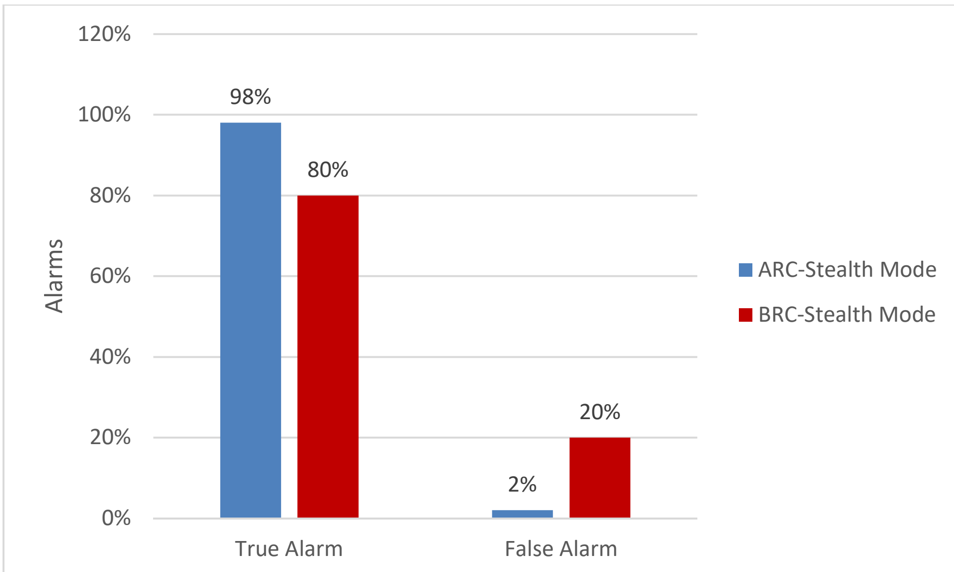

Figure E- 6: Accuracy of Headway Warning

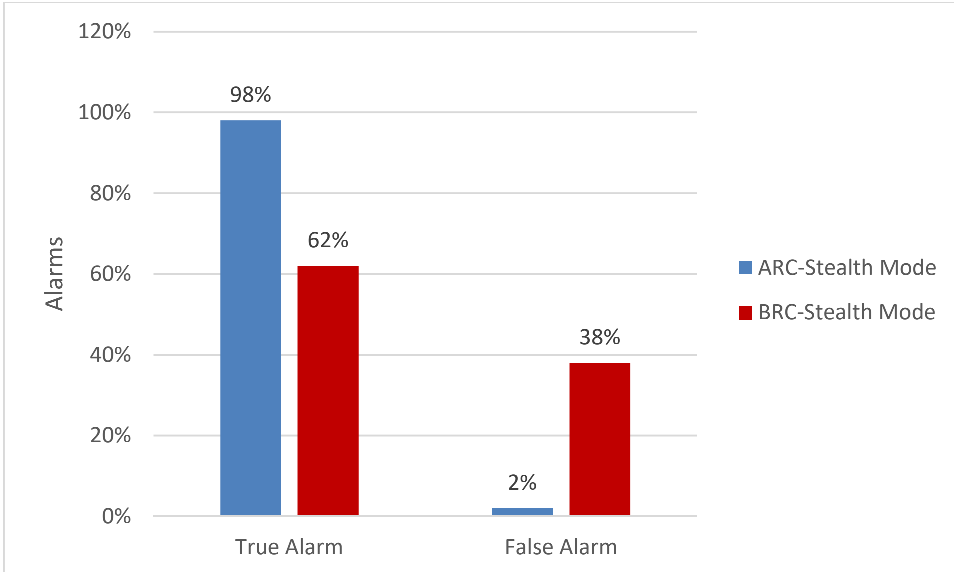

Figure E- 7: Accuracy of Urban FCW Warning

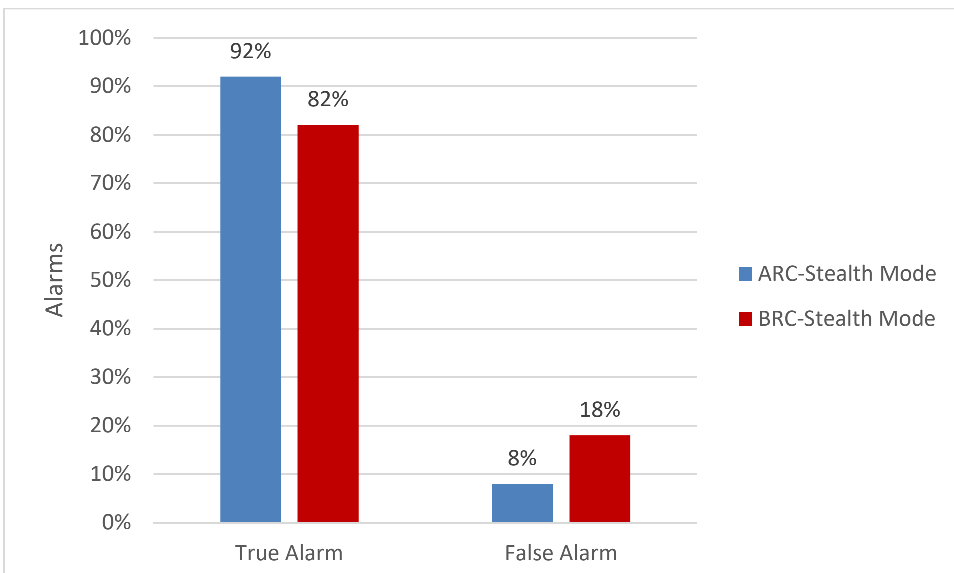

Figure E- 8: Accuracy of FCW Warning

E.3 SYSTEM EFFECTIVENESS IN REDUCING PEDESTRIAN AND BICYCLE CRASHES

This section presents a comparison of the performance of the active and stealth mode for reaction to pedestrian threats.

E.3.1 Percentage of Pedestrian Safety Events Reacted to by Bus Drivers

For the warnings based on the middle front, left front, and left rear cameras; the driver reaction improved from 77% to 98%, 27% to 100%, and 32% to 95%; respectively. For the warning based on the right rear cameras, the reaction was better in the stealth mode compared to the active mode (85% vs. 68%). Overall, Figure E- 9 shows a 26% improvement in the reaction with the active mode (from 46% to 58%). Hypothesis testing indicates that this difference in proportion is significant at the 95% significance level.

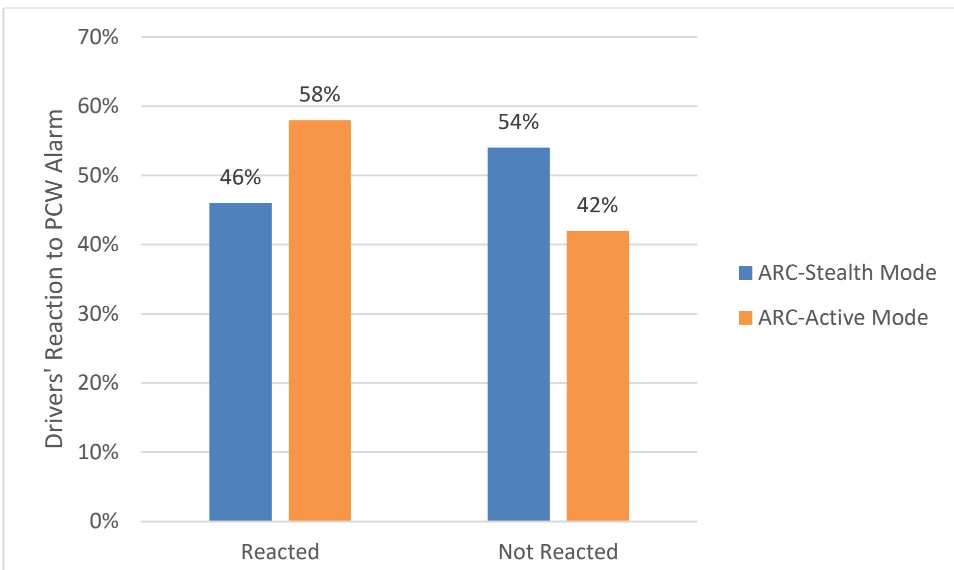

Figure E- 9: Overall Bus Drivers' Reaction

E.3.2 Percentage of Times with Conflicting Events that Driver Yields to Pedestrian.

To further check the bus drivers' reaction to the PCWs, their yielding to the pedestrians who were crossing or intended to cross the streets was also observed from the video clips. For the warnings based on the middle front, left front, right front camera; the driver yielding behavior improved from 29% to 70%, 41% to 94%, and 83% to 87%. For the warning based on the rear-right camera; the yield was 100% in both cases. Overall, Figure E- 10 shows an improvement in the yielding with the active mode (from 58% to 88%). Hypothesis testing indicates that this difference in proportion is significant at the 95% significance level.

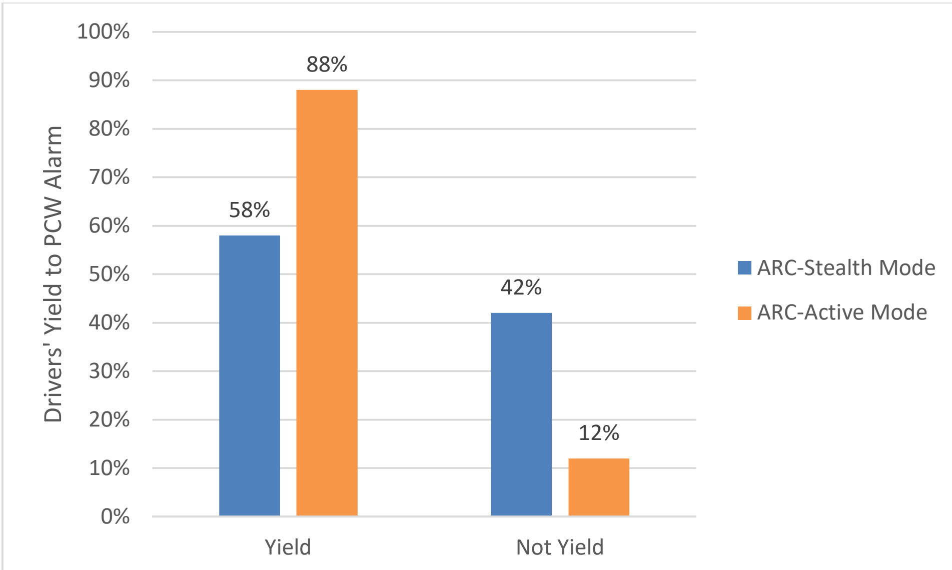

Figure E- 10: Overall Drivers' Yielding to Pedestrians

E.3.3 Number of Generated Pedestrian and Bicycle Conflict Alerts.

This study also examined the number of recorded warning in the stealth and active modes for the PCW. It was determined that the number of miles per warning is 15.9 with the stealth mode and 11.7 with the active mode. The number of warnings per bus per day was 24 with the stealth mode and 23 with the active mode. This indicates that there is no improvement that can be assessed for this measure. This may be due to the fact that pedestrian warnings is less related to driver behaviors and more related to the random activities and behaviors of the pedestrians themselves.

E.3.4 Accuracy

To estimate the accuracy of the pedestrian/bicyclist alarms, 60 videos were also downloaded and observed for each warning category (by camera location). If there is no observed pedestrian in the field of view at the warning time, the alarm is regarded as a false alarm. Figure E- 11 shows the percentages of false alarms for each direction of the warning and for the overall observations. It can be seen that, before changing the route, the warning based on the right-rear and left-front directions have high false alarm rate (45% and 40%, respectively). After changing the route, the false alarms for these two cameras are only 10% and 13%, respectively.

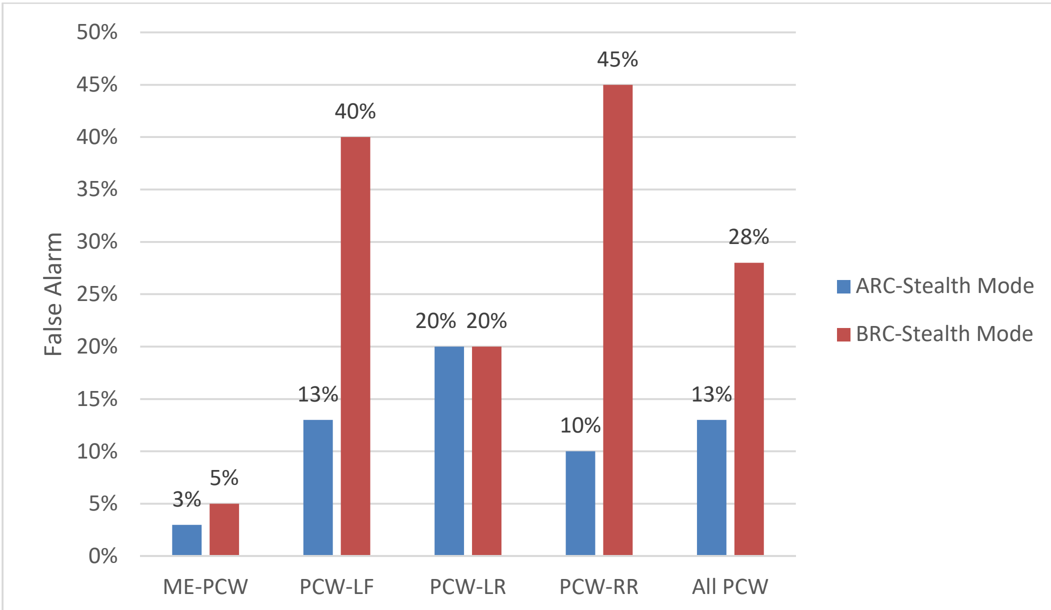

Figure E- 11: Percentage of False PCW

E.4 USER ACCEPTANCE

One of the objectives of this project is to determine the bus operator's acceptance of the system in relation to:

- Performance measure 3-1: Operator's perception of ease of use
- Performance measure 3-2: Operator's perception of overall usefulness
- Performance measure 3-3: Operator's perception of rear-end collision warning effectiveness
- Performance measure 3-4: Operator's perception of pedestrian collision warning effectiveness
- Performance measure 3-5: Operator's perception of accuracy

A survey of the operators that experienced the system was conducted. First, a set of questionnaire was prepared. The questionnaire was sent to a manager in Bus Operations of Miami-Dade County

Department of Transportation and Public Works. The manager distributed the questionnaire list the operators, collected the response, and sent the response back to the research team. Overall, 57 operators filled the survey.

Based on the survey results, it appears that 20%-22% of the drivers liked the system and gave consistently positive responses when assessing the overall system effectiveness, system usefulness, and accuracy. 50-55% of the responder had negative impressions and decided to provide negative responses to most of the questions. 25% to 30% were neutral. 30% to 35% disagreed that the system is easy to use and indicated the need for more training. There may be a need for additional training in future efforts. From the above, the driver acceptance seems to be low but as indicated in the earlier sections there are evidence of positive impacts of the system. The low driver acceptance points to the need for additional outreach and education of the drivers of the system and its effectiveness.

From the above, the driver acceptance seems to be low but as indicated in the earlier sections there are evidence of positive impacts of the system. Thus, the researchers conducted face-to-face interviews with ten bus drivers selected randomly from the drivers that drove the system. Among these drivers, three were very supportive of the system. The remaining were between neutral and negative. Some drivers said that the device make them drive more carefully to avoid the alarms. A number of drivers said that there was a benefit of the blind spot alerts of pedestrian crossing and they like this feature. Some drivers said that the indicators' (visual displays') location need to be optimized. However, a couple of drivers said that some of the sound alarms are too late and need to start sooner. Some drivers pointed to the need to change from the flashing yellow that is displayed under certain conditions to red and to sound alerts earlier. Drivers also indicate the preference for sound alerts rather than visual alerts since they are busy, and it is difficult to pay attention to the visual displays. The low driver acceptance points to the need for additional outreach and education of the drivers of the system and its effectiveness.

E.5 INSTALLATION AND OPERATION ISSUES

There were several issues with the installation and operation of the devices that delayed the project. The issues were mainly related to the coordination with the County Bus Operations Division, calibration of the devices to meet the requirements of the county, and the initial installation of the devices on older buses that did not provide accurate speeds to the systems. All of these issues were eventually resolved

E.6 BENEFIT-COST ANALYSES

An important criterion in the selection and adoption of a technology is the return on investment of the technology. The return on investment analysis is conducted by calculating estimates of the net present value (NPV) or benefit-cost ratio of the analyzed solution. This involves estimating of the present values of the current and future benefits and costs over the project's economic life. A discount rate is used to calculate the present values of the cash flows.

The annual benefits of the Mobileye device per bus was calculated first by estimating the base (do-nothing) number of crashes per year. The base number of crashes was then multiplied by a crash modification factor (CMF), which represents the percentage reduction in crashes due to the device, to obtain the number of crashes that are expected to reduce due to the installation of the device. Finally, the reduction in the number of crashes per year was multiplied by the dollar value of crashes to obtain the annual benefits in dollars. The present worth of the benefits is calculated using an interest rate of 7% and a project life-cycle of five years. The results show that the return on installing the Mobileye system on all the buses in Miami-Dade County may not be cost effective, installing the system on only the buses of routes with high crash frequencies can be justified based on the return-on-investment analysis. The estimated B-C ratios were 1.86 and 1.24 for Route 119 and Route 120, respectively. These are among the bus routes with the highest crash frequencies in Miami-Dade County.

E.7 CONCLUSIONS

The results from this evaluation study indicates that the Mobileye system had a positive effect on improving the reaction time to rear-end and pedestrian conflicts. Overall, the reaction time improved by 13% for rear-end conflicts and a 26% improvement in pedestrian conflicts. Most of the improvement in the reactions to rear-end conflicts occurred with situations in which there was a very close stopped vehicle in the front of the subject bus and the speed of the subject bus is higher than 0.6 mph to 19 mph with an improvement of 21% in this case. Significant improvement in the driver's yielding to pedestrian behavior was also observed.

The study also indicates improvement in driver's behavior as reflected by the reduction in time headways between vehicles, and more clearly by the number of alerts for both rear-end and pedestrian crashes and the number of hard break events. The study also found high accuracy of the system after moving the buses to the new route and re-calibrating the system. Somewhat less accuracy was observed before moving the buses.

Based on the driver survey results, it appears that about 55% of the drivers do not see a value of the system and had negative opinions about the system. The driver acceptance of the system seems to be low, pointing to the need for additional outreach and education of the drivers of the system and its effectiveness.

The results from the return-on-investment analysis show that installing the Mobileye system on every bus in Miami-Dade County may not be cost effective. However, installing the devices on the buses operating on high crash bus routes is cost-effective based on the results of the return-on-investment analysis.

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1 INTRODUCTION

The Florida Department of Transportation (FDOT) has recognized that emerging vehicle technologies and applications such as those associated with connected vehicles (CV) and automated vehicles (AV) hold significant potential for improving mobility and safety in the State of Florida. Applications of these technologies to transit vehicles have always been considered as potential early applications.

One of the issues facing transit agencies is the need to reduce transit vehicle crashes. In addition to the fatality, injury, and property damage costs associated with these crashes; there are additional significant costs to transit agencies including claim payments, legal fees, workers' compensation, and lost productivity. Collisions can also impact bus services, highway traffic, and public perceptions of transit safety. Pedestrian safety is also an important transportation system issue facing transportation agencies. A national report on the subject estimated the annual frequency of pedestrian collisions per 1000 transit buses to be 27 collisions.[1]

In 2015, the state of Florida had the third highest number of traffic deaths (2,939)[2] in the nation and the largest increase in fatalities (445 additional fatalities, an increase of 17.8 percent) among all states. The number of fatalities in Miami-Dade County accounted for the 12 percent of the total fatalities in Florida; having the highest number of fatalities across all population segments including pedestrian and bicycle fatalities in the state. This traffic safety challenges has led to local and regional efforts to improve the safety performance across all transportation modes.

Collision Avoidance Systems (CAS) have the potential for improving transportation system safety including the safety of transit vehicles and pedestrians. Among these technologies, pedestrian collision warning systems on transit vehicles have the promise of reducing transit-pedestrian collisions. In particular, video-based rear-end and pedestrian warning systems have been proposed as the leading technology for CAS with Mobileye being one of the providers of such technologies.

1 Pecheux, K. K., Bauer, J., Miller, S., Rephlo, J., Saporta, H., Erickson, S., Knapp, S., and Quan, J. (2008). TCRP Report 125: Guidebook for Mitigating Fixed-Route Bus-and-Pedestrian Collisions. Transportation Research Board, Washington, D.C.
2 Florida Department of Transportation. (2016). Florida Strategic Highway Safety Plan. http://www.fdot.gov/safety/SHSP2012/FDOT_2016SHSP_Final.pdf. Accessed March 17, 2017.

Rear-end collision avoidance systems have also been developed to prevent collisions with the vehicle ahead using the technologies such as radar sensors or video image sensors .

Recognizing the importance of improving the safety performance of transit services, FDOT in collaboration with the Miami-Dade County Public Work Department (the County) has initiated this research project to evaluate the effectiveness of Mobileye CAS technologies in addressing transit vehicle-pedestrian and rear-end conflicts and the associated safety problem. The technologies have been tested on Miami-Dade County bus routes with the goal of helping agencies in Florida and around the nation in making decisions regarding investment in CAS technologies, considering the safety effectiveness of these technologies.

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2 REVIEW OF PREVIOUS EVALUATION STUDIES

A number of studies have been conducted in the literature to evaluate pedestrian-related collision detection and avoidance systems. Chan et al. (2006) [3] tested various pedestrian detection technologies through field experiments, including capacitance and electric field sensing, computer vision with image processing, Eaton-Vorad radar, IBEO laser scanner, Senix ultrasonic sensor, infrared sensor, and connected vehicle concepts. The study found that each technology has its limitations. According to the authors, computer vision with image processing technology is particularly suitable for vehicle-based safety applications such as sign or lane recognition. The application of the connected vehicle concept is best accomplished by focusing on the high pedestrian accident locations.

Various collision detection and warning technologies were assessed by Dunn et al. (2007) [4] based on collision data from National Transit Database and crash data from six transit agencies. The study reported that only side object detection systems showed the potential to be cost effective. Pedestrian detection system was found to be cost effective for agencies with above-average transit-pedestrian collision rates or high collision costs.

The effectiveness of camera-based systems for minimizing transit bus side collisions was assessed by Lin et al. (2010) [5]. The study used controlled driving tests and surveys and assessed blind zone reduction for side view video system. This study showed that camera-based systems with regular-angle lens can lead to a 64% more reduction in blind zones than mirror-based system and 43% more reduction than combined flat and convex mirror that is commonly used. Side collision due to blind zones can be completely avoided by using wide-angle lens. It was also found from the

3 Chan, C., Bu, F. & Shladovern, S. (2006). Experimental Vehicle Platform for Pedestrian Detection. Technical Report Documentation Page TR0003 (REV. 10/98), Rep. No. FHWA/CA-2006/0674. Institute of Transportation Studies University of California Berkeley, CA.

4 Dunn, T., Laver, R., Skorupski, D., & Zyrowski, D. (2007). Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses. Federal Transit Administration U.S. Department of Transportation, Washington.

5 Lin, P., Lee, C., Kourtellis, A., & Saxena, M. (2010). Evaluation of Camera-based Systems to Reduce Transit Bus Side Collision. Final Report No. BDK85 Two 977-08, Prepared by Center for Urban Transportation Research (CUTR) for the Florida Department of Transportation. pp. 90.

controlled driving test that 28 bus drivers were able to accurately perceive distance/depth and lane changing maneuver using side view video systems.

The effectiveness of Volvo's pedestrian detection system was evaluated by Vertal et al. (2014) [6] by reconstructing real fatal pedestrian crashes. The results showed that this pedestrian detection system does not work under certain conditions, including distance to pedestrian less than 80 cm, dark conditions, vehicle moving in levorotatory and dextrorotatory corner and pedestrian moving into the road from the left. This system can detect the pedestrian who are in a perpendicular direction to the vehicle and up to an angle of +/- 45°. The system was found to be able to warn the driver more than one second before the collision and detect and stop the vehicle completely when the vehicle speed is up to about 19 mile/hour (30 km/h).

Another study[7] designed and developed transit-specific safety applications that can communicate using vehicle-to-vehicle (V2V) and Vehicle-to-Infrastructure (V2I) connected vehicle technologies. Different technologies were installed and tested in three transit vehicles, including Emergency Electronic Brake Lights, Forward Collision Warning, Curve Speed Warning, Pedestrian in Signalized Crosswalk Warning (PCW), and Vehicle Turning Right in Front of Bus Warning (VTRW). The test results reveal that PCW and VTRW applications provided high rate of false alerts because of the Global Position System (GPS) and pedestrian detection limitation. With regard to pedestrian detection, it was reported that Doppler microwave-based crosswalk detectors are not sufficient for the PCW application as it cannot distinguish properly between pedestrians and slow moving vehicles.

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6 Vertal, P., Kledus, R. and Steffan, H. (2015). Evaluation of the Effectiveness of Volvo's Pedestrian Detection System Based on Selected Real-Life Fatal Pedestrian Accidents. 24th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Gothenburg, Sweden.

7 Zimmer, R. E., Burt, M., Zink, G. J., Valentine, D. A., Knox, W. J. Jr. (2014). Transit Safety Retrofit Package Development Final Report. TRP Concept of Operations, Report No. FHWA-JPO-14-117, U.S. Department of Transportation, Washington, DC.

Three systems were tested and evaluated[8] to warn pedestrians of turning buses. Two of these systems provide auditory external warning to pedestrians and one has a directional LED headlights that are housed with the main headlights. Each of these systems was installed in 15 buses for 7 months. The evaluation results showed that the systems produced false activation in the situation of sharp roadway curves and parking with curb wheels. The study stated that the false alarms might be related to the set speed thresholds in the system. Therefore, it was recommended that the maximum speed threshold to be 15 mph to minimize some false activation. The benefit/cost analysis indicates an overall benefit per bus/warning system of $65,300 and a total benefit of $3 million, which resulted in a payback period of about three years. All the scenarios considered produced net positive benefits. Based on the same study, the survey results of Pecheux et al. (2016) [9] showed a range of perception and level of acceptance. The benefit/cost ratio was found to be positive for two of three systems.

Another study[10] examined the safety benefits of integrated pedestrian protection systems based on driver simulation and finite element simulation. The results indicated that 90% of the fatalities can be reduced by implementing an integrated pedestrian protection system.

Transit bus collision avoidance warning systems were also tested by Lutin et al. (2016) [11] by installing a modified commercially available collision avoidance warning system (CAWS) on 38 standard transit buses operating by eight agencies. Each bus was also equipped with a cellular

8 Pecheux, K. and Kennedy, J. (2015). Evaluation of Transit Bus Turn Warning Systems for Pedestrians and Cyclists. FTA Report No. 0084. Federal Transit Administration.

9 Pecheux, K. K., Strathman, J., and Kennedy, F. J. (2016). Test and Evaluation of Systems to Warn Pedestrians of Turning Buses. Transportation Research Record: Journal of the Transportation Research Board, No. 2539, Transportation Research Board, Washington, D.C., pp. 159–166.

10 Choi, S., Jang, J., Oh, C., and Park, G. (2015). Safety Benefits of Integrated Pedestrian Protection Systems. International Journal of Automotive Technology, Vol. 17, No. 3, pp. 473–482.

11 Lutin, J. M., Spears, J., & Wang, Y. (2016). Testing Transit Bus Collision Avoidance Warning Systems in Revenue Operations – Active Safety Collision Warning Pilot in Washington State. Transportation Research Board. Paper 17-01283. Washington, D.C.

telematics unit and supplemental cameras with video recording. Incident data, telematics unit data, and video data were collected for 3 months. Analyses were conducted to examine the false positive (warning is produced even when there is no threat of collision) and false negative (no warning is issued when there is collision or near collision) events. The study results show that the one-time payment of $3,875.00 per bus for installing the CAWS system is high and needs to be reduced.

3 EXISTING CONDITIONS

The transit system managed by Miami-Dade County is the 15th largest transit system in the United States (based on annual vehicle revenues), with a service area of approximately 306 square miles and serving all of metropolitan Miami-Dade, and parts of Broward and Monroe Counties. The Metrobus system in Miami-Dade County provides over 28.8 million miles of revenue service along 98 routes throughout the County utilizing articulated, full size, and mini-buses. Buses (fleet size of 813 buses) are equipped with Computer Aided Dispatch/Automatic, Vehicle Location (CAD/AVL) and Automatic Passenger Counters (APC) to monitor the system performance in off-line and real-time operations.

Miami-Dade Transportation and Public Work (DTPW) maintains a detailed database of their vehicle incidents. The data includes the site type, injury severity, injury person role (driver, passenger, pedestrians), and whether the bus operator is wrong.

The project team analyzed the DTPW transit data for three years. It was determined that from 2013 to 2016, DTPW documented a total of 5,164 bus collisions (at a rate of 1,721 collisions per year or about five crashes per day). As shown in Table 1, a large proportion of the collisions occurred at intersections or influenced by intersection (37.9%) and at bus stops and terminals (28.1%). Table 3-1 shows that at least 15% of the crashes resulted in injuries and/or fatalities, at least 10.5% involved passengers and pedestrians, and at least 38.5% were reported to be due to inappropriate bus operator actions.

Table 3-1: Summary of the MSPW Transit Crash Statistics between 2013 and 2016

Site Description	Number of Incidents	Percentage of Incidents
At Intersection	1351	26.2%
Bridge	22	0.4%
Bus Stop Curb	1189	23.0%
Bus Stop Driveway	75	1.5%
Bus Terminal	186	3.6%
Driveway Access	112	2.2%
Entrance Ramp	22	0.4%
Influence By Intersection	604	11.7%
N/A	1	0.02%
Not Applicable	279	5.4%
Not at Intersection/RR Xing/Bridge	388	7.5%
Other	563	10.9%
Parking Lot - Private	117	2.3%
Parking Lot - Public	31	0.6%
Private Property	27	0.5%
Rail Station	64	1.2%
RR Xing	29	0.6%
Unknown	104	2.0%
Total	5164	100%
Injury Type	**Number of Incidents**	**Percentage of Incidents**
Fatality	8	0.2%
Injury	734	14.2%
N/A	4290	83.1%
Not Injury	111	2.1%
Sick	21	0.4%
Total	5164	100%
Injury Role	**Number of Incidents**	**Percentage of Incidents**
Driver/Owner	304	5.9%
N/A	4290	83.1%
Passenger	478	9.3%
Pedestrian	64	1.2%
Unknown	28	0.5%
Total	5164	100%
Operator Wrong	**Number of Incidents**	**Percentage of Incidents**
N/A	291	5.6%
No	2883	55.8%
Yes	1990	38.5%
Total	5164	100%

Route specific analysis of the crashes was also conducted based on the DTPW data. Table 3-2 shows the number of crashes for the eleven transit routes with the highest crash frequencies. The crash frequency for all 96 routes are presented in Appendix B. It was found that among the 96 Metrobus routes in the County, the eleven routes with the highest number of crashes had high proportions of the total crashes (a total of 35.1%). Four of these eleven routes serve Miami Beach and the remaining routes are in the Miami-Dade County Mainline. This concentration of crashes on limited numbers of routes provide opportunities for addressing a significant proportion of the safety problems with a relatively low technology implementation cost.

Table 3-2 Crash Frequencies for the Eleven Routes with the Highest Crash Frequencies

Route	Number of Incidents	Percentage of Incidents
119	254	4.92%
77	228	4.42%
112	181	3.51%
120	179	3.47%
27	168	3.25%
9	165	3.20%
11	165	3.20%
3	131	2.54%
8	129	2.50%
103	109	2.11%
123	101	1.96%

Table 3-3 shows a description of the six routes with the highest crashes. Appendix B presents a summary of the crashes statistics for the six routes based on DTPW data. **Table 3-4** shows a summary of the route information as well as incident statistics for those routes. It appears from this table that the ranking of the routes according to the rate in crashes per day-mile (the statistics in the last column) is different from the ranking based on incident frequencies. The two highest frequency routes are Route 119 followed by Route 77. The two highest incident rate routes are Route 123 followed by Route 77. Examining the number of pedestrian crashes, the crashes influenced by the intersections, and the crashes at bus stops; it appears that Route 119 and Route 77 have the highest number of crashes. Thus, one of these two routes will be selected for installing the crash warning devices in this project.

Table 3-3 Route Descriptions for the Six Routes with the Highest Number of Crashes

Route	Route Description	Attributes		
119-S	Downtown (Miami) Bus Terminal, Main Library, Historical Museum, Miami Art Museum, Government Center Metrorail station, Omni Bus Terminal, MacArthur Causeway, City of Miami Beach, South Beach, Lincoln Road, Collins Avenue, 192 Street Causeway, City of Aventura, Aventura Mall	NB	Weekday	Day time: 10 – 12 minutes Night time: 24 – 60 minutes
			Saturday	Day time: about 15 minutes Night time: 20 – 60 minutes
			Sunday	Day time: about 15 minutes Night time: 30 – 6 0minutes
		SB	Weekday	Day time: 10 – 11 minutes Night time: 14 – 60 minutes
			Saturday	Day time: 12 – 15 minutes Night time: 16 – 60 minutes
			Sunday	Day time: 12 – 15 minutes Night time: 13 – 6 0minutes
77	NW 199 Street/NW 2 Avenue (SR 441), Golden Glades Park & Ride Lot, NW 7 Avenue, Liberty City, Culmer Metrorail station, Government Center Metrorail station, Main Library, Historical Museum of South Florida, Miami Art Museum, Downtown (Miami) Bus Terminal	NB	Weekday	Day time: 8 - 10 minutes Night time: 20 – 60 minutes
			Saturday	Day time: 15 - 30 minutes Night time: 60 – 70 minutes
			Sunday	Day time: 30 minutes Night time: 55 – 60 minutes
		SB	Weekday	Day time: 12 – 15 minutes Night time: 35 – 62 minutes
			Saturday	Day time: 5 – 30 minutes Night time: 60 minutes
			Sunday	Day time: 22 – 38 minutes Night time: 60 minutes
112	Lincoln Road Mall, Miami Beach Convention Center, Miami Beach Senior High School, 41 St./Indian Creek Dr., JFK Causeway, Northside Metrorail station, Amtrak Terminal, Hialeah Metrorail station	EB	Weekday	Day time: 9 – 24 minutes Night time: 26 – 35 minutes
			Saturday	Day time: 26 – 30 minutes Night time: 20 – 50 minutes
			Sunday	Day time: 35 - 41 minutes Night time: 30 – 61 minutes
		WB	Weekday	Day time: 12 – 17 minutes Night time: 20 – 60 minutes
			Saturday	Day time: 15 minutes Night time: 21 – 60 minutes
			Sunday	Day time: 20 minutes Night time: 30 - 60 minutes
120	Downtown Bus Terminal, Main Library, Historical Museum, Miami Art Museum, Govt. Center Metrorail station, Miami Dade College Wolfson Campus, Omni Bus Terminal, MacArthur Causeway, City of Miami Beach, Collins Avenue, Town of Surfside, City of Bal Harbour, Haulover Park Marina, Aventura Mall	NB	Weekday	Day time: 11 – 30 minutes Night time: 30 –45 minutes
			Saturday	Day time: 15 -30 minutes Night time: 30 minutes
			Sunday	Day time: 30 minutes Night time: 60 minutes
		SB	Weekday	Day time: 9– 34 minutes Night time: 29 – 31 minutes
			Saturday	Day time: 26 – 30 minutes Night time: 44 – 55 minutes
			Sunday	Day time: 22 - 40 minutes Night time: 28 – 30 minutes

Route	Route Description	Attributes		
27	Calder Casino & Race Track, Sun Life Stadium, Carol City, NW 27 Avenue, Miami Dade College North Campus (weekdays/Saturdays; no overnight trips), Dr. Martin Luther King Jr. Metrorail station (no overnight trips), Brownsville Metrorail station (no overnight trips), Coconut Grove Metrorail station	NB	Weekday	Day time: 15 – 18 minutes Night time: 23 – 60 minutes
			Saturday	Day time: 20 minutes Night time: 25 – 60 minutes
			Sunday	Day time: 28 - 30 minutes Night time: 40 – 60 minutes
		SB	Weekday	Day time: 13 – 19 minutes Night time: 35 – 66 minutes
			Saturday	Day time: 15 – 22 minutes Night time: 28 – 68 minutes
			Sunday	Day time: 27 – 37 minutes Night time: 33 – 68 minutes
123	Belle Isle, Collins Park, South Miami Beach, Biscayne St., Ziff Jewish Museum, Washington Ave., The Filmore Miami Beach at the Jackie Gleason Theatre, 17 St., City Hall, Meridian Ave., Holocaust Memorial, Dade Blvd., Bay Rd./20 St., Lincoln Rd., West Ave., Alton Rd., Miami Beach Marina	Clockwise	Weekday	Day time: 13 – 30 minutes Night time: 20 minutes
			Saturday	Day time: 13 - 30 minutes Night time: 20 minutes
			Sunday	Day time: 13 - 30 minutes Night time: 20 minutes
		CntrClock wise	Weekday	Day time: 13– 30 minutes Night time: 20 minutes
			Saturday	Day time: 13 – 30 minutes Night time: 20 minutes
			Sunday	Day time: 13 – 30 minutes Night time: 20 minutes

Table 3-4 Route Information and Incident Statistics for the Six Routes with the Highest Number of Crashes

Route	Direction	# of Stops	# of Signalized Intersections	Length (Miles)	Schedule			No. of Runs			# of Incidents	*Incidents per Day-mile	Crashes at Intersection/ Influenced by intersection	Pedestrian Crashes	Bus Stop Crashes
					Weekday	Saturday	Sunday	Weekday	Saturday	Sunday					
119	NB	11	121	21.78	24 Hours	24 Hours	24 Hours	90	77	74					
	SB	11	110	21.24	24 Hours	24 Hours	24 Hours	95	78	75					
	Total	**22**	**231**	**43.02**				**185**	**155**	**149**	**254**	**0.00434**	**111**	**7**	**55**
77	NB	10	57	15.45	24 Hours	24 Hours	24 Hours	98	59	35					
	SB	10	64	16.23	24 Hours	24 Hours	24 Hours	97	59	35					
	Total	**20**	**121**	**31.68**				**195**	**118**	**70**	**228**	**0.00529**	**79**	**4**	**82**
112	EB	9	92	17.47	24 Hours	24 Hours	24 Hours	88	72	52					
	WB	9	98	15.75	24 Hours	24 Hours	24 Hours	87	73	54					
	Total	**18**	**190**	**33.22**				**175**	**145**	**106**	**181**	**0.00400**	**55**	**1**	**51**
120	NB	9	119	21.11	5:00 AM – 9:30 PM	6:00 AM – 9:30 PM	6:00 AM – 9:00 PM	70	56	30					
	SB	9	120	20.5	6:00 AM –10:30 PM	5:49: AM – 10:30 PM	6:01 AM – 9:27 PM	71	56	32					
	Total	**18**	**239**	**41.61**				**141**	**112**	**62**	**179**	**0.00443**	**71**	**3**	**40**
27	NB	12	63	20.13	24 Hours	24 Hours	24 Hours	69	52	39					
	SB	12	60	17.18	24 Hours	24 Hours	24 Hours	69	56	41					
	Total	**24**	**123**	**37.31**				**138**	**108**	**80**	**168**	**0.00331**	**50**	**2**	**80**
123	Clockwis e	8	48	7.57	7:50 AM-11:50 PM	7:50 AM-11:50 PM	10:10 AM-11:50 PM	61	61	51					
	Counterc lockwise	8	53	7.47	7:40 AM-12:00 AM	7:40 AM-12:00 AM	10:00 AM-12:00 AM	62	62	52					
	Total	**16**	**101**	**15.04**				**123**	**123**	**103**	**101**	**0.00740**	**39**	**1**	**28**

*The incidents were from Jan 1, 2013 to Sep 22, 2016 (1361 days). Route 120 and 123 are not available 24-hours, so their days were converted based on their schedule to calculate more comparable Incidents per Day-mile. That is, 970 days for route 120 and 907 days for route 123 were used to calculate Incidents per Day-mile.

4 MOBILEYE SYSTEM

Mobileye has produced three vision-based crash avoidance systems (CAS): Mobileye 5-Series, Mobileye C2-Series, and Mobileye Safety Shield. The first two systems utilize a single camera located on the front windshield inside the vehicle, allowing the system to provide warnings and headway measurements using a display and control unit. However, the Mobileye 5-Series has also Bluetooth connectivity, allowing the provision of audio-visual warnings utilizing a smartphone application. Mobileye Safety Shield allows better detection of pedestrians and bicycles by utilizing up to four cameras. The latest Mobileye Safety Shield product can be equipped with up to four multi-vision smart cameras on the exterior of the vehicle (one center, two side cameras and one side front bumper).

The provided features by the Mobileye system include:

- Forward Collision Warning (Mobileye FCW)
- Pedestrian Collision Warning (Mobileye PCW)
- Headway Monitoring Warning (Mobileye HMW)
- Lane Departure Warning (Mobileye LDW)
- Intelligent High-beam Control (IHC)
- Speed Limit Indicator (SLI)
- Traffic Sign Recognition

The product used in this study is the *Mobileye Shield + System*, part number VQS4560. The system consists of four Mobileye Model 560 sensors, two Rosco exterior sensor housings, two interior windshield mounted vision sensors, three Rosco driver interface displays and one junction unit. The center Rosco driver display contains the Mobileye Eyewatch driver display. The system includes:

- Front and side sensing of pedestrians and cyclists in complex urban environments including turns and intersections, with outputs to the bus driver that will improve the ability to detect potential collisions with these targets in time to stop the bus.

- Mobileye’s standard features for urban and highway forward collision warning, lane departure warning, headway following time monitoring and warning, pedestrian and cyclist detection, and speed limit indication, all visible and audible through the Mobileye Eyewatch Display.
- Three Rosco driver displays which visually and audibly alert the driver of potential collisions with pedestrian or cyclists.
- Shield+ Telematics mapping of Mobileye Shield+ sensor messages for route evaluation of activity and conditions.

The tested system has three indicators located on the windshield. One of the two side indicators shows a yellow light if the system determines that a pedestrian or bicycle is within 2.5 seconds or less from collision with the bus. The indicators shows red light and the system provides a sound alarm if a pedestrian or a bicycle is within 1.0 second from Collison with bus. The indicator mounted at the center provides FCW, HMW, LDW, and SLI.

It should be emphasized that the Mobileye PCW is only operational in daylight conditions. Discussions with Mobileye representative indicates that an enhancement to the side PCW was introduced by adding a gyro to reduce the false alarm due to detecting pedestrians on the sidewalks. The addition of gyro allows the system to provide warnings only when the vehicle turning. The system also only operates when the vehicles are moving.

The evaluation team coordinated with the FDOT, the County, and Mobileye device vendor on installing the required devices. The Mobileye device vendor (Rosco) installed the cameras and worked with the research team for access to Shield+ telematics data and marked continuous video events of alerts (PCWs). The vendor installed the devices and trained staff from the County, designated as “trainers,” who later trained other staff. Glove box cards werealso be provided for each driver to provide information about the system and how and when it works.

5 PROJECT STAKEHOLDERS

Project stakeholders provided valuable inputs to the evaluation and were informed of project activities. The key stakeholders of the project include the FDOT, Miami-Dade County DTPW department, and the Mobileye device vendor (Rosco).

6 PERFORMANCE MEASURES AND EVALUATION HYPOTHESIS

The goal of this project is to assess the safety effectiveness of the installed devices in addressing rear-end and pedestrian crashes and the user acceptance of the technology. The specific objectives and associated performance measures are listed below:

- Objective 1: Assess the system effectiveness in reducing rear-end crashes
    - Performance measure 1-1: Percentage of rear-end safety events that are reacted to by bus drivers
    - Performance measure 1-2: Time headways of participating drivers
    - Performance measure 1-3: Frequency of hard brakes
    - Performance Measure 1-4: Frequency of generated rear-end conflict alerts
    - Performance Measure 1-5: Percentage of accurate alarms
- Objective 2: Assess the system effectiveness in reducing pedestrian and bicycle crashes
    - Performance measure 2-1: Percentage of pedestrian and bicycle conflicts that are reacted to by bus drivers
    - Performance measure 2-2: Percentage of times with conflicting events that driver yields to pedestrian
    - Performance measure 2-3: Frequency of generated pedestrian and bicycle conflict alerts
    - Performance Measure 2-4: Percentage of accurate alarms

The hypotheses associated with Performance Measures 1-1, 2-1, and 2-2 are that the alerts provided by the installed devices will improve the driver reactions to events that are determined to be a high risk for collision. The hypotheses associated with Performance Measure 1-2, 1-3, 1-4, 2-3, and 2-4 are that the drivers will start leaving longer time headways and be more careful when approaching leading vehicles and locations where pedestrian and cyclists are expected, as a result of the day-to-day learning with the provision of the alarms.

- Objective 3: Assess the user acceptance of the system
    - Performance measure 3-1: Operator's perception of ease of use
    - Performance measure 3-2: Operator's perception of overall usefulness
    - Performance measure 3-3: Operator's perception of rear-end collision warning effectiveness
    - Performance measure 3-4: Operator's perception of pedestrian collision warning effectiveness
    - Performance measure 3-5: Operator's perception of accuracy
- Objective 4: Assess the ease of the installations and operations of the devices
    - Performance measure 4-1: Issues associated with the installation and operations of the system
- Objective 5: Assess the cost-effectiveness of the technology
    - Performance measure 5-1: the present worth of the technology considering the estimated benefits and costs

7 EXPERIMENTAL DESIGN

It is important to select an experimental design that eliminates the threats to the validity of the evaluation. Below are common threats to the validity that need to be addressed by selecting a sound experimental design.

Confounding (or influencing) factors may account for at least portions of any observed difference in observed performance. For example, if the vehicular, transit passenger, and pedestrian volumes are different in the before and after conditions, then the number of conflicts will be different. The difference could be for example due to seasonal variations, transit services, change in economy and fuel prices, or construction activities. Another example is the change in weather conditions between seasons in Florida. This threat was accounted for by using a control group of vehicles equipped with the devices to measure conflicts but with no alarms provided and the data for the control and treatment groups were collected simultaneously.

Selection bias is another common threat to validity. In this project, this can involve the selection of drivers and buses for the alarm activation experiment that are different from those used as a control group. In this project, the drivers and buses were selected to ensure random sampling of both groups.

A third threat is ***maturation,*** which occurs when there is a significant difference in the measures between different seasons and days of the weeks that will affect the results. In this study, the data for the treatment and control groups were collected simultaneously, eliminating this threat.

Another threat is ***instrument change***; which occurs if the data collection and processing methods is not uniform between the treatment and the control groups. In this study, the data collection methods and devices were consistent between the before and after conditions and between the treatment and control groups.

A number of evaluation designs are available to reduce threats to different types of validity. There are three categories of evaluation designs that are listed below from the most preferred to the least preferred.

- Randomized Experimental Designs: Designs that use experimental structures to test whether a program has impacts. Test subjects are randomly assigned to the treatment and control groups.
- Quasi-Experimental Designs: Research designs shares similarities with the traditional experimental design or randomized controlled trial, but they specifically lack the element of random assignment to treatment or control. Typically, these designs attempt to control threats to validity via statistical analysis.
- Pre-Experiment Designs: Designs that are not explicitly intended to test program impacts in an experimental manner – normally used to collect information and generate insights.

The design used in this study is a randomized experimental design, which as mentioned above is the preferred type of design. Test subjects are randomly assigned to a treatment and control group. The treatment group receives the treatment and the control group does not.

8 DATA COLLECTION PLAN

As stated earlier, according to the original plan, the system would be assessed under both before and after the installation conditions. However, the County moved the buses to a new route for the after conditions. This prevented the team from conducting a before-after analysis. Instead, the evaluation was conducted by comparing the performance measures between the treatment group (five buses with active alarms) and the control group (five buses in the stealth mode) for the after route change period (ARC). The analysis for the stealth mode for the before route change (BRC) was also done and some of the analysis is included in this document, as appropriate. No active mode is associated with the BRC because the buses were moved from this route before there was a chance to activate the devices, as discussed above.

Data and video from buses on the selected routes in Miami-Dade County were collected and analyzed. .The vendor installed telematics and video recording equipment for the pilot that tracked alerts and associated video and telematics. The Mobileye device vendor (Rosco) worked with the research team for access to Shield+ telematics data and marked continuous video events of alerts. The telematics unit communicated in real-time with a central server, where they were archived and processed for use in the analysis. Below are the examples of event data that were uploaded through a telematics unit:

- Exceeded speed limits
- Headway monitoring
- Urban forward collision warning: speed between 0.6 and 19 mph
- Forward collision warning: speed > 19 mph
- Pedestrian collision warning: right
- Pedestrian collision warning: left
- Pedestrian collision warning: left front
- Pedestrian collision warning: forward
- 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

The video recording was uploaded to a central server from the maintenance facility using Wi-Fi communications. These videos were used to identify the false positive events (System produces a warning when there is no threat of collisions) and false negative events (System does not produce a warning when there is a possible collision), in addition to confirming driver behaviors. 60 videos were downloaded for each analyzed scenario.

In addition, feedback was obtained from the drivers regarding their opinions of the system usefulness, effectiveness, and reliability performance. Driver surveys was conducted of the participating drivers before and after they participate in the tests. A focus group meeting will also be conducted to obtain further information about driver experience with the system.

9 DATA COLLECTION AND PROCESSING

As stated earlier, data from multiple sources were collected and preprocessed in this project. The following is a detailed description of this data collection and processing effort.

9.1 Device Installation and Associated Challenges

This section describes several issues with the installation, training, and operation of the devices that delayed the project. Mobileye has asked the County to sign a term and conditions agreement that took the county sometime to review and sign, delaying the device installation process for a number of months. After a long period of discussion and agreement negotiations between the vendor and county that faced several obstacles, the vendor finished installing the devices in October 2017. The vendor trained the trainers after the installation. The evaluation team started the assessment of the evaluated performance measures once the data started to be available in January 2018 and completed downloading the data and video and analyzing them in the first quarter of 2018.

In the beginning of 2018, issues were identified with the installed devices including the need to optimizing the height of the master camera in the windshields to improve forward crash warning detection without creating potential blockage by bicycles in the bike rack. In addition, a demonstration made to the County staff who rode a bus generated requests to fine-tune the devices to change the sensitivity of the devices.

Accordingly, in February and March 2018, the vendor came down to Miami a couple of times to fine-tune the devices according to the County staff requirements, which the County wanted before activation. They increased the sensitivity of the right front camera to give more alarms and lower the field of view of the front camera to provide better warning at low speed and shorter distance spacing. However, in their trips, they found that the bus-device interface provides the wrong speeds in some cases to their devices. They attributed this to the fact that the buses that they install the devices were old (2005 models). They recommended moving the devices to newer buses that they know that their devices work correctly on. What they found was that the analog speed signal from the device has some interference at 0 speed on the bus (bus is not moving, but speed signal on speedometer is moving). The Shield+ was using this signal to determine the speed of the bus. This would cause warnings to occur while the bus is stopped. An example is when the bus pulls up to a stoplight and stops – with pedestrians crossing in the crosswalk ahead of the bus – IF the Shield+ system is receiving a speed signal from the bus that indicates movement, the system may respond by giving a pedestrian collision warning, even though the bus is not moving. The vendor felt that this could cause the operators to form a negative impression on the system performance when switching the system to LIVE. It also will lead to some challenges when analyzing the data. The vendor explained that they believed that the problem is because the old buses with the issue has to do with the bus transmission speed sensor and the way we to acquire that signal (analog, not CAN as in the new buses).

After long discussion to identify buses for the deployment, the devices were switched from the 2005 NABI to newer Gillig buses in July 2018. The researchers had to repeat the analysis for the stealth (before activation conditions) once the video and data from the new buses became available. The results for the BRC in this document are based on this repeated analysis. Once the research team was ready to do the after analysis, the County moved the buses to a new route. Thus, the evaluation experimental design had to be revised from before-after design with a control group to after condition evaluation with control group. The activation for the after conditions was delayed by the difficulty in arranging agreed on time for the County and Vendor to train the trainers again.

Another issue faced in the installation was that the buses cannot be taken out of service for long periods to accommodate retrofits or maintenance. This had to be accounted for in the installation schedule. In addition, drivers on the equipped buses were different every day. This reduced the driver's day-to-day learning of the system.

9.2 Safety and Alarms Data via Telematics

The vendor installed the telematics equipment to relay the alarms data. The data can be downloaded from the project website set by the vendor. Figure 9-1 shows the screenshot of the website.

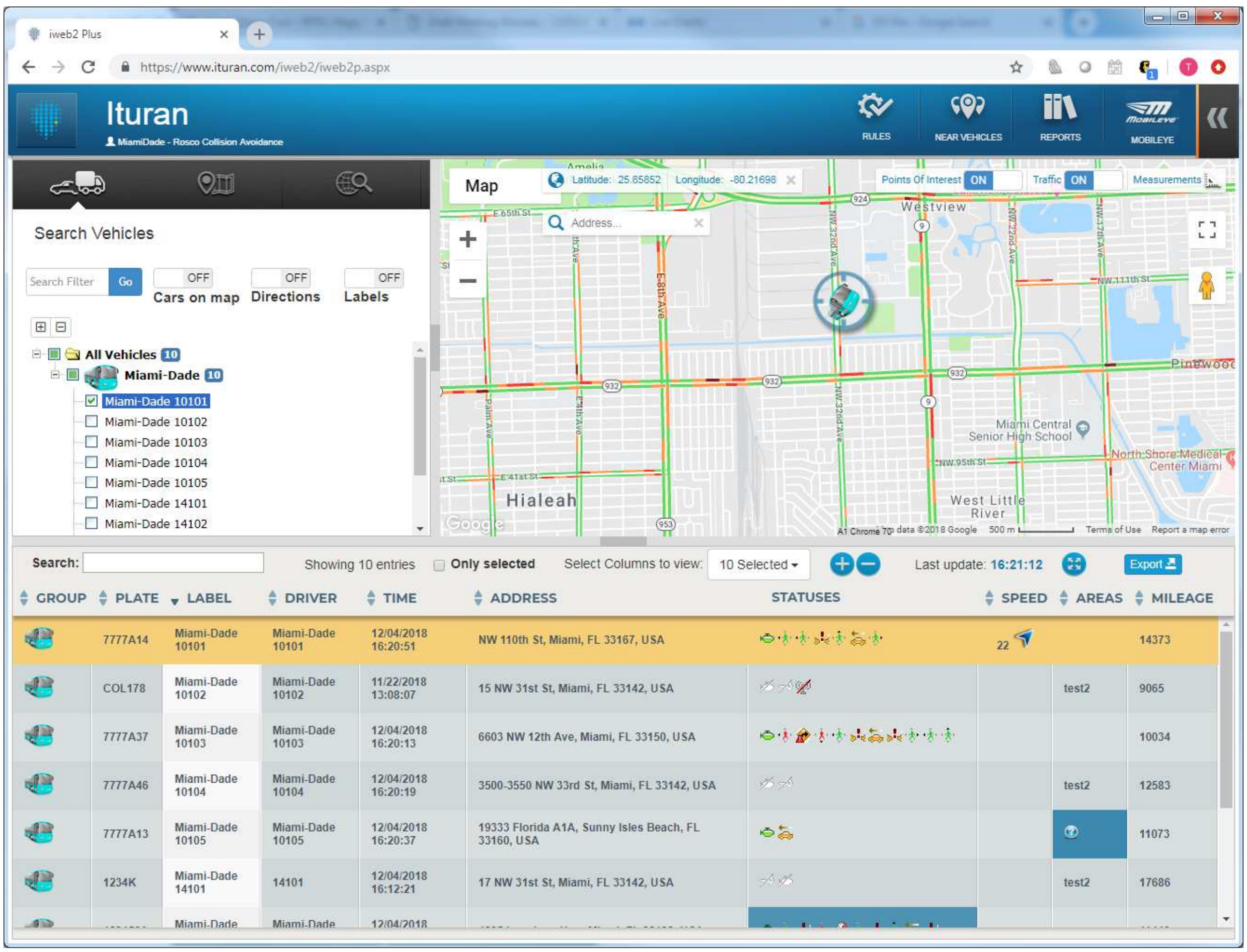

Figure 9-1: Vendor Project Website to Download Telematics Data

From the project website, one can generate the summary report as shown in Figure 9-2. The report provides the safety related statistics information for each bus such as the number of hard brake events, the average headway, and the number of different types of alarms, etc. These information were collected to research the impact of the Mobileye system on the bus drivers' driving behavior.

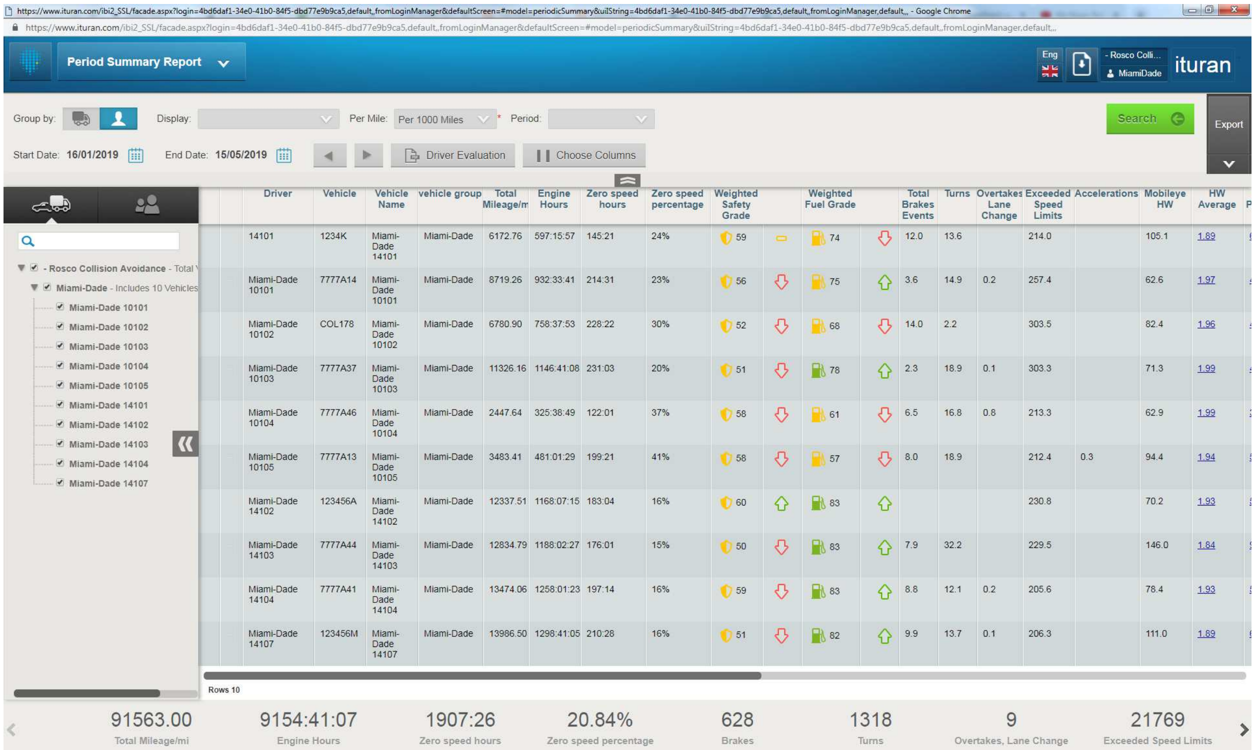

Figure 9-2: Ituran Website Interface to Generate Summary Report

From the project website, one can also generate detailed alarm data reports by specifying the time period, vehicles, statuses including the types of alarm generated by the system, and other attributes such as the speed, and heading of the bus, etc. These detailed alarm data were collected and verified with the video recording to estimate the accuracy of the Mobileye system. Figure 9-3 shows the interface to generate the reports.

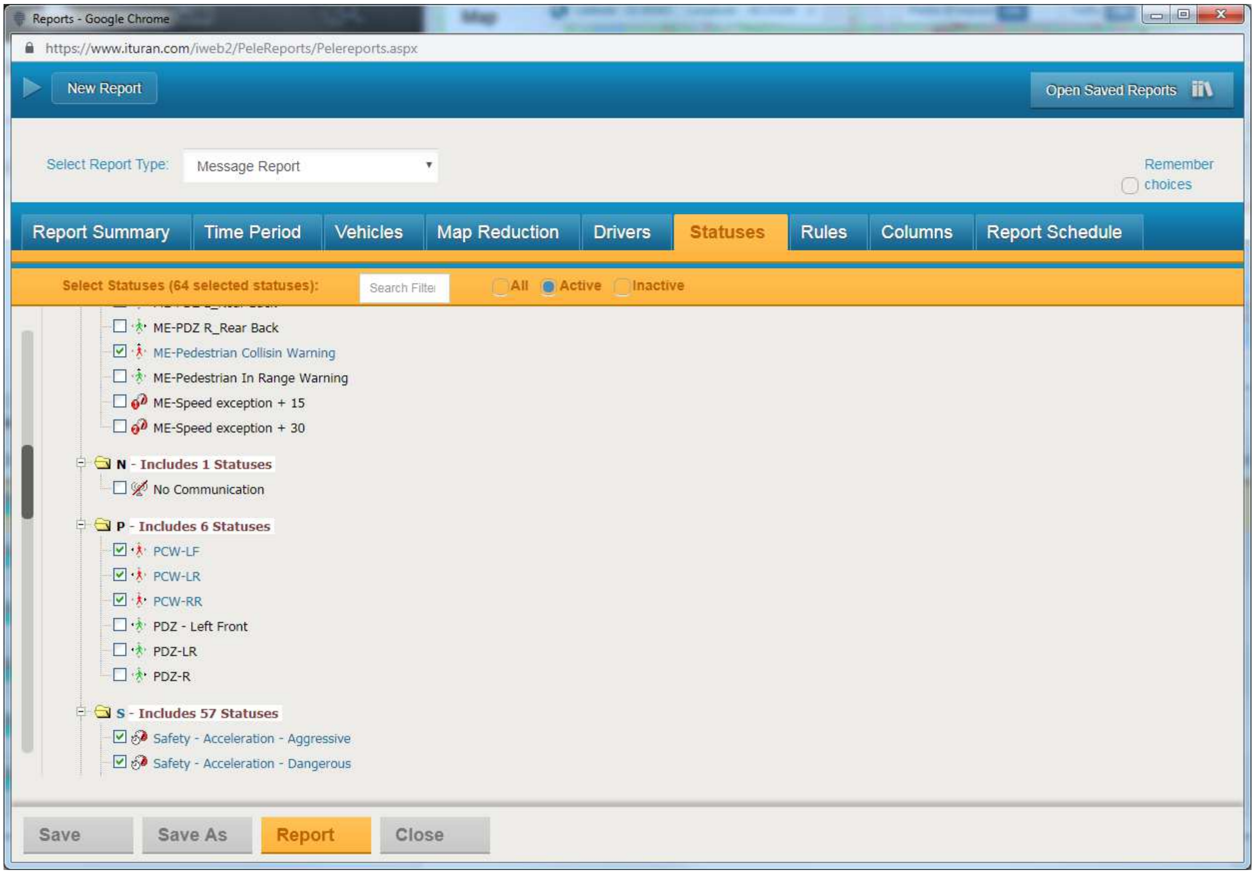

Figure 9-3: Ituran Website Interface to Generate Alarm Data Report

For this study, the following alarm types were used in the evaluation:

- **Headway Warning** indicates that the spacing to the front vehicle has dropped below the safe limit and that the bus operator is advised to reduce the speed and increase the distance to the leading vehicle.
- **FCW Warning** is forward collision warning indicating rear-end collision is imminent and the bus operator must stop the vehicle immediately.
- **Urban FCW (UFCW)** warnings are given when there is a very close stopped vehicle in the front and the speed of the subject bus is higher than 0.6 mph.
- **ME – PCW** is pedestrian collision warning based on the front middle camera
- **PCW – LF** is pedestrian collision warning based on the left front camera
- **PCW - LR** is pedestrian collision warning based on the left rear camera
- **PCW – RR** is Pedestrian collision warning based on the right rear camera

Figure 9-4 shows a generated report. The report can be exported to an Excel file, as shown in Figure 9-5.

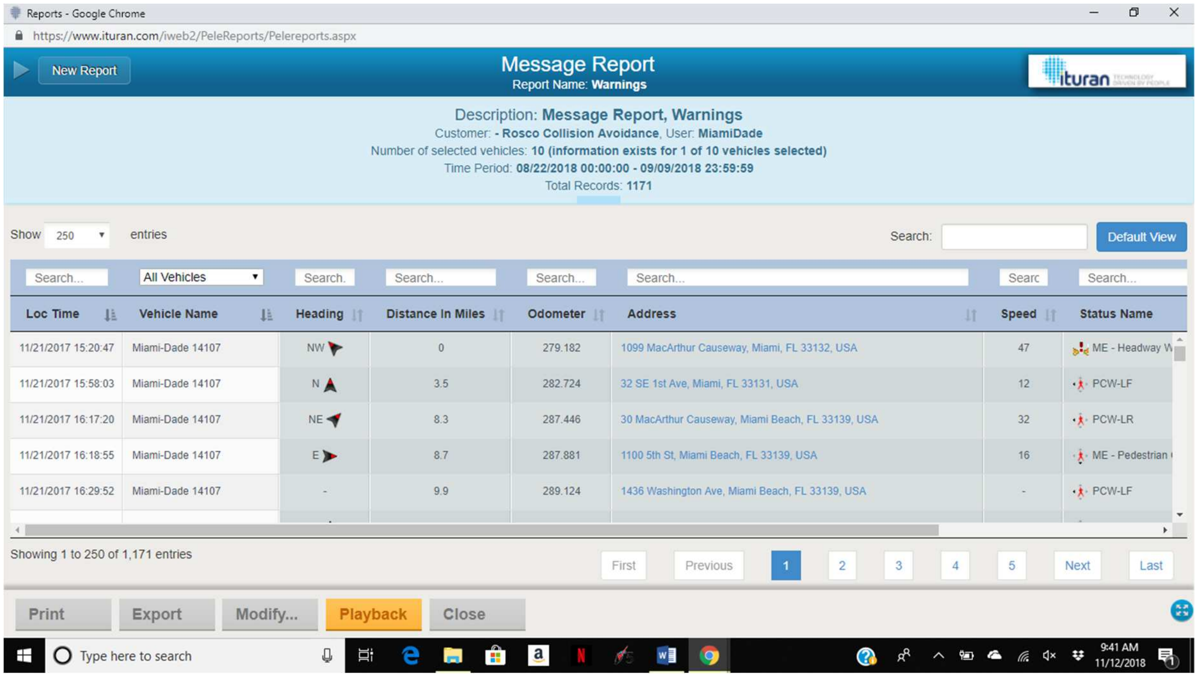

Figure 9-4: Alarm Data Report Generated within the Project Website

Loc Time	Vehicle Name	Screenshots	Videos	Heading	Distance In Miles	Plate	Odometer	Driver Nam	Address	Speed	Status Name	Latitude	Longitude
07/15/2018 16:57:31	Miami-Dade 10105			E	19.9	7777A13	27.837		100-122 Will	11	ME - Pedestrian Collis	25.95362	-80.120741
07/15/2018 17:19:54	Miami-Dade 10105			S	25.5	7777A13	33.43		9024 Florida	30	ME - Pedestrian Collis	25.87679	-80.122688
07/15/2018 17:32:57	Miami-Dade 10105			S	29.0	7777A13	36.972		5100 Collins	24	PCW-LR	25.82566	-80.122055
07/15/2018 18:40:33	Miami-Dade 10105			E	40.9	7777A13	48.84		9947 Omni St	10	PCW-LF	25.78939	-80.188678
07/15/2018 19:01:13	Miami-Dade 10105			-	46.4	7777A13	54.37		1655 Washir	-	PCW-LR	25.79070	-80.131853
07/15/2018 19:01:27	Miami-Dade 10105			E	46.4	7777A13	54.37		330 Lincoln R	7	ME - Pedestrian Collis	25.79067	-80.131266
07/15/2018 19:07:24	Miami-Dade 10105			N	46.7	7777A13	54.681		1775 Florida	10	PCW-LR	25.79381	-80.129473
07/16/2018 07:11:12	Miami-Dade 10105			N	126.8	7777A13	134.713		5875 Collins	6	ME - Pedestrian Collis	25.84092	-80.121171
07/16/2018 08:53:36	Miami-Dade 10105			-	146.0	7777A13	153.976		7626 Harding	-	PCW-LR	25.86188	-80.122208
07/16/2018 10:17:35	Miami-Dade 10105			W	158.3	7777A13	166.217		1-99 NW 2nd	7	PCW-LR	25.77496	-80.197611
07/16/2018 13:40:48	Miami-Dade 10105			SW	193.3	7777A13	201.262		2400 Collins	6	ME - Pedestrian Collis	25.80033	-80.127108

Figure 9-5: Alarm Data Exported to Excel File

9.3 Video Recording

The vender installed the video recording equipment on the buses to record the video using digital video recording (DVR). The cameras were installed at four locations of each bus. One is facing inside to the driver. Another one is facing forward to the front of the bus. The other two are at the left rear and right rear of the bus, respectively. The recorded video was available to be requested and downloaded from the ROSCO Live website provided by the vender. Figure 9-6 shows a screenshot of the website.

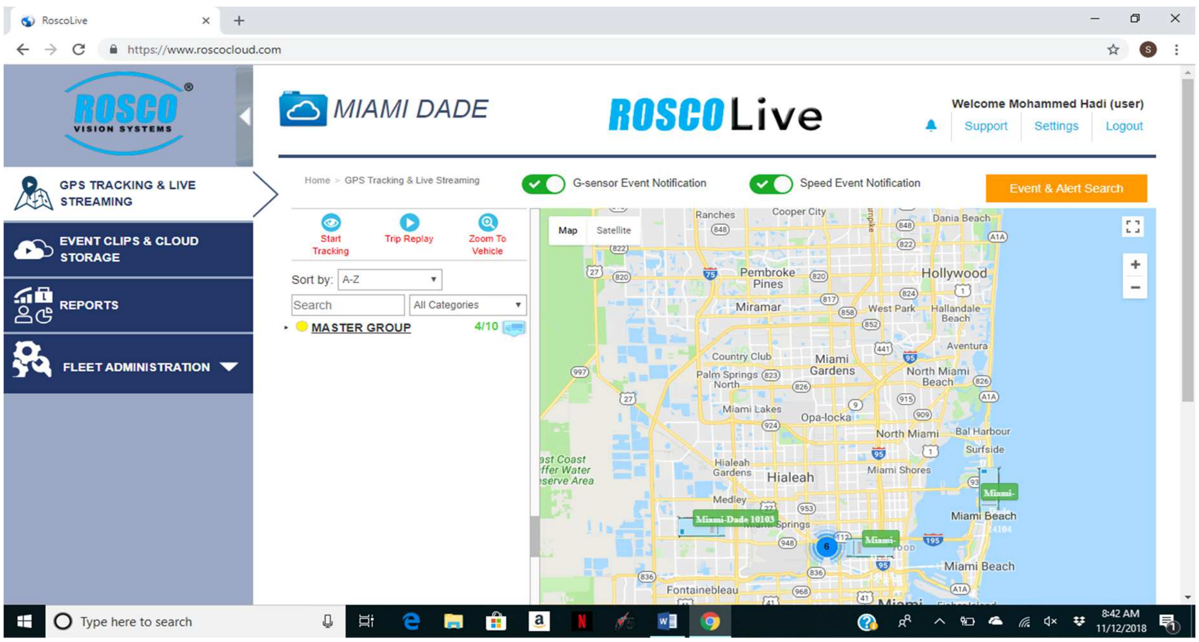

Figure 9-6: Screenshot of ROSCO Live Website

Figure 9-7 shows the pages of the website to customize the video request. The specific bus, date and time, and video length can be specified. One minute of video around the time of each alarm was requested and downloaded. For each alarm type, 60 videos were downloaded and used for the evaluation under before condition.

The downloaded video files are in NVR format and can be opened by the software DV-Pro provided by the vendor. As shown in Figure 9-8, the software can play the videos from the four cameras at the same time, and the metadata part can show information such as the time, bus location, and bus speed.

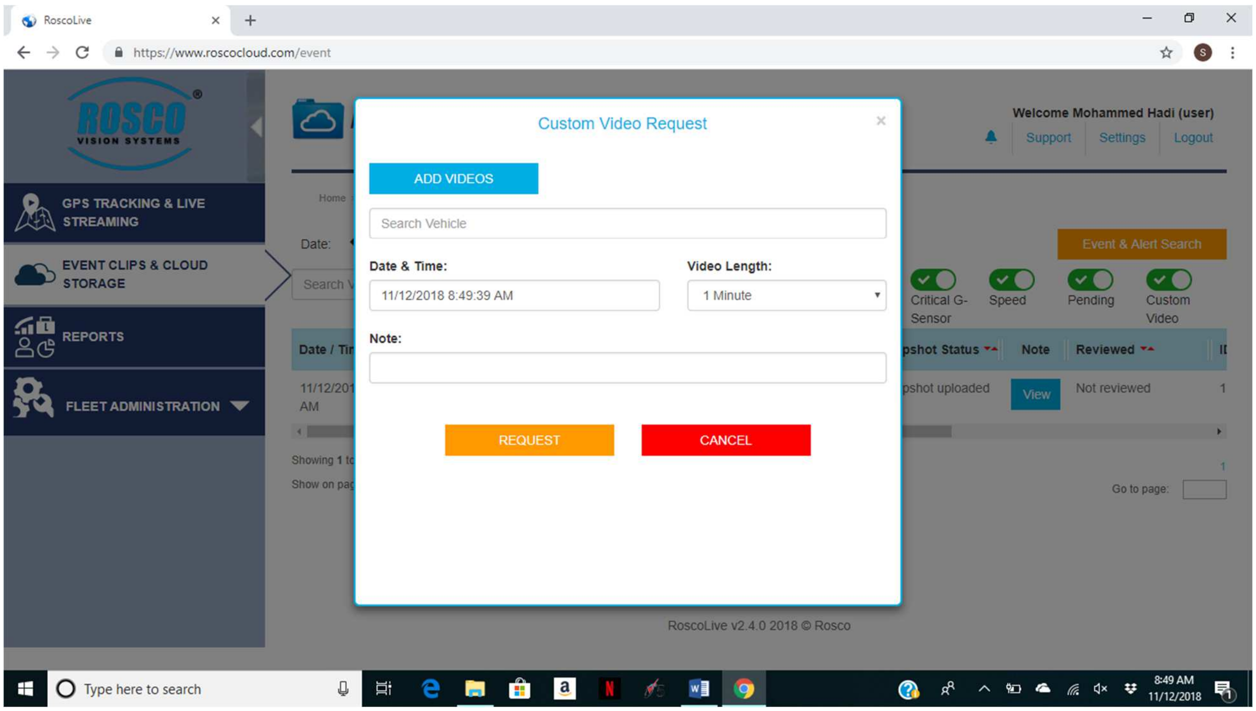

Figure 9-7: Custom Video Request from ROSCO Live Website

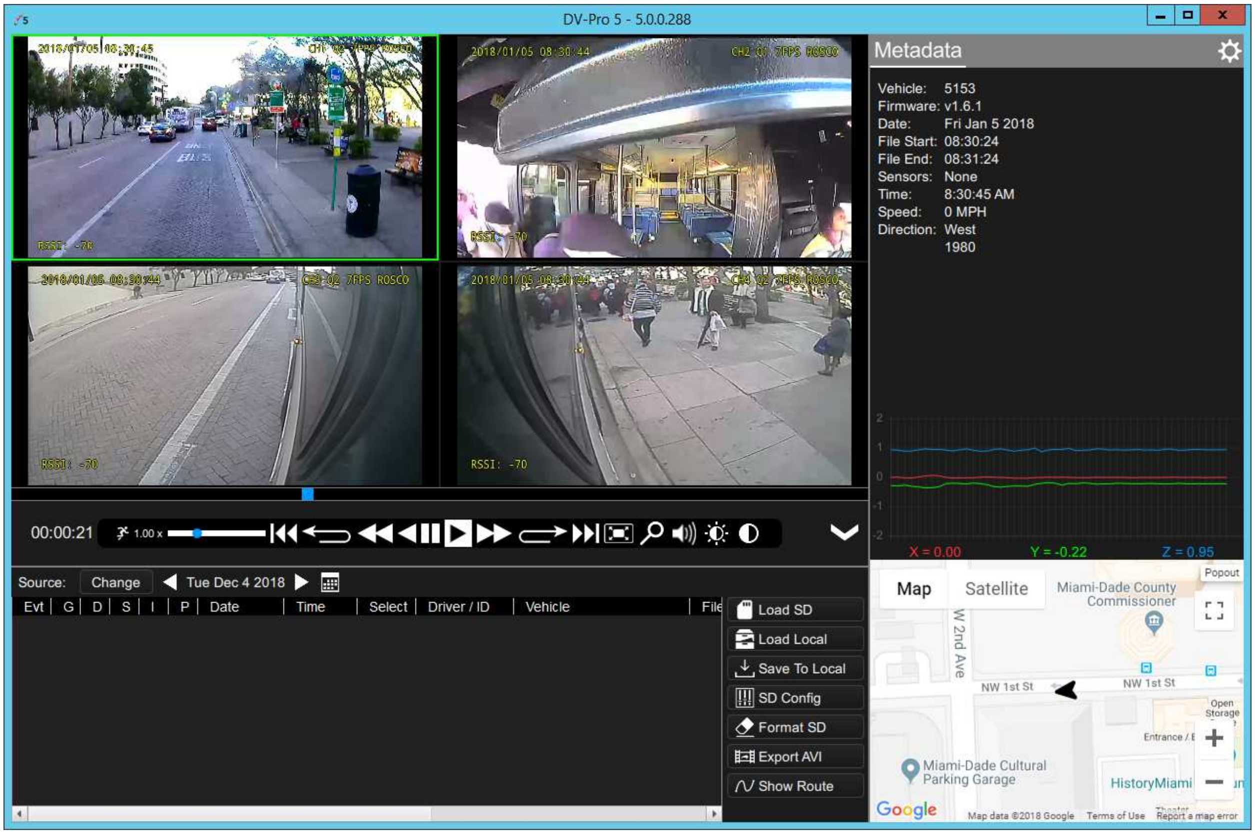

Figure 9-8: NVR Video Played by DV-Pro

10 PERFORMANCE ASSESSMENT

This section presents a comparison of the performance of the active and stealth mode after route changing (ARC). The evaluation was conducted by comparing the performance between the treatment group (five buses in the active mode) and the control group (five buses in the stealth mode). Some measures are also reported in this section based on the analysis of stealth mode before route changing (BRC). No active mode is associated with BRC because the buses were removed as discussed above.

10.1 Rear-end Warnings

This section assesses the rear end warnings by analyzing the types, accuracy, induced changes in driving reactions, and induced changes in driving behaviors associated with warnings.

10.1.1 Warning Types

The distribution of the types for the forward collision warning (HW, FDW, and UFDW) is shown in

Figure 10-1. It can be seen that for BRC, a higher percentage of the alarms is due to front vehicle stopping or decelerating compared to ARC (65% vs. 42%). The alarms for approaching a front moving vehicle is higher for ARC (39% vs. 12%). This possibly reflects the more dense urban nature of the streets that constitute BRC (the Miami Beach area). The alarms due to turning left and right in front of the leading vehicle in front of the bus are comparable (15% vs. 22%).

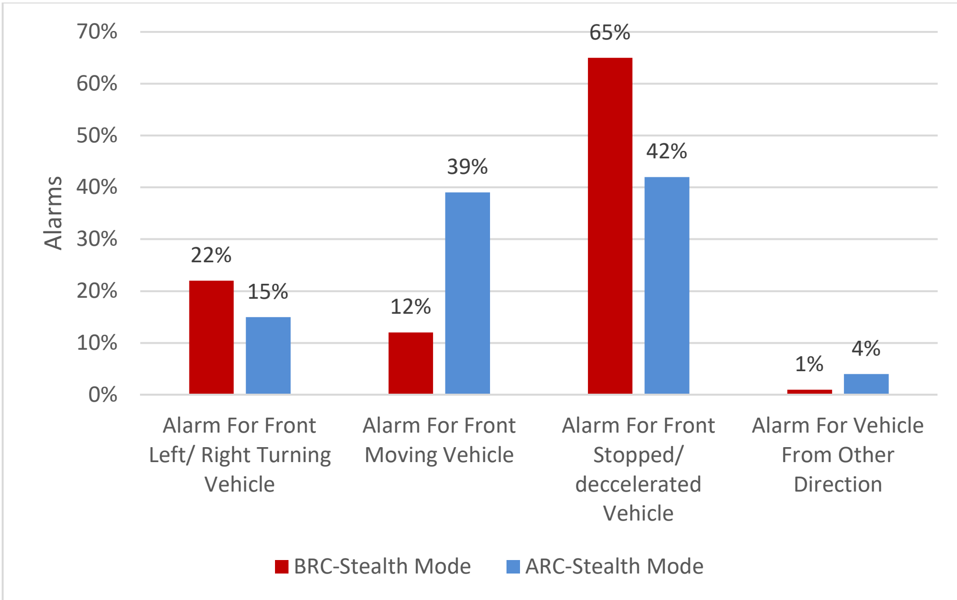

Figure 10-1: Statistical Distributions of the Alarm Types

10.1.2 Bus Drivers' Reaction

The hypotheses associated with this performance measure is that when the installed devices are active, the number of the bus drivers' reactions to potential threats will increase. Under the stealth mode, the bus drivers are not aware of the alarms, but the researchers are able to obtain the alarm times via the telematics data. The results presented in this section is only for ARC since there is no active mode for BRC. The driver's reaction were observed from the video clips. Figure 10-2 to Figure 10-4 show the results for the HW, UFCW, and FCW, respectively. These figures indicate there is a minor difference in the reaction between the active and stealth modes with regard to the Headway and FCW threats (2%-3% higher reaction with the active mode). However, there is a significant improvement in the reaction to UFCW threats with the active mode (by 21% from 82% to 100%, as shown in Figure 10-3). When considering all alarms, there was an improvement of 13%, from 67% reaction to 80% reaction, as shown in Figure 10-5. Hypothesis testing indicates that this difference in proportion is significant at the 95% significance level.

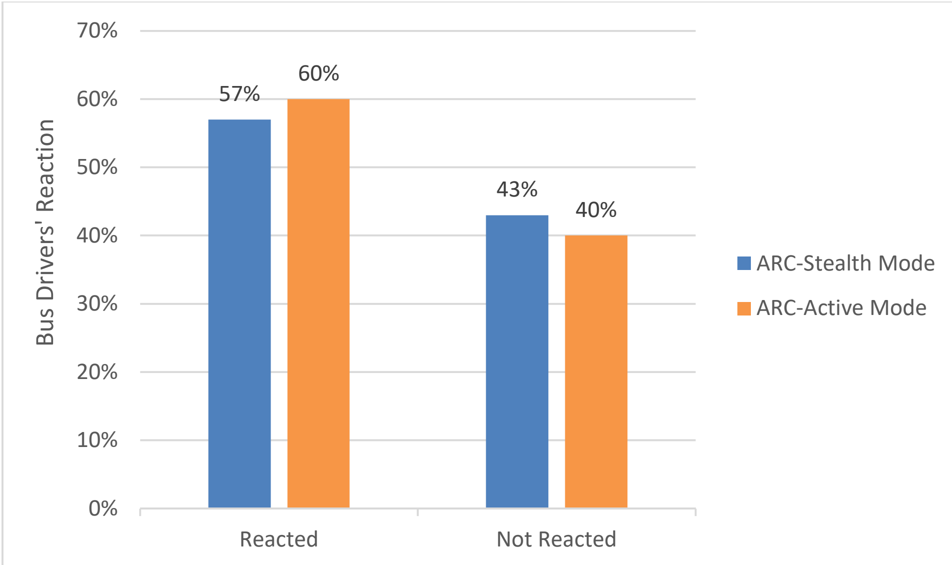

Figure 10-2: Bus Drivers’ Reaction to Headway Threats

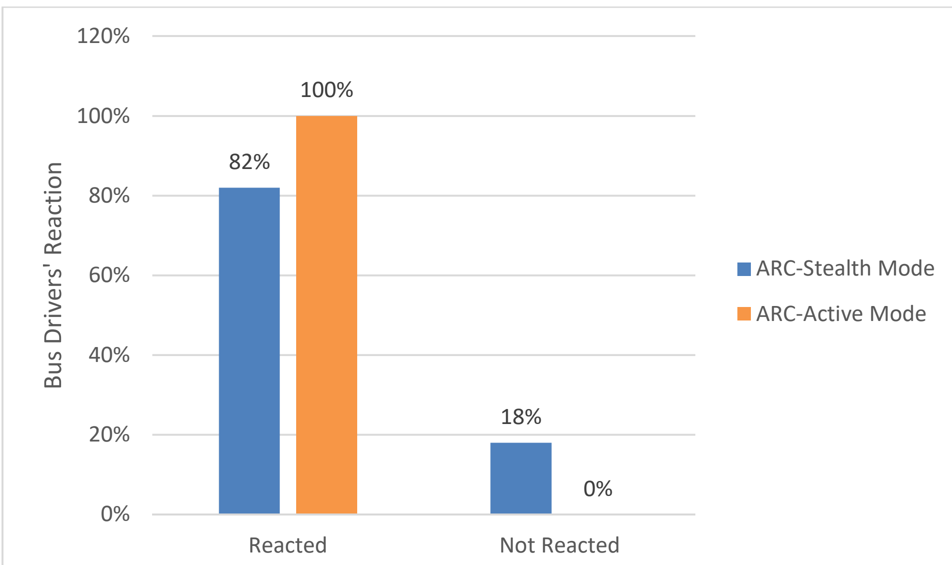

Figure 10-3: Bus Drivers’ Reaction to Urban FCW Threats

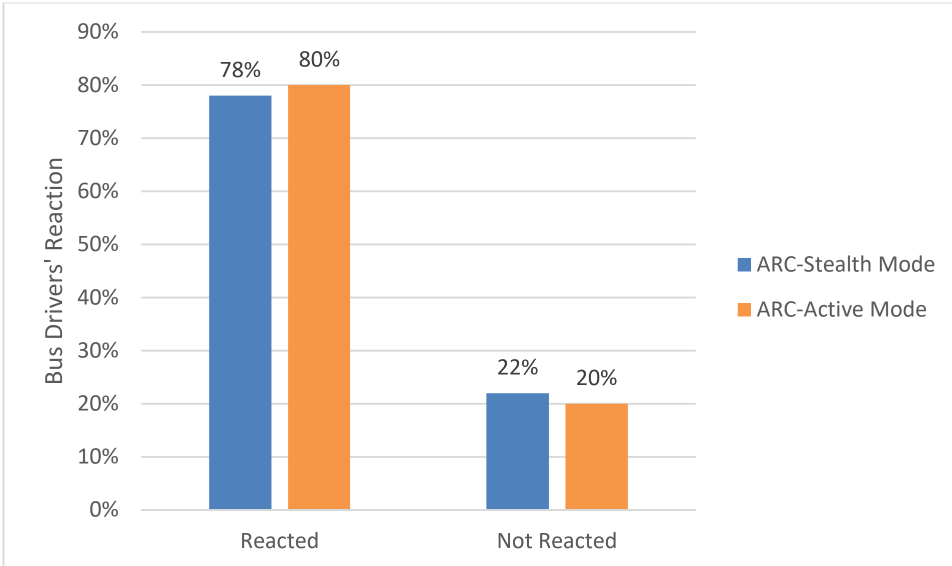

Figure 10-4: Bus Drivers' Reaction to FCW Threats

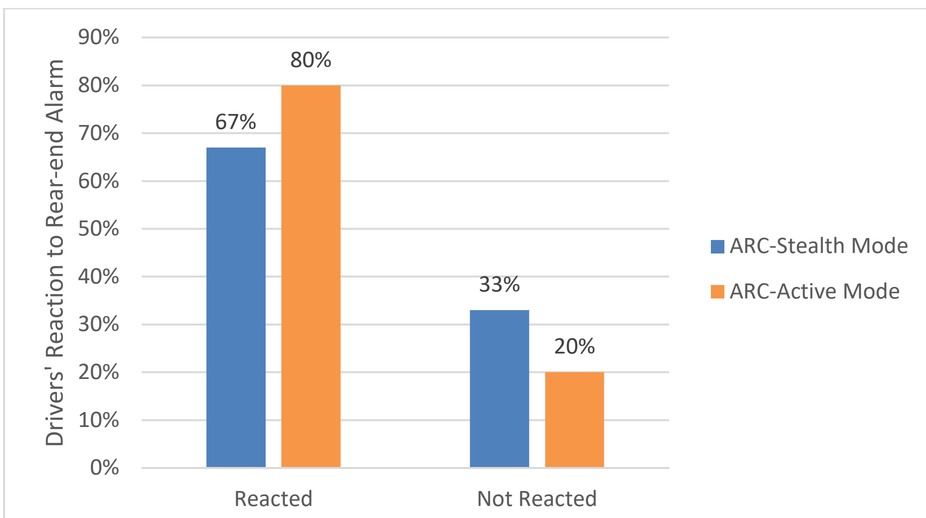

Figure 10-5: Drivers' Reaction to Overall Rear-End Collision Threats

10.1.3 Frequency of Generated Rear-End Conflict Alerts

The hypotheses associated with this performance measure is that when the installed devices are active, the drivers tend to drive in a safer manner as a result of being informed on safer driving behavior and to avoid the alarms. The results presented in this section is only for ARC since there is no active mode for BRC. The data were obtained from the vendor's web site. Figure 10-6 shows that the drivers tend to leave longer headways on average with the active mode (1.968 seconds vs. 1.896 seconds, which is 3.8% improvement). Figure 10-7 shows that the drivers tend to perform the hard brake less frequently with the assistance of the Mobileye system (166 miles per hard brake vs 105 per hard brake, which is 37% improvement). Figure 10-8 and Figure 10-9 show a significant reduction in the warnings with the active mode of all three types of threats. For example, when measured in mile per warning the reduction ranges from 28% (13.6 miles per warning vs. 9.8 miles per warning) to 34% improvement (70.6 miles per warning vs. 46.0 miles per warning), depending on the warning type. The lower number of warning with the active mode indicates more conservative driving.

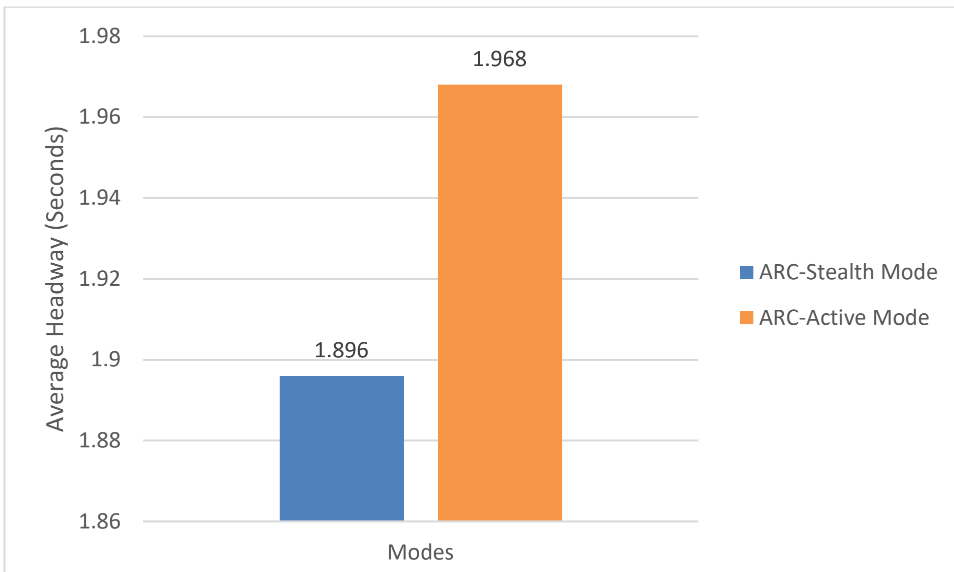

Figure 10-6: Average Headway Comparison between Stealth and Active Modes

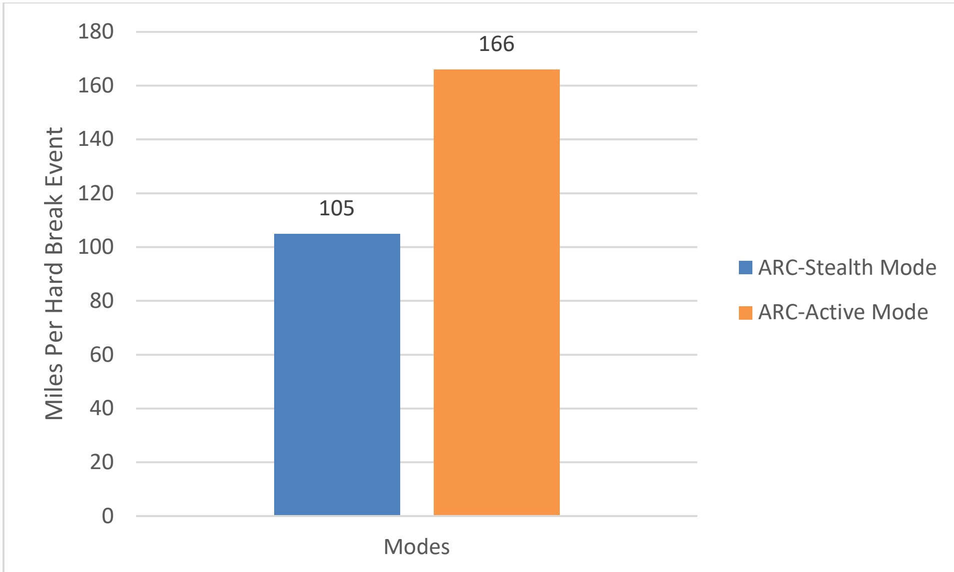

Figure 10-7: Frequency of Hard Brakes in Miles per Hard Brake Event

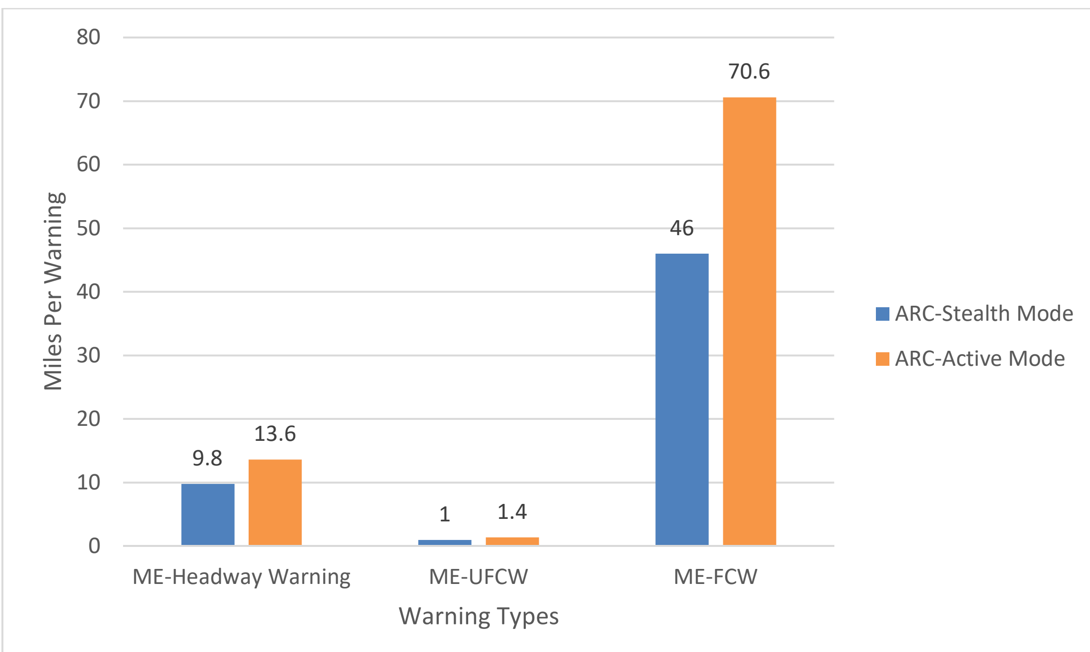

Figure 10-8: Frequency of Rear-End Warning in Miles per Warning

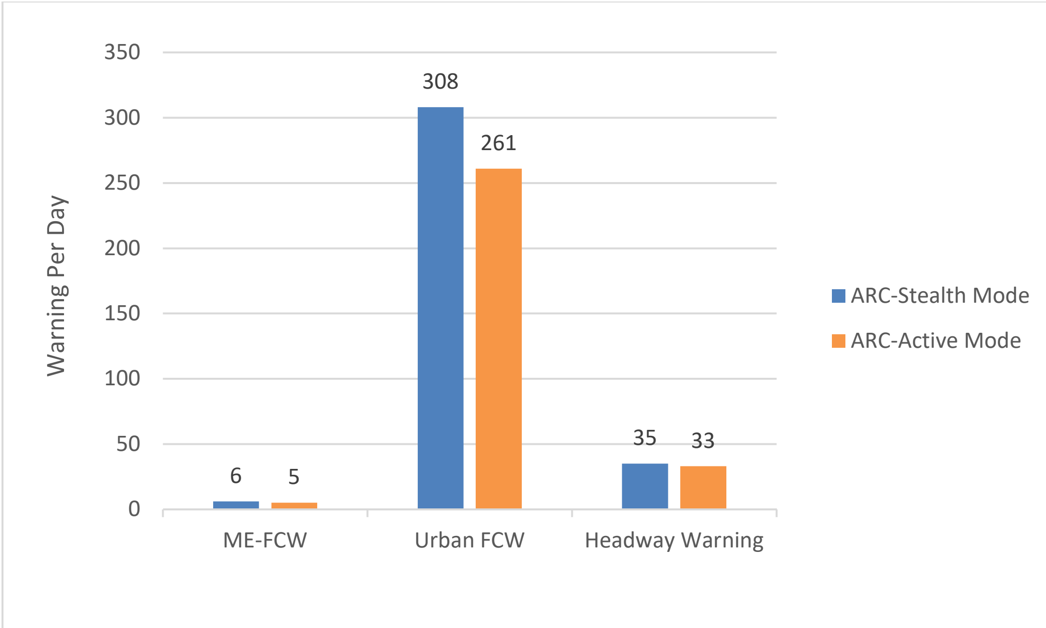

Figure 10-9: Frequency of Rear-End Alarms in Warning per Day per Bus

10.1.4 Accuracy

To estimate the accuracy of the rear-end alarms, 60 videos were downloaded and observed for each of the three alarm types (HW, UFCW, and FCW) for the before changing the route and after changing the route condition. If there was no observed vehicle in front of the bus or the front vehicle was too far from the bus at the alarm time, then the alarm was regarded as a false alarm. Figure 10-10 to Figure 10-12 show the percentage of and false alarms for headway warnings, UFCW, and FCW, respectively. After route changing, it can be seen that the percentage of the true alarm is 98%, 98%, and 92% for the three warnings, respectively; indicating a very high accuracy. Before route changing, the corresponding true alarms were 80%, 62%, and 82%; respectively.

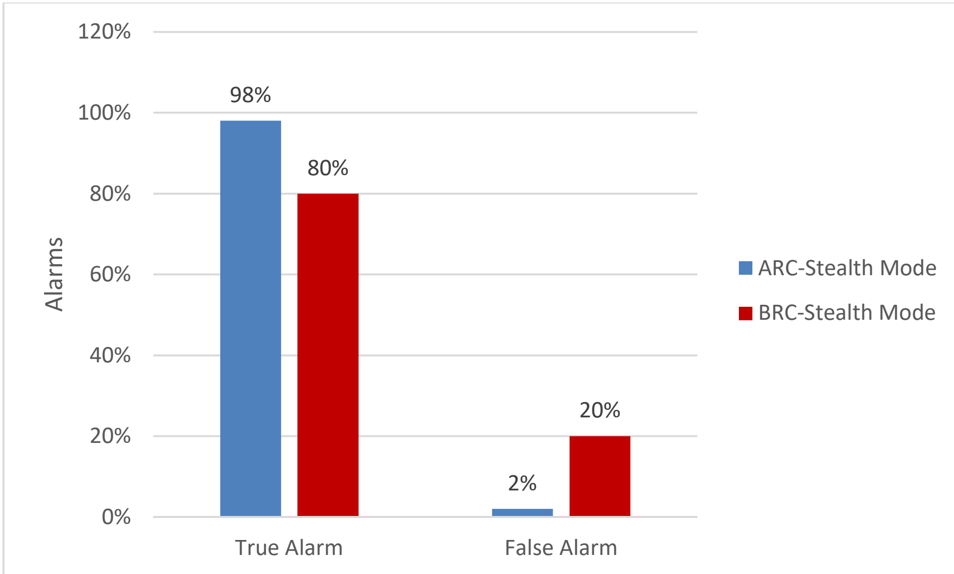

Figure 10-10: Accuracy of Headway Warning

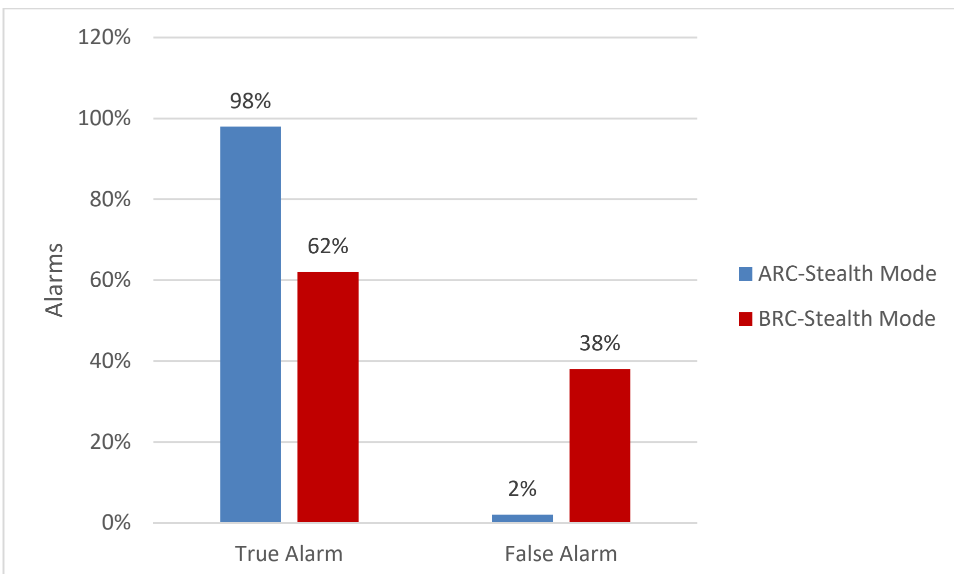

Figure 10-11: Accuracy of Urban FCW Warning

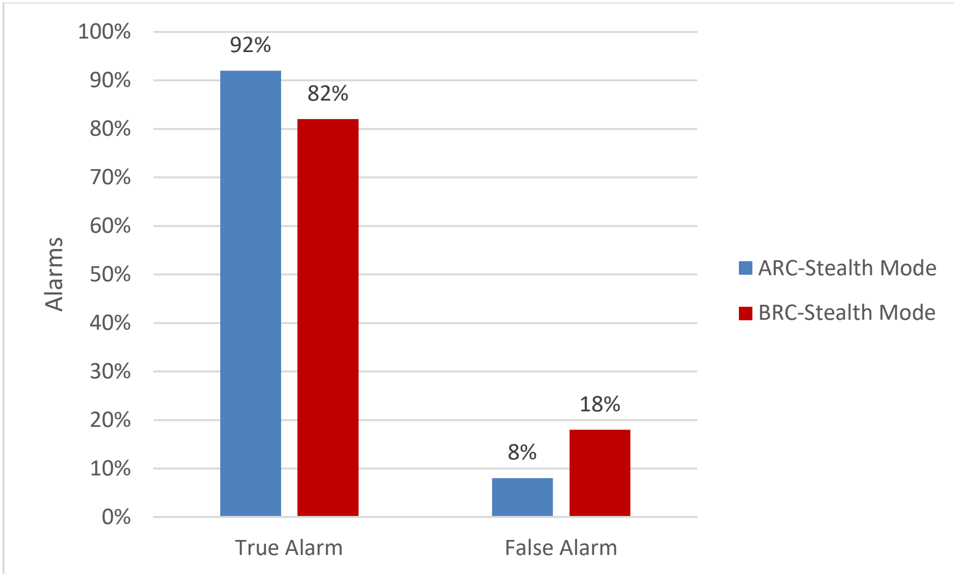

Figure 10-12: Accuracy of FCW Warning

10.2 Pedestrian Collision Warnings

This section includes the assessment of the pedestrian warnings by analyzing the types, accuracy, induced changes in driving reactions, and induced changes in driving behaviors associated with warnings.

10.2.1 Warning Reasons

To get the distribution of the reasons for the pedestrian collision warnings, 60 videos were observed for each detection direction. The results are shown in Figure 10-13 to Figure 100-16. The figures show that the pedestrians walking on the sidewalks, waiting on the bus stops, crossing the roads, and running to catch the bus are the main causes of the warnings.

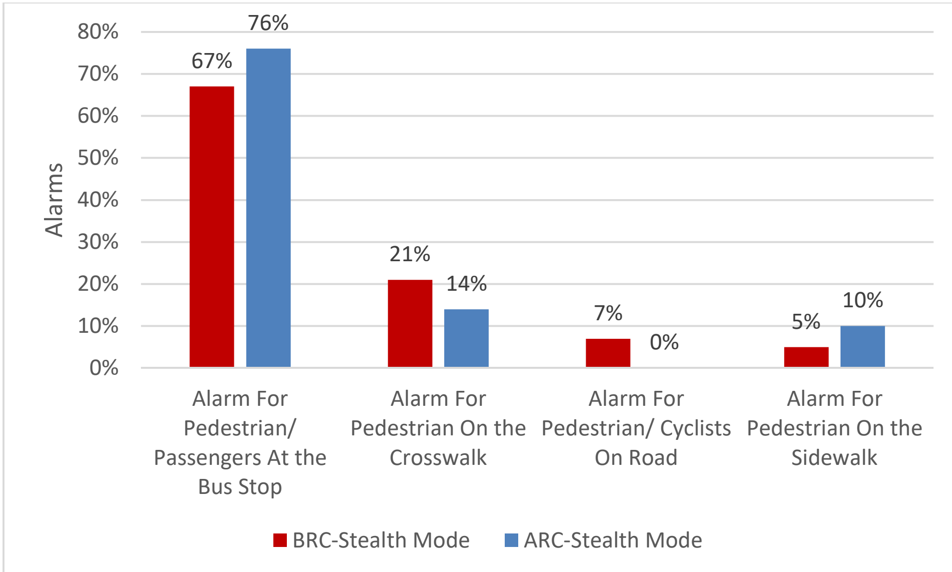

Figure 10-13: Statistical Distribution of PCW based on Front Camera (ME-PCW)

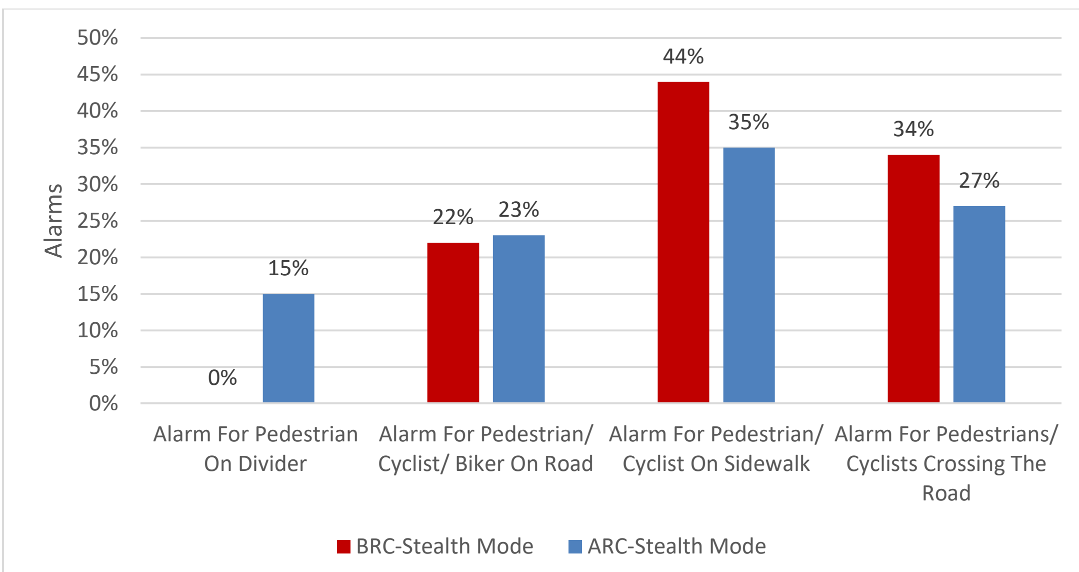

Figure 10-14: Statistical Distribution of PCW based on the Left Front Camera (PCW-LF)

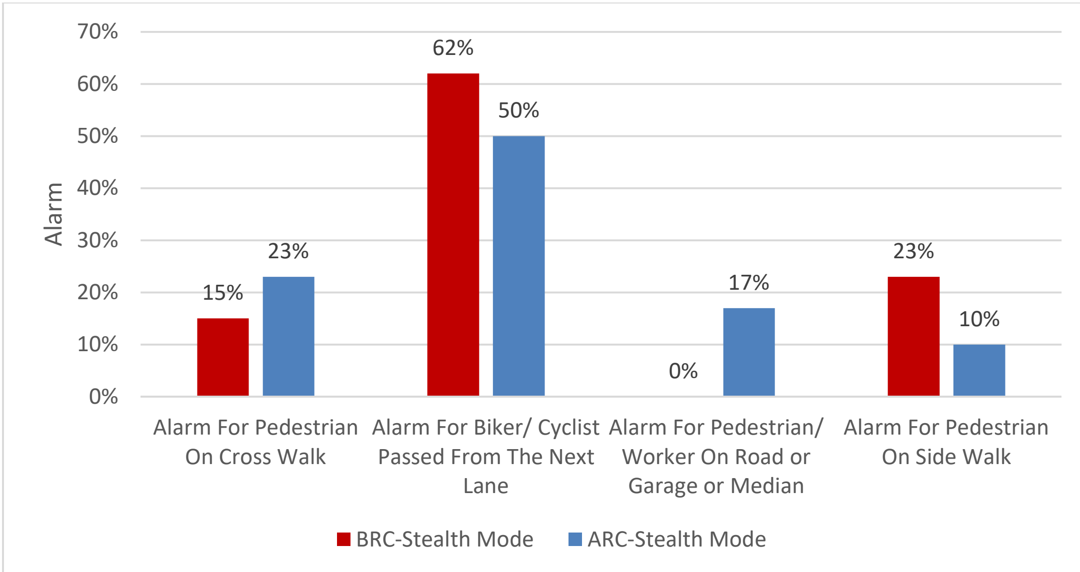

Figure 100-15: Statistical Distribution of PCW based on the Left Rear Camera PCW-LR

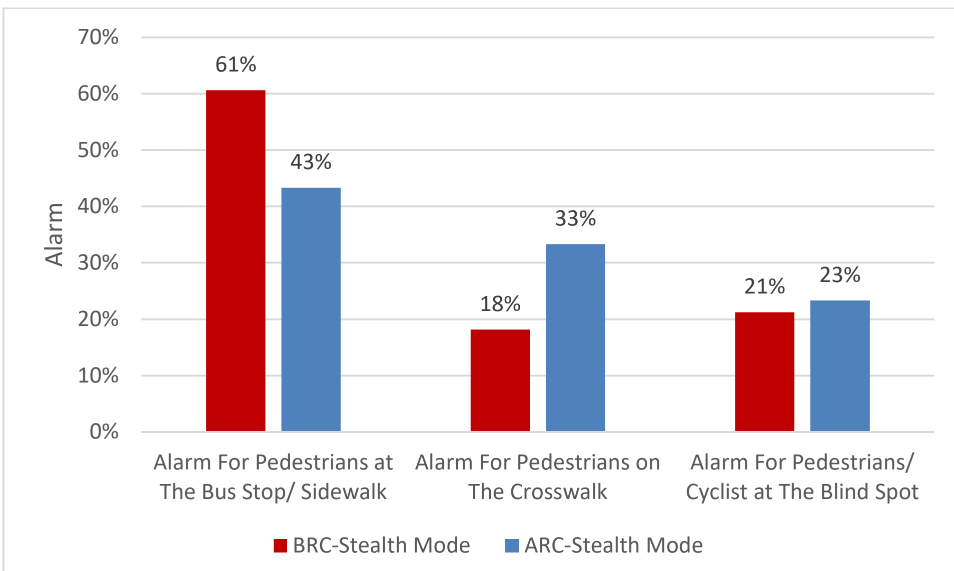

Figure 100-16: Statistical Distribution of PCW based on the Right Rear Camera PCW-RR

10.2.2 Bus Drivers' Reaction

Figure 10-17 to Figure 10-20 show the results of the examination of the bus drivers' reaction to the warnings of the pedestrian based on the four camera locations. The alarm time of PCW was compared to the time when the bus started to reduce the speed, if the driver did react. It's also possible that the driver had no response. For the warnings based on the middle front, left front, and right front cameras; the driver reaction improved from 77% to 98%, 27% to 100%, 32% to 95%; respectively. For the warning based on the rear-right cameras, the reaction was better in the stealth mode compared to the active mode (85% vs. 68%). Overall, Figure 10-21 shows an improvement in the reaction with the active mode (from 46% to 58%). Hypothesis testing indicates that this difference in proportion is significant at the 95% significance level.

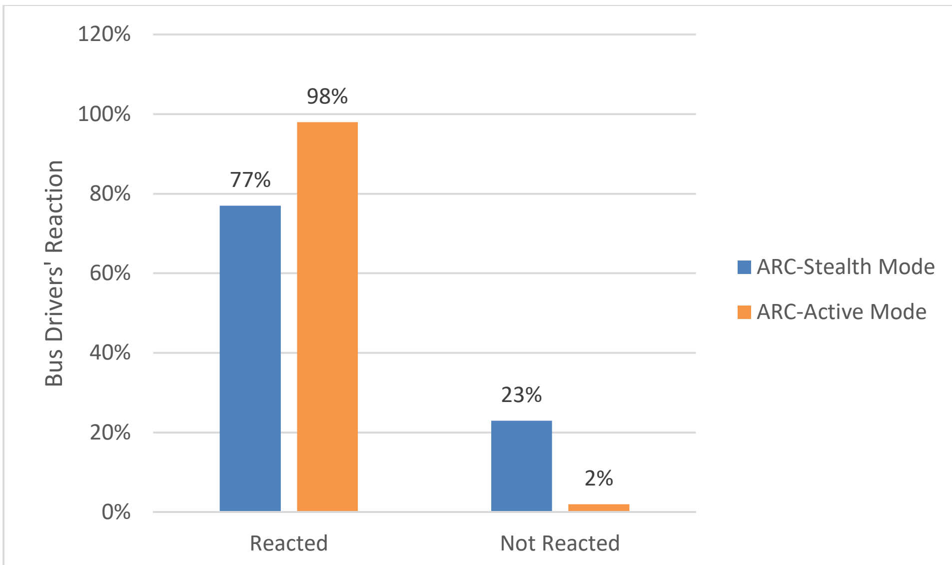

Figure 10-17: Bus Drivers' Reaction to ME-PCW

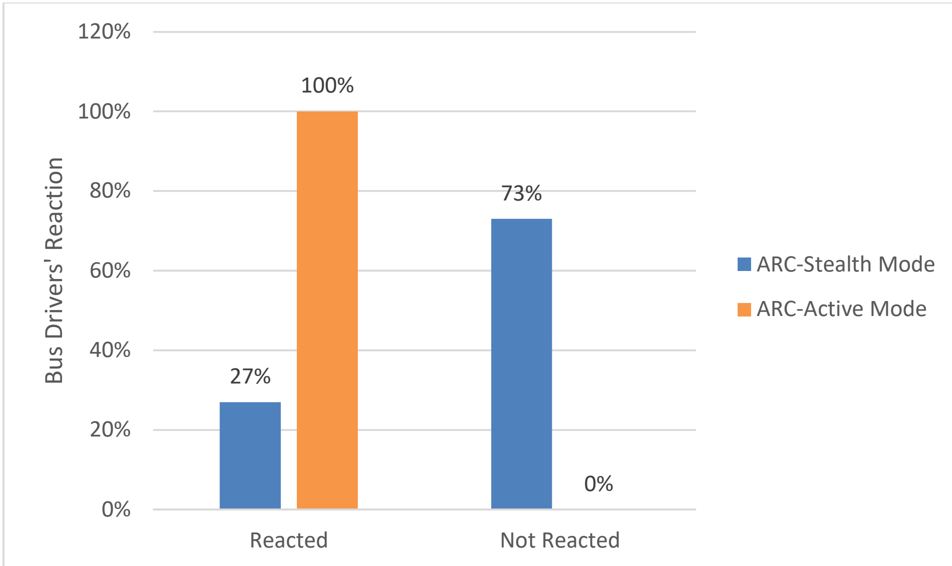

Figure 10-18: Bus Drivers' Reaction to PCW-LF

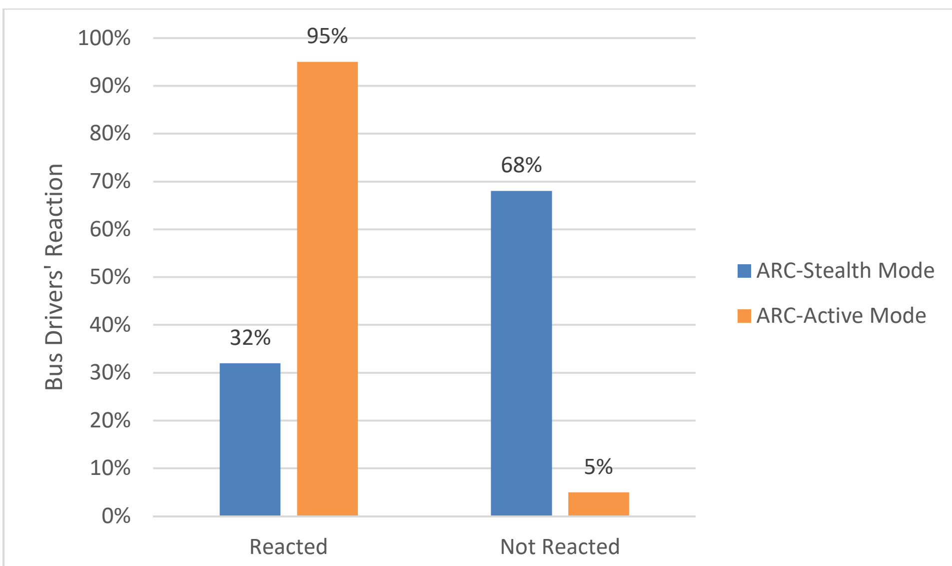

Figure 10-19: Bus Drivers' Reaction to PCW-LR

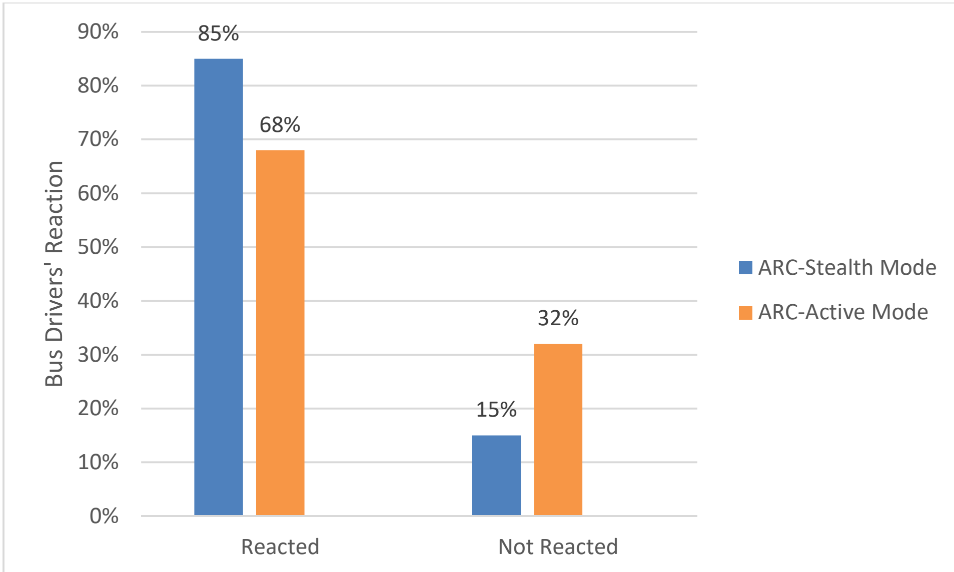

Figure 10-20: Bus Drivers' Reaction to PCW-RR

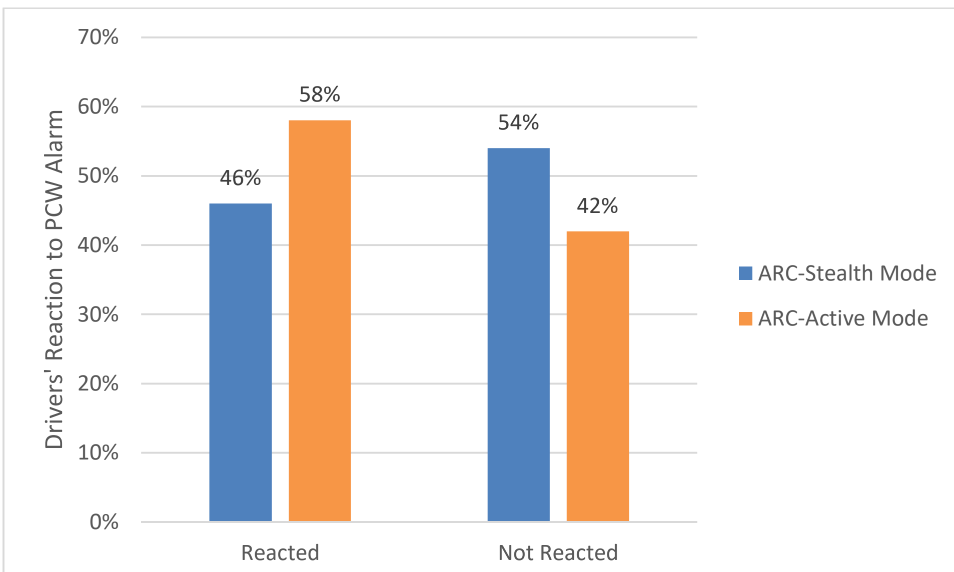

Figure 10-21: Overall Bus Drivers' Reaction

To further check the bus drivers' reaction to the PCWs, their yielding to the pedestrians who were crossing or intended to cross the streets was observed from the video clips. The results are shown in Figure 10-22 to Figure 10-25. For the warnings based on the middle front, left front, right front, the driver yielding behavior improved from 29% to 70%, 41% to 94%, and 83% to 87%. For the rear-right, the yield was 100% in both cases. Overall, Figure 10-26 shows an improvement in the yielding with the active mode by 51.7% (from 58% to 88%). Hypothesis testing indicates that this difference in proportion is significant at the 95% significance level.

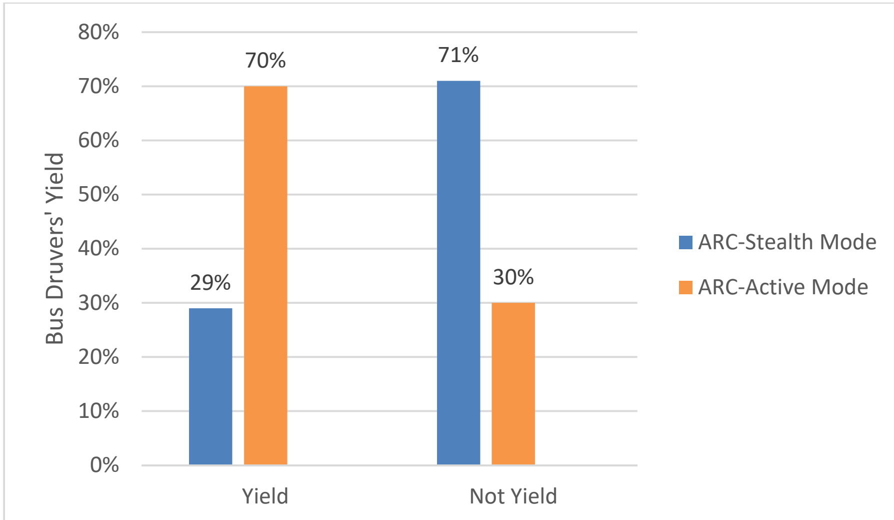

Figure 10-22: Bus Drivers' Yielding to Pedestrians for ME-PCW

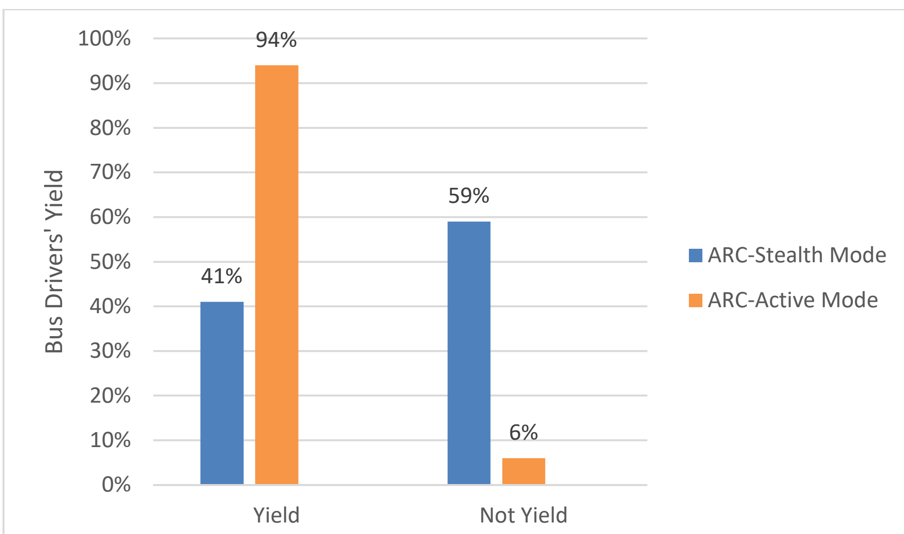

Figure 10-23: Bus Drivers' Yielding to Pedestrians for PCW-LF

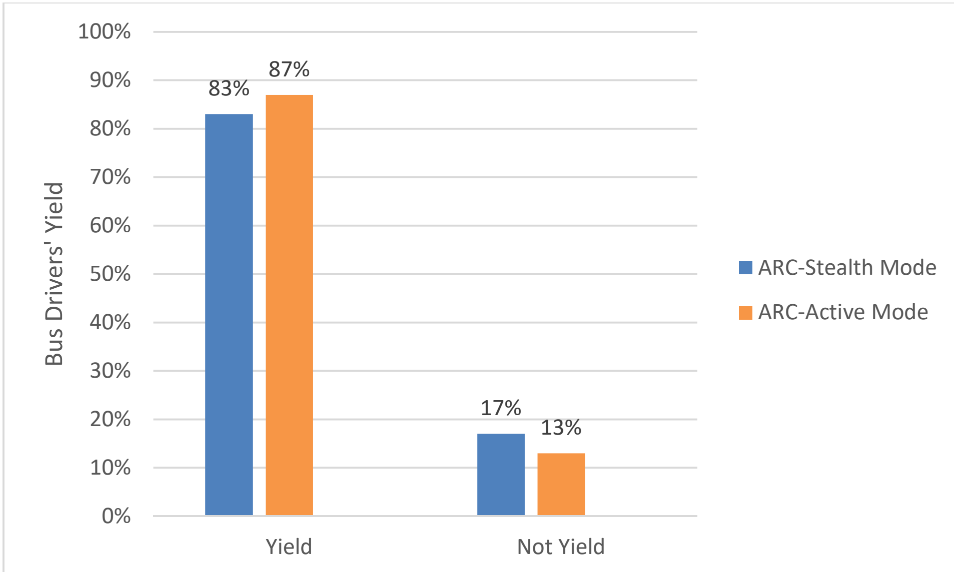

Figure 10-24: Bus Drivers' Yielding to Pedestrians for PCW-LR

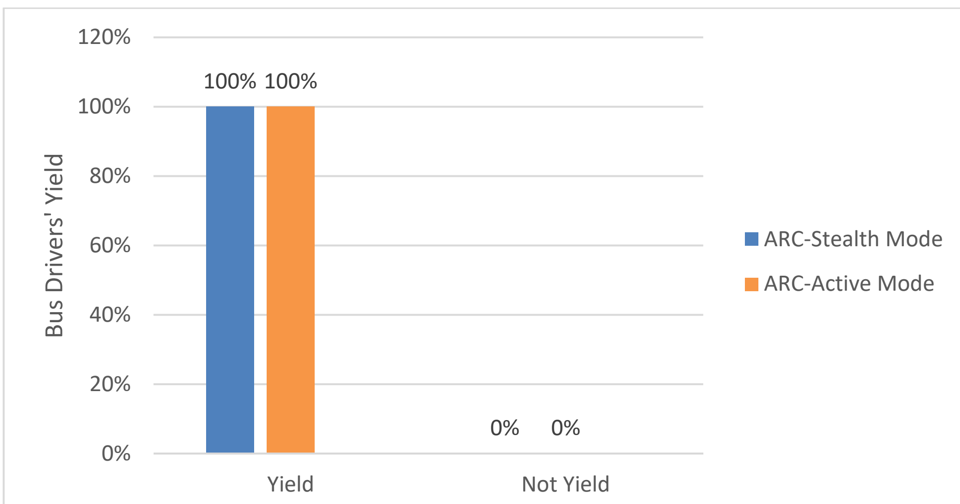

Figure 10-25: Bus Drivers' Yielding to Pedestrians for PCW-RR

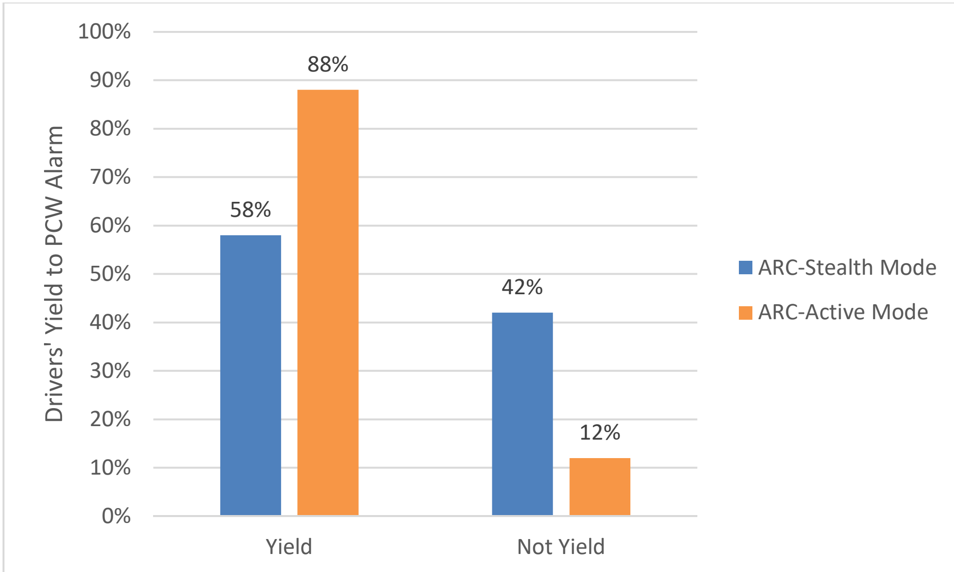

Figure 10-26: Overall Drivers' Yielding to Pedestrians

10.2.3 Number of Generated Pedestrian and Bicycle Conflict Alerts.

This study also examined the number of recorded warning in the stealth and active modes for the PCW. It was determined that the number of miles per warning is 15.9 with the stealth mode and 11.7 with the active mode. The number of warnings per bus per day was 24 with the stealth mode and 23 with the active mode. This indicates that there is no improvement that can be assessed for this measure. This may be due to the fact that pedestrian warnings is less related to driver behaviors and more related to the random activities and behaviors of the pedestrians themselves

10.2.4 Accuracy

To estimate the accuracy of the pedestrian/bicyclist alarms, 60 videos were also downloaded and observed for each warning category (by camera location). If there is no observed pedestrian in the field of view at the warning time, the alarm is regarded as a false alarm. Figure 10-27shows the percentages of false alarms for each direction of the warning and for the overall observations. It can be seen that, before changing the route, the warning based on the right-rear and left-front directions have high false alarm rate (45% and 40%, respectively). After changing the route, the false alarms for these two cameras are only 10% and 13%, respectively.

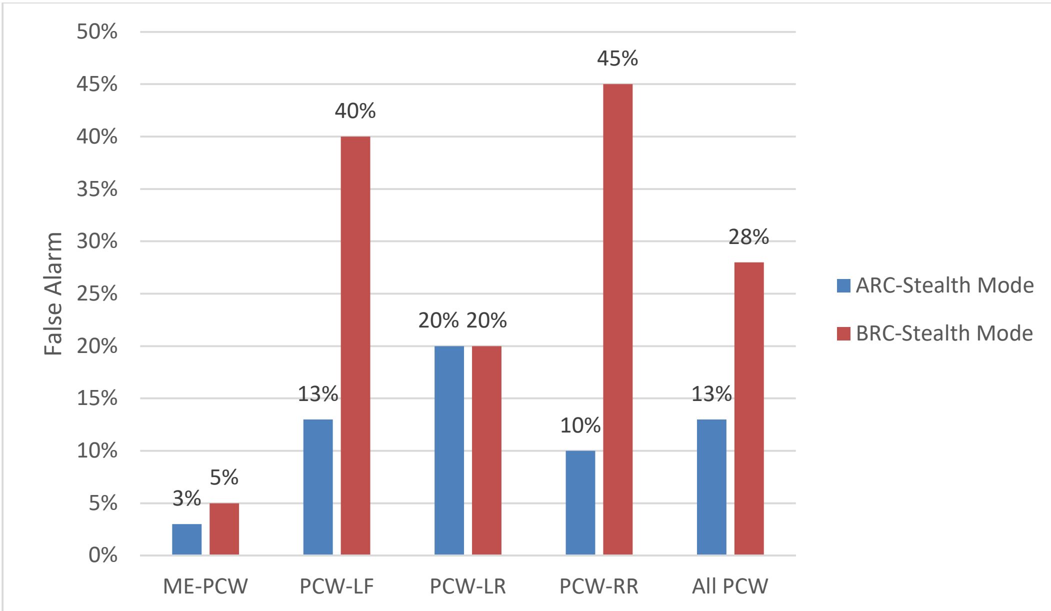

Figure 10-27: Percentage of False PCW

11 OPERATOR SURVEY

One of the objectives of this project is to determine the bus operator's acceptance of the system in relation to:

- Performance measure 3-1: Operator's perception of ease of use
- Performance measure 3-2: Operator's perception of overall usefulness
- Performance measure 3-3: Operator's perception of rear-end collision warning effectiveness
- Performance measure 3-4: Operator's perception of pedestrian collision warning effectiveness
- Performance measure 3-5: Operator's perception of accuracy

.A survey of the operators that experienced the system was conducted. First, a set of questionnaire was prepared. The set is included in Appendix A. The questionnaire was sent to a manager in Bus Operations of Miami-Dade County Department of Transportation and Public Works. The manager distributed the questionnaire list the operators, collected the response, and sent the response back to the research team. Overall, 57 operators filled the survey. This section provides a summary and analysis of the responses. A focus group face-to-face one hour meeting was also supposed to be conducted to obtain further information about driver perception and experience with the system. However, the research team is still trying to coordinate a good time for the County and the vendor to arrange for the meeting.

11.1 Ease of Use

As shown in Figure 11-1, when asked if the training on the Mobileye system was clear and comprehensive, 30% disagree. 35% disagreed that the visual and audible alerts of the Mobileye system are simple to understand as shown in Figure 11-2. 35% of the operators said that the system is not easy to use, as shown in Figure 11-3. It should be mentioned that the vendor trained personnel in the County designated as trainers by the County (the vendor trained the trainers).

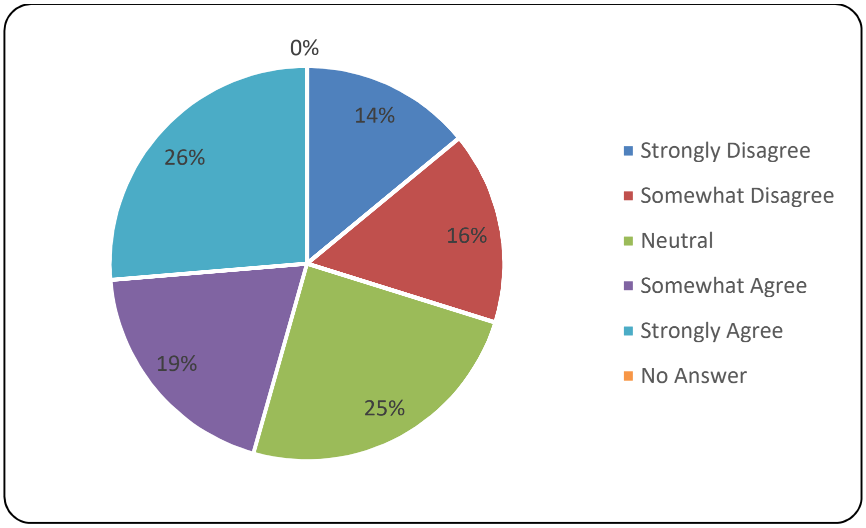

Figure 11-1: Comprehensive of Mobileye Training

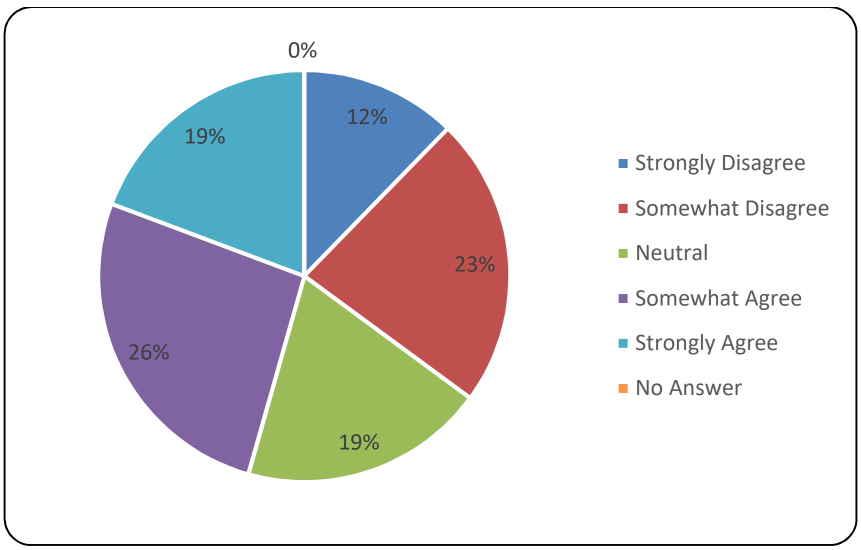

Figure 11-2: Simplicity of Visual and Audible Alerts

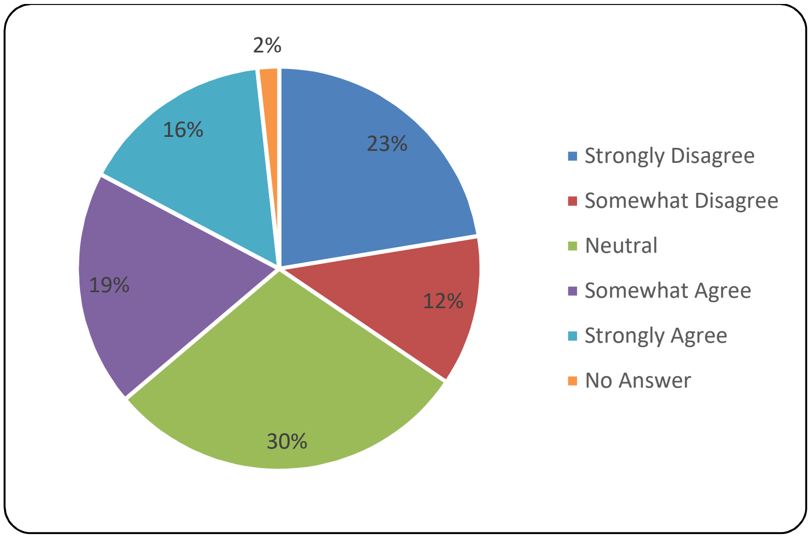

Figure 11-3: Ease of Use of Mobileye Device

11.2 Long Term Impact on Driving Behavior

As shown in Figure 111-4, 37% of the operators disagreed that the system has had a long-term positive impact on their driving behavior resulting in the system generating fewer alerts with more driving. 35% agreed or strongly agreed that the system has this impact and 26% were neutral. However, when the question was asked more directly in whether the system made the operator aware of his/her driving habits and ways to drive more safely, only 21% agreed and 46% disagreed, as shown in Figure 11-5.

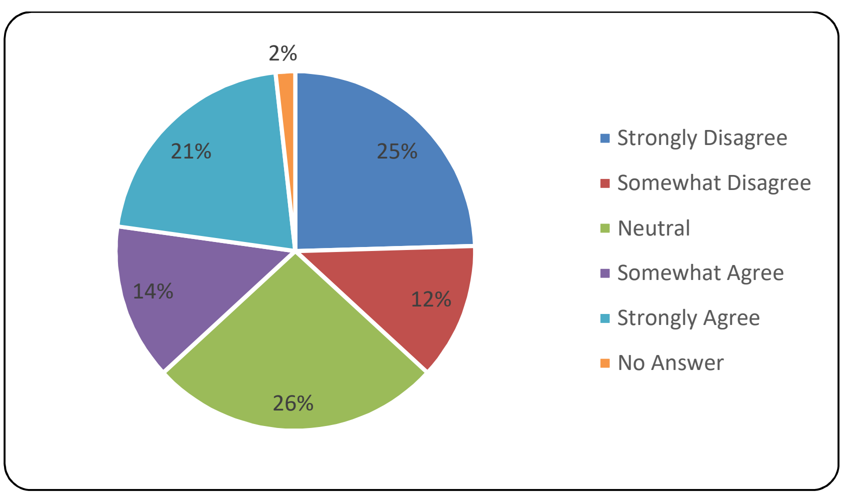

Figure 111-4: Fewer Alert Ratio with more Driving

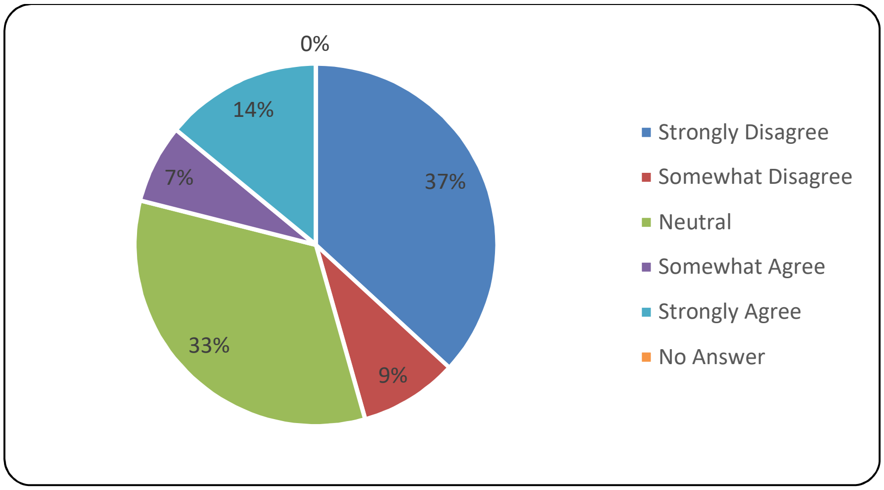

Figure 11-5: Devices Contribution to Change Drivers Behavior

11.3 Overall Assessment of System Usefulness

Figure 11-6 shows that 22% of the drivers stated that the system is helpful, 23% were neutral, and the remaining 57% disagreed. About the same split in opinion occurred when the operators were asked if the device makes them feel safer, as shown in Figure 11-7, and when asked whether at least in one occasions the Mobileye system proved its value with an alert of a possible incident, as shown in Figure 11-8. 55% of the drivers said that they would not recommend the device to other drivers, while 18% said they would recommend it, as shown in Figure 11-9.

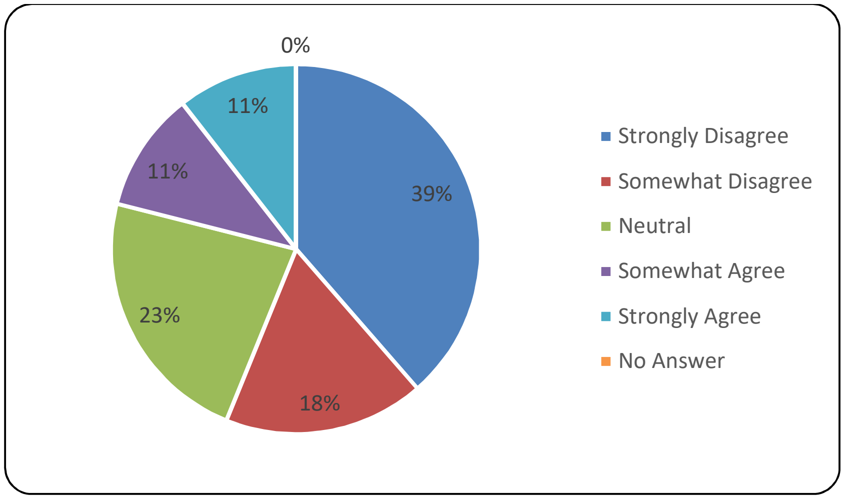

Figure 11-6: Device Helpfulness to Drivers

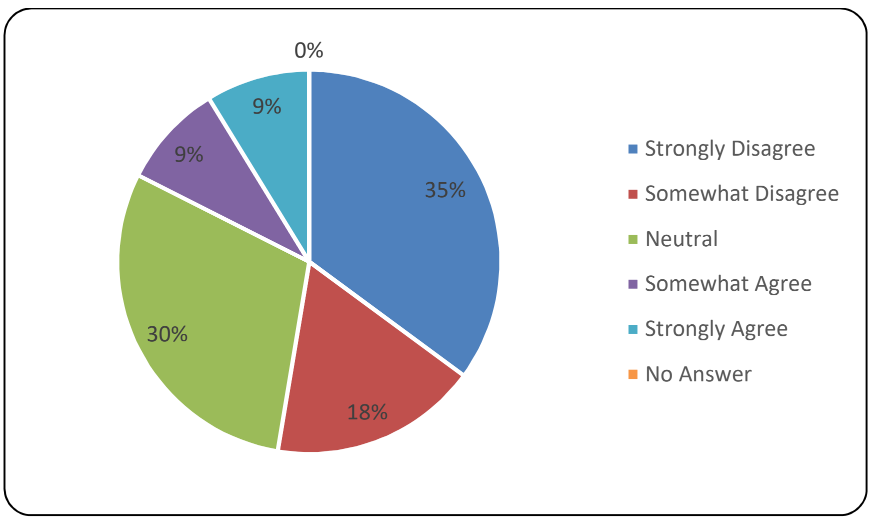

Figure 11-7: Drivers Safety Assurance

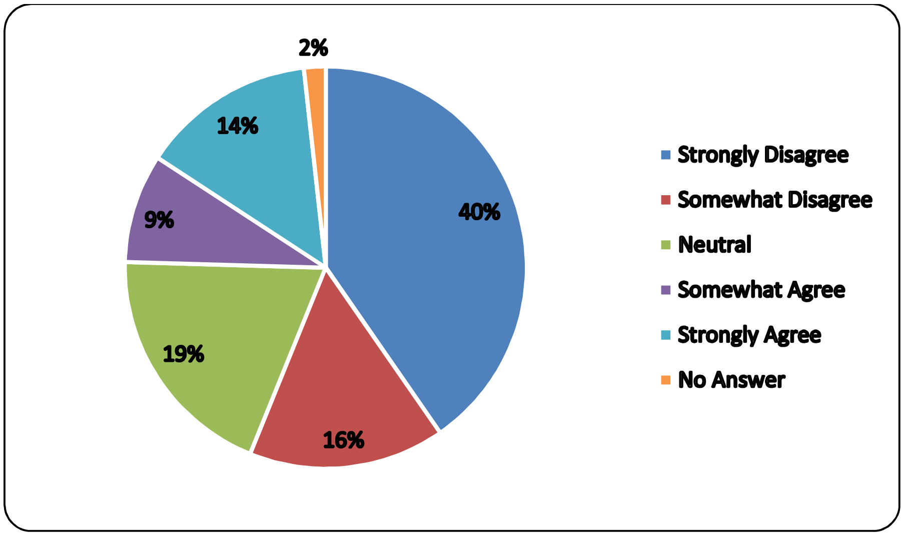

Figure 11-8: Alarm in Possible Crash

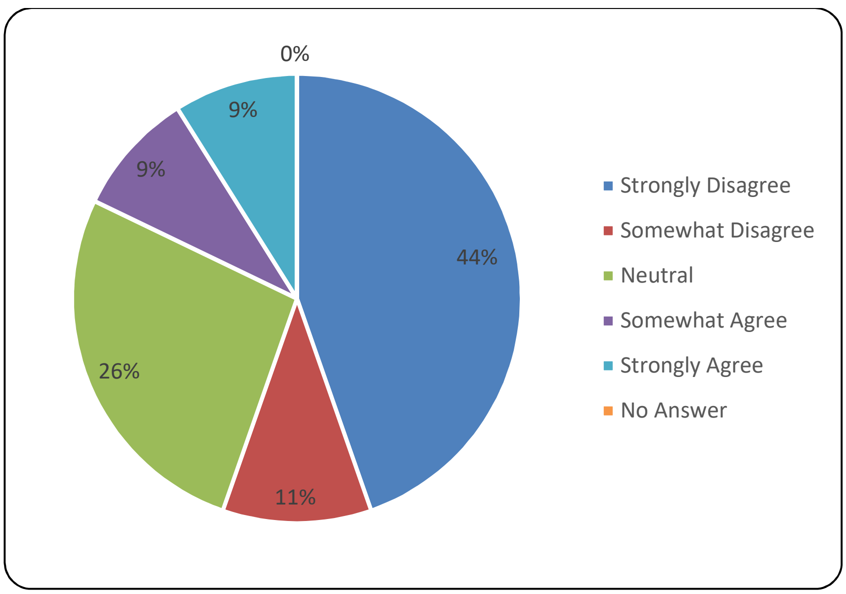

Figure 11-9: Drivers Recommendation to Other Drivers

11.4 Pedestrian Crash Warning Effectiveness

When operators were asked whether they felt that the pedestrian crash warnings were justified and reasonable, 21% agreed, 33% were neutral, and 45% disagreed, as shown in Figure 11-10. Figure 11-11 shows that 49% of drivers agreed that they saw conflicting pedestrians, but there were no pedestrian alarms given by the device; 33% disagreed and 16% were neutral.

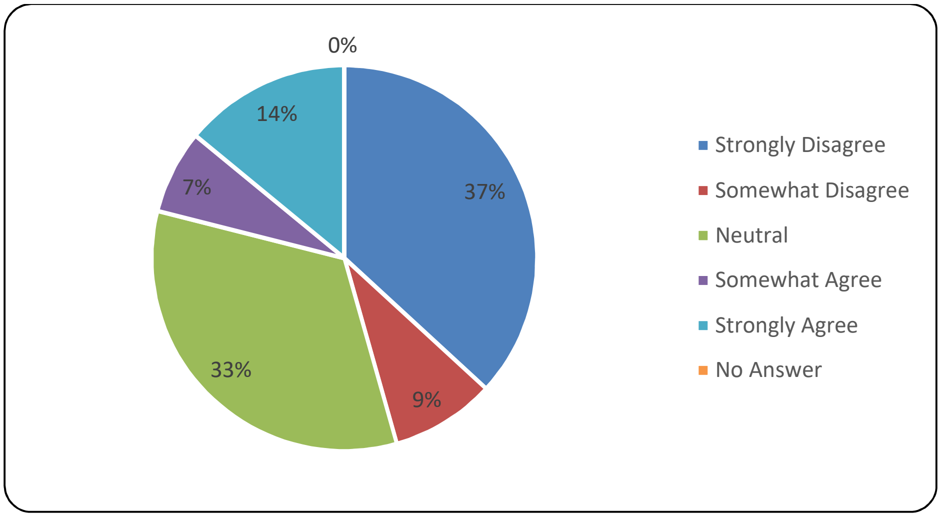

Figure 11-10: Confirmed Pedestrian Conflict Alarm

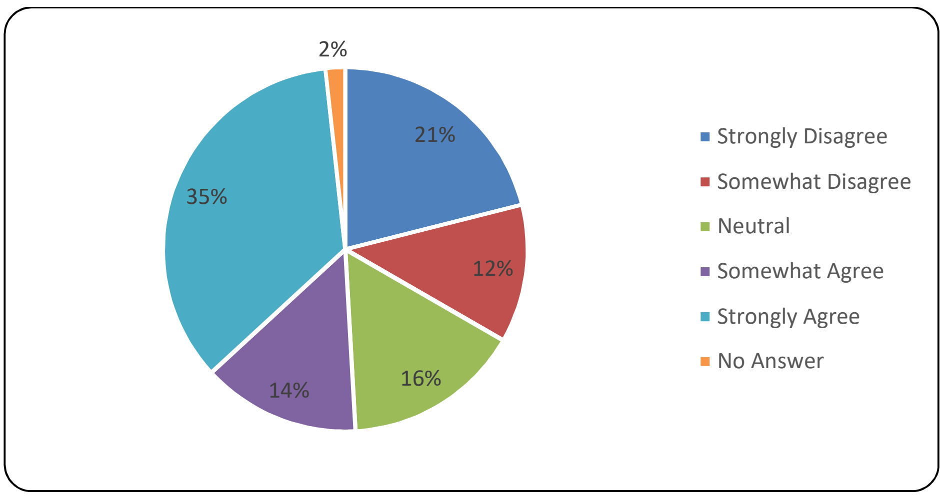

Figure 11-11: No Pedestrian Conflict Alarm for Pedestrians

11.5 Rear-End Crash Warning Effectiveness

When operators were asked about the rear-end alarms, 22% felt that the alarm is justified and reasonable, as shown in Figure 11-12, which is about the same percentage as that of the pedestrian alarms. However, the disagreement is 37% for rear-end alarms compared with 25% for pedestrian alarms.

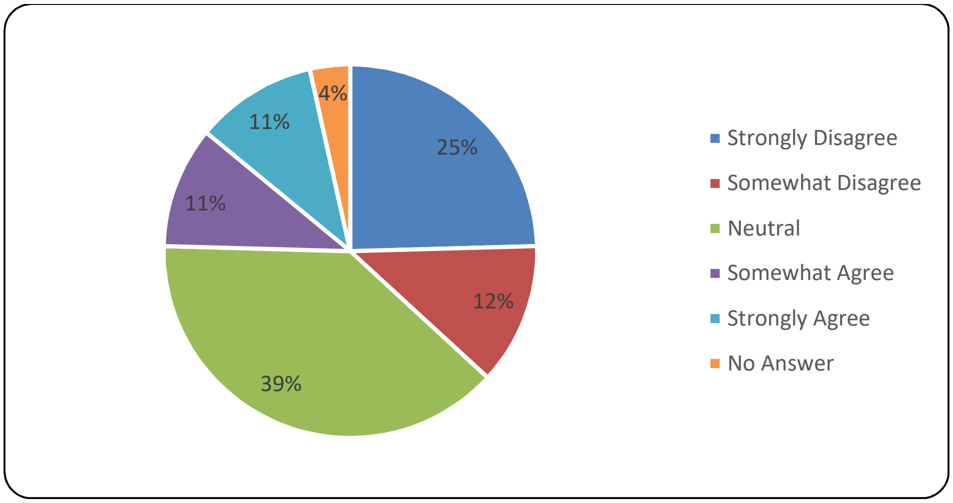

Figure 11-12: Confirmed Rear-end Conflict Alarm

47% of drivers agreed that sometimes the front vehicle was close and the operators and felt that alarms should have been given, but there were no rear-end alarms; 27% disagreed and 33% were neutral, as shown in Figure 11-13.

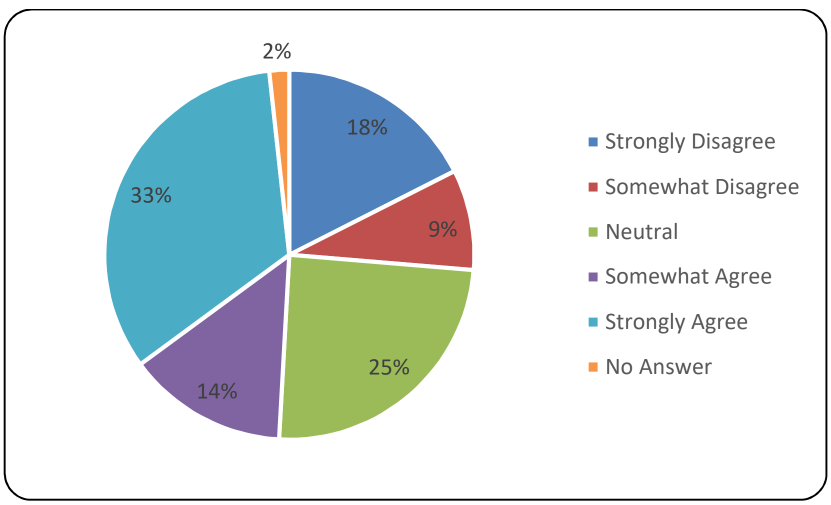

Figure 11-13: No Rear-end Conflict Alarm

11.6 Warning Accuracy

Figure 11-14 indicates that 20% found the system to be accurate, 54% disagreed, and 26% were neutral.

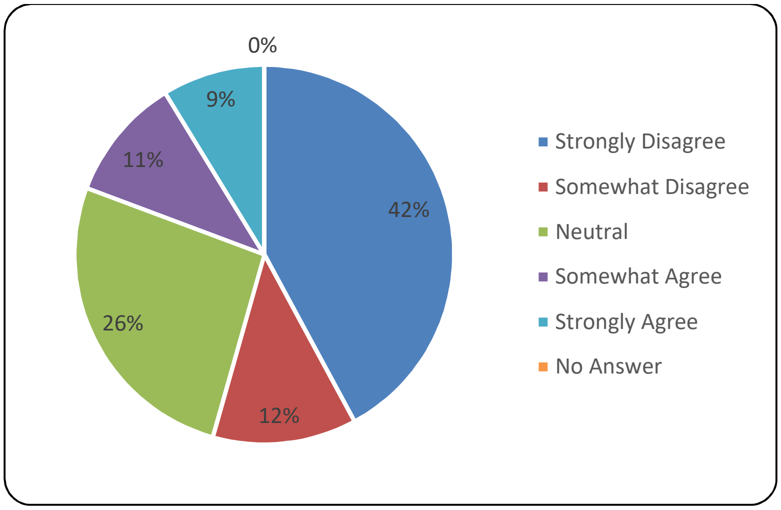

Figure 11-14: Drivers Observation on Mobileye's Accuracy

11.7 Survey Summary and Face-to-Face Interview Results

Based on the survey results, it appears that 20%-22% of the drivers liked the system and gave consistently positive responses when assessing the overall system effectiveness, system usefulness, and accuracy. 50-55% of the responder had negative impressions and decided to provide negative responses on most of the questions. 25% to 30% were neutral. 30% to 35% disagreed that the system is easy is to use and indicated the need for more training. There may be a need for additional training in future efforts. From the above, the driver acceptance seems to be low but as indicated in the earlier sections there are evidence of positive impacts of the system.

Thus, the researchers conducted face-to-face interviews with ten bus drivers selected randomly from the drivers that drove the system. Among these drivers, three were very supportive of the system. The remaining were between neutral and negative. Some drivers said that the device make them drive more carefully to avoid the alarms. A number of drivers said that there was a benefit of the blind spot alerts of pedestrian crossing and they like this feature. Some drivers said that the indicators' (visual displays') location need to be optimized. However, a couple of drivers said that some of the sound alarms are too late and need to start sooner. Some drivers pointed to the need to change from the flashing yellow that is displayed under certain conditions to red and to sound alerts earlier. Drivers also indicate the preference for sound alerts rather than visual alerts since they are busy, and it is difficult to pay attention to the visual displays. The low driver acceptance points to the need for additional outreach and education of the drivers of the system and its effectiveness.

12 BENEFIT-COST ANALYSES

An important criterion in the selection and adoption of a technology is the return on investment of the technology. The return on investment analysis is conducted by calculating estimates of the net present value (NPV) or benefit-cost ratio of the analyzed solution. This involves estimating of the present values of the current and future benefits and costs over the project's economic life. A discount rate is used to calculate the present values of the cash flows.

The annual benefits of the Mobileye device per bus was calculated first by estimating the base (do-nothing) number of crashes per year. The base number of crashes was then multiplied by a crash modification factor (CMF), which represents the percentage reduction in crashes due to the device, to obtain the number of crashes that are expected to reduce due to the installation of the device. Finally, the reduction in the number of crashes per year was multiplied by the dollar value of crashes to obtain the annual benefits in dollars. The present worth of the benefits is calculated using an interest rate of 7% and a project life-cycle of five years. The present worth of the costs was calculated by summing up the cost of the devices, installation cost, and the present worth of the recurrent cost of the technical support.

The benefit-cost analysis were performed for three scenarios. The first two are for installing the devices on two bus routes (Routes 119 and 120) that are among the routes with the highest number of bus crashes in Miami-Dade County. The third scenario is to install the devices on the buses of all the routes in the county.

12.1 Base Condition Crash Estimation

The base condition crash estimation per bus per year was estimated based on the bus crash statistics per year provide by the County. It is worth noting that only pedestrian and rear-end (a bus collides with the vehicle in front) crashes were used in the calculation, since the Mobileye system is a counter measure for these bus crash types. The crash data for Miami-Dade County buses from January 2013 to August 2016 were analyzed in this study. As shown in Table 12-1, the calculated crash rates are categorized based on the three crash severity levels: fatality, injury, and property damage only (PDO), since different crash severity has different dollar values.

Table 12-1: Base Condition Crash Rates

Route	Crash Severity	Rate (Crashes/Bus/Year)
Route 119	Fatality	0*
	Injury	0.156
	PDO	0.371
Route 120	Fatality	0*
	Injury	0.105
	PDO	0.231
All Routes	Fatality	0.002
	Injury	0.0508
	PDO	0.090

*There were no fatality crashes for Route 119 and 120 during the study period.

12.2 Crash Modification Factors

An important part of the return on investment analysis is to identify crash modification factors that can be used to multiply the base condition crash estimates to calculate the safety benefits. The results presented earlier in this document based on the tests conducted in this study indicates that the bus operator's reaction to the overall rear-end collision threat improved by 19.4% (from 67% to 80%). The bus operator's reaction to pedestrian collision threats improved by 26.1% (from 46% to 58%) and the yielding to pedestrian percentage improved by 51.7% (from 58% to 88%). These numbers can be used to inform the estimation of the crash modification factors. However, a review of the literature was also conducted to provide additional information for the calculations.

Lindman et al. (2010)[12] indicated that full deployment of pedestrian collision auto brake features has the potential to reduce pedestrian fatalities by 24 percent based on a Volvo Cars Traffic Simulator (VCTS). Pecheux and Kennedy (2015)[13] reported, based on a study in Portland, OR, that 23% of pedestrians reported that a crosswalk transit vehicle turn warning system helped them avoid a collision with a bus. A study on the effect of forward collision warning (FCW) alarms by Fitch, et al. (2008) determined that a nationwide deployment of FCW in heavy vehicles could reduce the number of rear-end crashes by 21 percent[14]. Anderson et. al. (2012)[15] reported a reduction of 20% to 40 % of all fatal crashes with FCW. Kuehn et al. (2009)[16] estimated 25% reduction of all crashes and 30 to 50 % reduction of all injury crashes with a combination of FCW and lane departure warning system. Based on the results of the evaluation and the review of literature above, it was decided to use CMF of 20% for both rear-end warning and pedestrian warning systems.

12.3 Dollar Value of Crashes

The safety benefit dollar values are also needed to determine the return -on-investment of different applications. A wide range of values has been used in the literature for these parameters. Table 12-2 provides a summary of the crash cost based on the literature review. The dollar values used in this study are $120,000 for fatality and injury crashes and $10,000 for PDO crashes. Relatively

12 Lindman, M., A. Ödblom, E. Bergvall, A. Eidehall, B. Svanberg and T. Lukaszewicz. Benefit Estimation Model for Pedestrian Auto Brake Functionality. 4th International Conference on Expert Symposium on Accident Research, 2010 http://bast.opus.hbz-nrw.de/volltexte/2012/536/pdf/Benefit_Estimation_Model_for_Pedestrian_Auto_Brake_Functionality.pdf.

13 Pecheux, K. and J. Kennedy (2015). Evaluation of Transit Bus Turn Warning Systems for Pedestrians and Cyclists (Final Report FTA Report No. 0084). Prepared for Federal Transit Administration (FTA), Washington, DC.

14 Fitch, G. M., Rakha, H. A., Arafeh, M., Blanco, M., Gupta, S. K., Zimmermann, R. P., & Hanowski, R. J. (2008). Safety benefit evaluation of a forward collision warning system: final report. NHTSA, US Department of Transportation, HS, 810(910), 100.

15 Anderson, R., Doecke, S., Mackenzie, J. R., Ponte, G., Paine, D., & Paine, M. (2012). Potential benefits of forward collision avoidance technology. Injury, 44(15), 24.

16 Kuehn, M., Hummel, T., & Bende, J. (2009, June). Benefit estimation of advanced driver assistance systems for cars derived from real-life accidents. In 21st International Technical Conference on the Enhanced Safety of Vehicles ESV (Vol. 15, p. 18).

higher values are used for injury and PDO considering the more severe types of crashes associated with buses compared to passenger cars, particularly those associated with pedestrians and considering previous studies that indicate that only more severe crashes are usually reported and archived in the crash databases of transit agencies. The high cost associated with fatal crashes was not used in this study to avoid biasing the results, since the crash rate is very small and the fatality per route is not a reliable estimate considering the sample size and stochasticity.

Table 12-2: Summary of the Crash Cost

Source	Doller Value
FITSEVAL (Hadi et al., 2008)[17]	Urban Street Fatal $2,935,000; Injury $72,000; PDO $1,776 Urban freeway Fatal $3,079,351; Injury $73,390; PDO $1,776
FDOT District 5 (2016)[18]	1 Fatal [K] $10,230,000; 2 Incapacitating [A] $580,320; 3 Non-Incapacitating [B] $157,170; 4 Possible or Minor [C] $97,650; 5 Property Damage Only [O] $7,600.
TOPS-BC (2019)[19]	Fatality Cost - $6,500,000; Injury Cost - $67,000; PDO - $2,300.
B-C Wiki (2019)[20]	Blincoe, et al. state that the value of a fatality lies in the range of $2-7 million, and assign a "working value" of $3,366,388. This suggests that a reasonable range is from about 40% lower to about 200% higher than their assigned values, at least for crashes involving significant non-market (quality of life) damages
Highway Safety Manual (HSM, 2010)[21]	1 Fatal [K] $4,008,900; 2 Disabling Injury [A] $216,000; 3 Evident Injury [B] $79,000; 4 Fatal/Injury [K/A/B] $158,200; 5 Possible Injury [C] $44,900; 6 Property Damage Only [O] $7,400.

17 Hadi, M., Y. Xiao, H. Ozen, and P. Alvarez. Evaluation Tools to Support ITS Planning Process: Development of a Sketch Planning Tool in FSUTMS/Cube Environment. Final Report, Lehman Center for Transportation Research, Florida International University, October 2008.

18 FDOT Plans Preparation Manual 2016. https://www.fdot.gov/roadway/PPMManual/2016PPM.shtm

19 Tool for Operations Benefit Cost Analysis (TOPS-BC) [Computer software]. (2019). Retrieved from https://ops.fhwa.dot.gov/plan4ops/topsbctool/

20 Blincoe, L., Seay, A., Zaloshnja, E., Miller, T., Romano, E., Luchter, S., Spicer R., (2002), The Economic Impact of Motor Vehicle Crashes 2000, DOT HS 809 446, National Highway Traffic Safety Administration, Washington, D.C.

21 AASHTO, 2010. The Highway Safety Manual, American Association of State Highway Transportation Professionals, Washington, D.C., http://www.highwaysafetymanual.org.

12.4 Device Costs

The product installed in this project was provide by the Mobileye vendor. The product is the *Rosco's Shield + (Vision Quest) System*, part number VQS4560. The system consists of four Mobileye Model 560 sensors, two exterior sensor housings, two interior sensor housings, and three driver interface displays. The System Includes:

- Front and side sensing of pedestrians and cyclists in complex urban environments including turns and intersections, with outputs to the bus driver that improve the ability to detect potential collisions with these targets in time to stop the bus.
- Mobileye's Eyewatch driver display for urban and highway forward collision warning, lane departure warning, headway following time monitoring and warning, pedestrian and cyclist detection, speed limit indication and intelligent high beam control.
- Three Rosco driver displays that visually and audibly alert the driver of potential collisions with targets.

The system hardware is $6,900 per bus. The installation is $2,000 per bus. The annual recurrent cost is the telematics subscription of $239.88 per bus annually.

12.5 Return on Investment Results

This section presents the results from the return on investment analysis conducted in the analysis. As stated earlier, all the benefits and costs were converted to present worth using Uniform Series Present Worth Factor (P/A, i, N). The factor value for an interest rate of 7% and project life of 5 years is 4.1.
Table 12-3 shows the calculations of the B-C ratio. The results show that the return on installing the Mobileye system on all the buses in Miami-Dade County may not be cost effective, installing the system on only the buses of routes with high crash frequencies can be justified based on the return-on-investment analysis. The estimated B-C ratios were 1.86 and 1.24 for Route 119 and Route 120, respectively. These are among the bus routes with the highest crash frequencies in Miami-Dade County.

Table 12-3: B-C Ratio Results

Route	Crash Severity	Crash Rate	Dollar Value	Crash Reduction	Benefits ($)	5-year Benefits ($)	5-year Cost ($)	B-C Ratio
Route 119	Fatality	0	$120,000	20%	-	(0+ 3,747+742) * 4.1 = $ 18,404	(6900+2000)+239.88*4.1 = $ 9,884	**1.86**
	Injury	0.156	$120,000	20%	$3,747			
	PDO	0.371	$10,000	20%	$742			
Route 120	Fatality	0	$120,000	20%	-	(0+2,522 +462)*4.1 = $ 12,236		**1.24**
	Injury	0.105	$120,000	20%	$2,522			
	PDO	0.231	$10,000	20%	$462			
All Routes	Fatality	0.002	$120,000	20%	$40	(40 +1,220 +180)*4.1 = $ 5,904		**0.60**
	Injury	0.0508	$120,000	20%	$1,220			
	PDO	0.090	$10,000	20%	$180			

13 CONCLUSIONS

The results from this evaluation study indicates that the Mobileye system had a positive effect on improving the reaction time to rear-end and pedestrian conflicts. Overall, the reaction time improved by 13% for rear-end conflicts and a 26% improvement in pedestrian conflicts. Most of the improvement in the reactions to rear-end conflicts occurred with situations in which there was a very close stopped vehicle in the front of the subject bus and the speed of the subject bus is higher than 0.6 mph to 19 mph with an improvement of 21% in this case. Significant improvement in the driver’s yielding to pedestrian behavior was also observed.

The study also indicates improvement in driver’s behavior as reflected by the reduction in time headways between vehicles, and more clearly by the number of alerts for both rear-end and pedestrian crashes and the number of hard break events. The study also found high accuracy of the system after moving the buses to the new route and re-calibrating the system. Somewhat less accuracy was observed before moving the buses.

Based on the driver survey results, it appears that about 55% of the drivers do not see a value of the system. The driver acceptance of the system seems to be low, pointing to the need for additional outreach and education of the drivers of the system and its effectiveness.

The results from the return-on-investment analysis show that installing the Mobileye system on every bus in Miami-Dade County may not be cost effective. However, installing the devices on the buses operating on high crash bus routes is cost-effective based on the results of the return-on-investment analysis.

APPENDIX A DRIVER EXPERIENCE SURVEY

1. ***Please select one from each row:***

	Strongly Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongly Agree
Training on the Mobileye system was clear and comprehensive	☐	☐	☐	☐	☐
The visual and audible alerts of the Mobileye system are simple to understand	☐	☐	☐	☐	☐
The Mobileye system is easy to use	☐	☐	☐	☐	☐
I noticed fewer alerts were generated the more I drove with the Mobileye system	☐	☐	☐	☐	☐
I found the Mobileye system to be helpful	☐	☐	☐	☐	☐
I feel safer driving with the Mobileye system in my vehicle	☐	☐	☐	☐	☐
On at least one occasion the Mobileye system proved its value with an alert of a possible incident	☐	☐	☐	☐	☐
The Mobileye system made me more aware of my own driving habits and ways I can drive more safely	☐	☐	☐	☐	☐

	Strongly Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongly Agree
When pedestrian alarms were given, I felt that the alarm is justified and reasonable	☐	☐	☐	☐	☐
I saw conflicting pedestrians, but there were no pedestrian alarms given by the device.	☐	☐	☐	☐	☐
When rear-end alarms were given, I felt that the alarm is justified and reasonable	☐	☐	☐	☐	☐
Sometimes the front vehicle was close and I felt that alarms should have been given, but there were no rear-end alarms.	☐	☐	☐	☐	☐
Overall, I found the Mobileye system to be accurate.	☐	☐	☐	☐	☐
I would recommend the Mobileye system to other drivers	☐	☐	☐	☐	☐

2. ***Additional Comments about the Device:***

Name (optional):

APPENDIX B INCIDENT STATISTICS FOR ROUTES

Table A- 1: Incident Statistics for Each Route

Route	Number of Incidents	Percentage of Incidents
N/A	420	8.13%
119	254	4.92%
77	228	4.42%
112	181	3.51%
120	179	3.47%
27	168	3.25%
9	165	3.20%
11	165	3.20%
3	131	2.54%
8	129	2.50%
103	109	2.11%
123	101	1.96%
7	88	1.70%
17	86	1.67%
38	85	1.65%
36	84	1.63%
32	83	1.61%
37	83	1.61%
54	83	1.61%
24	81	1.57%
95	74	1.43%
93	71	1.37%
22	69	1.34%
150	62	1.20%
35	61	1.18%
183	60	1.16%
208	60	1.16%
10	56	1.08%
51	55	1.07%
108	55	1.07%
73	54	1.05%
107	54	1.05%
105	52	1.01%
16	50	0.97%
33	49	0.95%
52	48	0.93%
42	46	0.89%

Route	Number of Incidents	Percentage of Incidents
62	46	0.89%
75	46	0.89%
110	45	0.87%
2	42	0.81%
40	42	0.81%
137	41	0.79%
12	40	0.77%
135	40	0.77%
297	40	0.77%
99	38	0.74%
6	37	0.72%
115	37	0.72%
87	35	0.68%
70	34	0.66%
113	34	0.66%
288	32	0.62%
21	31	0.60%
31	30	0.58%
238	30	0.58%
19	29	0.56%
34	29	0.56%
88	29	0.56%
117	29	0.56%
102	28	0.54%
207	25	0.48%
71	24	0.46%
104	23	0.45%
204	23	0.45%
249	23	0.45%
29	20	0.39%
195	20	0.39%
272	20	0.39%
1	19	0.37%
57	19	0.37%
252	19	0.37%
56	18	0.35%
72	18	0.35%
277	17	0.33%
0	12	0.23%
48	12	0.23%

Route	Number of Incidents	Percentage of Incidents
211	10	0.19%
202	9	0.17%
267	9	0.17%
996	9	0.17%
79	8	0.15%
101	8	0.15%
196	8	0.15%
287	8	0.15%
136	5	0.10%
296	5	0.10%
133	4	0.08%
254	4	0.08%
46	3	0.06%
132	3	0.06%
338	3	0.06%
344	3	0.06%
997	3	0.06%
243	2	0.04%
286	2	0.04%
295	2	0.04%
200	1	0.02%
Total	**5164**	**100%**

(420 out of 5164 crashes have no route assigned)

Table A- 2: Incident Statistics for All Routes

Site Description	Number of Incidents	Percentage of Incidents
At Intersection	1351	26.2%
Bridge	22	0.4%
Bus Stop Curb	1189	23.0%
Bus Stop Driveway	75	1.5%
Bus Terminal	186	3.6%
Driveway Access	112	2.2%
Entrance Ramp	22	0.4%
Influence By Intersection	604	11.7%
N/A	1	0.02%
Not Applicable	279	5.4%
Not at Intersection/RR Xing/Bridge	388	7.5%
Other	563	10.9%
Parking Lot - Private	117	2.3%
Parking Lot - Public	31	0.6%

Private Property	27	0.5%
Rail Station	64	1.2%
RR Xing	29	0.6%
Unknown	104	2.0%
Total	5164	100%
Injury Type	**Number of Incidents**	**Percentage of Incidents**
Fatality	8	0.2%
Injury	734	14.2%
N/A	4290	83.1%
Not Injury	111	2.1%
Sick	21	0.4%
Total	5164	100%
Injury Role	**Number of Incidents**	**Percentage of Incidents**
Driver/Owner	304	5.9%
N/A	4290	83.1%
Passenger	478	9.3%
Pedestrian	64	1.2%
Unknown	28	0.5%
Total	5164	100%
Operator Wrong	**Number of Incidents**	**Percentage of Incidents**
N/A	291	5.6%
No	2883	55.8%
Yes	1990	38.5%
Total	5164	100%

Table A- 3: Incident Statistics for Route 3

Site Description	Number of Incidents	Percentage of Incidents
At Intersection	27	20.6%
Bridge	1	0.8%
Bus Stop Curb	44	33.6%
Bus Stop Driveway	3	2.3%
Bus Terminal	6	4.6%
Driveway Access	4	3.1%
Influence By Intersection	10	7.6%
Not Applicable	7	5.3%
Not at Intersection/RR Xing/Bridge	3	2.3%
Other	16	12.2%
Parking Lot - Private	5	3.8%
Parking Lot - Public	3	2.3%
RR Xing	1	0.8%
Unknown	1	0.8%
Total	131	100%
Injury Type	**Number of Incidents**	**Percentage of Incidents**
Injury	13	9.9%
N/A	116	88.5%
Not Injury	2	1.5%
Total	131	100%
Injury Role	**Number of Incidents**	**Percentage of Incidents**
Driver/Owner	5	3.8%
N/A	116	88.5%
Passenger	7	5.3%
Pedestrian	3	2.3%
Total	131	100%
Operator Wrong	**Number of Incidents**	**Percentage of Incidents**
N/A	7	5.3%
No	94	71.8%
Yes	30	22.9%
Total	131	100%

Table A- 4: Incident Statistics for Route 8

Site Description	**Number of Incidents**	**Percentage of Incidents**
At Intersection	34	26.4%
Bus Stop Curb	40	31.0%
Bus Stop Driveway	2	1.6%
Bus Terminal	4	3.1%
Driveway Access	2	1.6%
Entrance Ramp	1	0.8%
Influence By Intersection	14	10.9%
Not Applicable	8	6.2%
Not at Intersection/RR Xing/Bridge	13	10.1%
Other	4	3.1%
Parking Lot - Private	1	0.8%
Parking Lot - Public	1	0.8%
Rail Station	2	1.6%
RR Xing	2	1.6%
Unknown	1	0.8%
Total	129	100%
Injury Type	**Number of Incidents**	**Percentage of Incidents**
Injury	13	10.1%
N/A	114	88.4%
Not Injury	2	1.6%
Total	129	100%
Injury Role	**Number of Incidents**	**Percentage of Incidents**
Driver/Owner	5	3.9%
N/A	114	88.4%
Passenger	7	5.4%
Pedestrian	3	2.3%
Total	129	100%
Operator Wrong	**Number of Incidents**	**Percentage of Incidents**
N/A	3	2.3%
No	85	65.9%
Yes	41	31.8%
Total	129	100%

Table A- 5: Incident Statistics for Route 11

Site Description	Number of Incidents	Percentage of Incidents
At Intersection	30	18.2%
Bridge	4	2.4%
Bus Stop Curb	58	35.2%
Bus Terminal	4	2.4%
Driveway Access	3	1.8%
Entrance Ramp	4	2.4%
Influence By Intersection	23	13.9%
Not Applicable	14	8.5%
Not at Intersection/RR Xing/Bridge	12	7.3%
Other	8	4.8%
Parking Lot - Private	2	1.2%
RR Xing	1	0.6%
Unknown	2	1.2%
Total	165	100%
Injury Type	**Number of Incidents**	**Percentage of Incidents**
Injury	13	7.9%
N/A	148	89.7%
Not Injury	3	1.8%
Sick	1	0.6%
Total	165	100%
Injury Role	**Number of Incidents**	**Percentage of Incidents**
Driver/Owner	4	2.4%
N/A	148	89.7%
Passenger	12	7.3%
Pedestrian	1	0.6%
Total	165	100%
Operator Wrong	**Number of Incidents**	**Percentage of Incidents**
N/A	14	8.5%
No	93	56.4%
Yes	58	35.2%
Total	165	100%

Table A- 6: Incident Statistics for Route 77

Site Description	Number of Incidents	Percentage of Incidents
At Intersection	55	24.1%
Bus Stop Curb	81	35.5%
Bus Stop Driveway	1	0.4%
Bus Terminal	5	2.2%
Driveway Access	8	3.5%
Entrance Ramp	2	0.9%
Influence By Intersection	24	10.5%
Not Applicable	10	4.4%
Not at Intersection/RR Xing/Bridge	15	6.6%
Other	18	7.9%
RR Xing	1	0.4%
Unknown	8	3.5%
Total	228	100%
Injury Type	**Number of Incidents**	**Percentage of Incidents**
Injury	51	22.4%
N/A	174	76.3%
Not Injury	1	0.4%
Sick	2	0.9%
Total	228	100%
Injury Role	**Number of Incidents**	**Percentage of Incidents**
Driver/Owner	16	7.0%
N/A	174	76.3%
Passenger	33	14.5%
Pedestrian	4	1.8%
Unknown	1	0.4%
Total	228	100%
Operator Wrong	**Number of Incidents**	**Percentage of Incidents**
N/A	15	6.6%
No	142	62.3%
Yes	71	31.1%
Total	228	100%

Table A- 7: Incident Statistics for Route 119

Site Description	Number of Incidents	Percentage of Incidents
At Intersection	72	28.3%
Bus Stop Curb	50	19.7%
Bus Stop Driveway	5	2.0%
Bus Terminal	7	2.8%
Driveway Access	1	0.4%
Entrance Ramp	2	0.8%
Influence By Intersection	39	15.4%
Not Applicable	18	7.1%
Not at Intersection/RR Xing/Bridge	24	9.4%
Other	21	8.3%
Parking Lot - Private	4	1.6%
Parking Lot - Public	5	2.0%
Private Property	2	0.8%
RR Xing	1	0.4%
Unknown	3	1.2%
Total	254	100%
Injury Type	**Number of Incidents**	**Percentage of Incidents**
Injury	23	9.1%
N/A	228	89.8%
Not Injury	3	1.2%
Total	254	100%
Injury Role	**Number of Incidents**	**Percentage of Incidents**
Driver/Owner	10	3.9%
N/A	228	89.8%
Passenger	6	2.4%
Pedestrian	7	2.8%
Unknown	3	1.2%
Total	254	100%
Operator Wrong	**Number of Incidents**	**Percentage of Incidents**
N/A	8	3.1%
No	132	52.0%
Yes	114	44.9%
Total	254	100%

Table A- 8: Incident Statistics for Route 112

Site Description	Number of Incidents	Percentage of Incidents
At Intersection	39	21.5%
Bus Stop Curb	47	26.0%
Bus Stop Driveway	4	2.2%
Bus Terminal	3	1.7%
Driveway Access	9	5.0%
Influence By Intersection	16	8.8%
Not Applicable	13	7.2%
Not at Intersection/RR Xing/Bridge	13	7.2%
Other	24	13.3%
Parking Lot - Public	1	0.6%
Private Property	2	1.1%
Rail Station	5	2.8%
Unknown	5	2.8%
Total	181	100%
Injury Type	**Number of Incidents**	**Percentage of Incidents**
Injury	23	12.7%
N/A	155	85.6%
Not Injury	3	1.7%
Total	181	100%
Injury Role	**Number of Incidents**	**Percentage of Incidents**
Driver/Owner	3	1.7%
N/A	155	85.6%
Passenger	22	12.2%
Pedestrian	1	0.6%
Total	181	100%
Operator Wrong	**Number of Incidents**	**Percentage of Incidents**
N/A	21	11.6%
No	106	58.6%
Yes	54	29.8%
Total	181	100%

Table A- 9: Incident Statistics for Route 120

Site Description	Number of Incidents	Percentage of Incidents
At Intersection	44	24.6%
Bridge	1	0.6%
Bus Stop Curb	37	20.7%
Bus Stop Driveway	3	1.7%
Bus Terminal	7	3.9%
Entrance Ramp	1	0.6%
Influence By Intersection	27	15.1%
Not Applicable	10	5.6%
Not at Intersection/RR Xing/Bridge	22	12.3%
Other	17	9.5%
Parking Lot - Private	2	1.1%
Parking Lot - Public	3	1.7%
Unknown	5	2.8%
Total	179	100%
Injury Type	**Number of Incidents**	**Percentage of Incidents**
Injury	15	8.4%
N/A	163	91.1%
Not Injury	1	0.6%
Total	179	100%
Injury Role	**Number of Incidents**	**Percentage of Incidents**
Driver/Owner	6	3.4%
N/A	163	91.1%
Passenger	7	3.9%
Pedestrian	3	1.7%
Total	179	100%
Operator Wrong	**Number of Incidents**	**Percentage of Incidents**
N/A	4	2.2%
No	85	47.5%
Yes	90	50.3%
Total	179	100%