Evaluation of a Transit Bus Collision Avoidance Warning System in Virginia

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The purpose of this study was to conduct an evaluation of the CAWS demonstration project in terms of system effectiveness and bus operator acceptance. The scope was limited to agencies participating in the demonstration project.

The study found that the benefits of the CAWS in a transit operating environment were mixed: the driving performance of operators, as measured by event rates in the CAWS data, generally improved after they began receiving system alerts. However, in surveys, operators had mixed reactions to the system, with 75% of respondents saying that they often or sometimes noticed false alarms and 76% of respondents saying that the system was very or somewhat distracting. At the same time, 70% of respondents said the system was very or somewhat helpful. These results align with findings from previous studies in that the CAWS improved safety surrogates yet was unpopular with many operators. Thus, transit and roadway agencies should exercise caution when using CAWS data for decision-making.

The study recommends that DRPT (1) identify ways to support transit agencies that are interested in deploying bus CAWS technology, and (2) monitor bus CAWS technology as it continues to develop. Implementing these recommendations will maximize the value of state and local technology investments by helping individual transit agencies achieve the safety benefits of CAWS while mitigating and managing the challenges. It will also position DRPT to make investments in CAWS technology when its benefits more clearly outweigh its challenges.

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Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
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ABSTRACT

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INTRODUCTION

Public transit is most efficient when serving dense, pedestrian-friendly districts such as downtowns, college campuses, and other activity centers. In these places, transit buses must mix with pedestrians and bicyclists, often in close proximity and during turning maneuvers, creating conditions that could lead to crashes. Crash risks also exist outside urban centers, where the presence of pedestrians and bicyclists may be unexpected. Although professional bus operators receive extensive safety training, even a safe operator can become distracted at times or can lose sight of a vulnerable road user in one of the vehicle's blind spots.

Urban bus travel has a relatively low risk of physical injury for both vehicle occupants and vulnerable road users. Bus occupants in the United States have lower fatality and injury rates per vehicle-distance-traveled than passenger car occupants (U.S. Department of Transportation, 2020). A Montreal study indicated that the risk of injury for car occupants there was 4 times greater than for bus occupants; in addition, bicyclists and pedestrians were 4 to 5 times less likely to be injured or killed in collisions with city buses than in collisions with cars (Morency et al., 2018). In 2019, single-vehicle crashes with buses killed 51 pedestrians in the United States, fewer than 1% of the total single-vehicle-crash pedestrian fatalities that year (Governors Highway Safety Association, 2021). Even so, U.S. bus collisions and fatalities have generally increased over the past decade while injuries have declined slightly (Staes et al., 2020b).

U.S. pedestrian crash fatalities have also increased—by 53% from 2009 to 2018—and the percentage of traffic fatalities that were pedestrians grew from 12% to 17%, with three-fourths of pedestrian fatalities in urbanized areas (Webb, 2019). Pedestrian fatalities in 2018 and 2019, and preliminary data for the first half of 2020, were at levels not seen since 1990, with much of the increase occurring at night and with nonwhite and Hispanic populations overrepresented (Governors Highway Safety Association, 2021). Large vehicles were disproportionately responsible for fatalities on U.S. roads, representing 4% of the vehicle fleet but involved in 7% and 11% of pedestrian and bicyclist fatalities, respectively, due in part to vehicle characteristics such as blind spots (Chiarenza et al., 2018) and vehicle mass (Paulozzi, 2005). By investing in crash mitigation strategies, transit agencies can save lives, improve public opinion, and reduce economic costs of casualty and liability payments. Preventing crashes between transit buses and vulnerable road users is a core part of the business case for automation technologies (Peirce et al., 2019).

In 2017, the Virginia Department of Rail and Public Transportation (DRPT) initiated a demonstration project to plan, implement, and evaluate a transit bus collision avoidance warning system (CAWS) on up to 50 buses. DRPT selected the Mobileye Shield+ Advanced Driver Assistance System (hereinafter "the CAWS"; generic systems are referred to as "CAWS") and requested assistance from the Virginia Transportation Research Council (VTRC) to evaluate the demonstration project.

The Collision Avoidance and Warning System

The CAWS evaluated in this study uses kinematic sensors and multiple external camera sensors to provide visual and/or audio alerts in various categories: daytime pedestrian/bicyclist detection, warning for exceeding the speed limit, lane departure warning, and headway monitoring / forward collision warning (FCW). Some settings are adjustable by the transit agency to account for normal operating conditions. The CAWS can be configured to provide warnings to both the operator and a database or to a database only. When warnings are not displayed to the operator, the CAWS is referred to as operating in stealth mode. When alerts are displayed to the operator, the CAWS operates in live mode.

CAWS has been deployed on trucks and buses in cities across the United States and Canada. Similar to blind spot warning systems and FCW systems becoming common in passenger cars, the system evaluated in this study provides a low level of vehicle automation through hardware and software that alerts bus operators of potential hazards and records incidents (DRPT, 2017). Four cameras are installed: on the left and right rear, front center, and front left. Figure 1 shows three alert displays installed at the left, center, and right. Most alerts were disabled at night or when deep shadows prevented the cameras from functioning. The system has optional audio warnings directed at pedestrians and cyclists, but this feature was not installed for these deployments.

The CAWS logs several types of events, broadly classified as collision warnings—including FCWs and pedestrian collision warnings (PCWs), danger zones where a vulnerable road user is in a potential blind spot, dangerous driving behavior based on vehicle speed and longitudinal/lateral acceleration, and similar but more severe aggressive driving behavior. Precise thresholds for triggering warnings are proprietary to the vendor and specific to the bus model and dimensions. All events are transmitted to a central database accessible to managers, which can be configured to review archived data, generate daily reports on bus and operator safety, or examine "hot spots" with clusters of near-miss events. Event attributes recorded in the database include time, date, latitude and longitude, speed, heading, odometer, route, and operator, among others. In these deployments, the operator field was set to a generic code to protect operator anonymity, and so safety was analyzed at the transit agency level, specific to the bus route.

Figure 1. Right Rear Collision Avoidance Warning System (CAWS) Camera (Left) and Operator's Compartment With Left Alert Display Illuminated Red, Center Alert Display Illuminated Green, and Center Camera Mounted Near Parked Wiper (Right)

The demonstration project was designed so that all equipped vehicles would initially operate for at least 2 months in stealth mode, followed by at least 6 months in live mode. Stealth mode and live mode would then be considered the "before" and "after" conditions for evaluation, respectively, with analysis focused on differences in event rates between these two modes. Actual deployment contexts varied.

Deployment Contexts

This study represented an evaluation of the CAWS deployment at multiple transit agencies in Virginia, focusing on bus routes with high pedestrian activity in contexts including university towns, rural and suburban areas, and major metropolitan regions. The study paired analysis of system alerts that monitor driver behavior before and after system activation with detailed, open-ended operator surveys regarding system effectiveness and shortcomings. This represents a unique contribution to the literature, which has predominantly focused on deployments in large urbanized areas.

The CAWS was installed on 51 buses at nine transit agencies, as shown in Table 1. Two agencies, Hampton Roads Transit (HRT) and the Washington Metropolitan Area Transit Authority (WMATA), operate regionally in major metropolitan areas. Alexandria Transit Company (DASH) serves a city within the WMATA service area, and Fredericksburg Regional Transit operates beyond that service area in a suburban and exurban portion of the same metropolitan area. Three agencies are in small cities with relatively large university populations: Blacksburg, Lynchburg, and Harrisonburg.

Table 1. Number of Equipped Buses and Service Area Populations for Participating Transit Agencies

Transit Agency	No. of Equipped Buses	Total Buses Operated[a]	Service Area[a]		Date Installed	Date Live Mode
			Population	Area (mi^2)		
Alexandria Transit Company (DASH)	19 (17 in live mode only)	101	139,966	16	8/5/18	1/6/19
Blacksburg Transit	5	40	73,554	34	1/6/19	3/4/19
Central Shenandoah Planning District Commission (BRITE) (Staunton)	3	9	50,043	25	11/25/18	11/25/18
Fredericksburg Regional Transit	3	21	113,716	242	11/18/18	2/10/20 (insufficient data for analysis)
Greater Lynchburg Transit Company	2	24	80,846	72	11/18/18	8/25/18
Hampton Roads Transit	10	243	1,142,181	432	9/30/18	7/7/19
Harrisonburg Department of Public Transportation	2	33	54,809	17	10/7/18	8/25/19
Virginia Regional Transit (Culpeper and Front Royal)	2	16	Rural[b]	Rural[b]	2/3/19	Remained in stealth
Washington Metropolitan Area Transit Authority (Washington, D.C., region)	5	1,379	3,719,567	950	10/20/19	11/24/19

Total Buses Operated = Vehicles Operated in Maximum Service, Bus mode.

[a] *Source:* 2019 Transit Agency profiles from National Transit Database (Federal Transit Administration, 2021).

[b] National Transit Database profiles for agencies classified as rural general public transit providers do not include service area population or geographic size.

In the United States, many large public universities are located in small cities, partly due to a precedent set with the passage in 1862 of the Morrill Act granting each participating state 30,000 acres to establish a college (Key, 1996). Populations of towns surrounding the universities may effectively double when classes are in session because enrolled students may outnumber full-time residents and often return to their hometown during a 1-month-long winter break and a 4-month-long summer break. These university towns represent a unique challenge for transit operators, as routes vary between suburban and rural settings to central campuses with high volumes of vulnerable road users. Further complicating operations, pedestrian and cyclist volumes are highly seasonal depending on the universities' academic calendars, requiring operators to adjust to variable conditions, often week by week.

The Central Shenandoah Planning District Commission (BRITE) operates routes in two small cities along with regional connections between and beyond the two cities in a mostly rural area. Virginia Regional Transit was the only one of the nine agencies that was classified for federal purposes as a rural general public transit provider. Its two CAWS-equipped buses operated in and between two small towns. They were instrumented later than the other buses in the study, and it was unclear whether operators had received training and whether the systems were functioning properly, so the agency was excluded from the analyses of quantitative telematics data and bus operator acceptance.

PURPOSE AND SCOPE

The purpose of this study was to conduct an evaluation of DRPT's CAWS demonstration project in terms of system effectiveness and bus operator acceptance. The scope was limited to agencies participating in the demonstration project. VTRC's role was further limited to data collection and analysis. DRPT funded the installation of systems on buses, and transit agencies in coordination with the system vendor were responsible for driver training.

METHODS

To achieve the study objectives, four tasks were performed:

1. Conduct a literature search and review of previous studies of driver assistance systems for buses.

2. Collect quantitative telematics data.

3. Collect qualitative data from transit agency staff.

4. Analyze quantitative and qualitative data.

Conducting the Literature Search

To obtain relevant information regarding driver assistance systems for buses, the research team carried out a literature search using the Transport Research International Documentation database. The search focused on evaluations of the selected CAWS in transit buses, including studies that had obtained feedback on it from bus operators. Of secondary interest were studies of CAWS other than the one DRPT chose to deploy, studies exploring related issues such as automation in transit vehicles, and other media (i.e., news and magazine articles) related to pedestrian interactions with transit buses.

Collecting and Preparing Quantitative Telematics Data

Quantitative telematics data were obtained from the vendor's data portal, Ituran. Data were cleaned and categorized using the following procedures. Data without location coordinates, representing less than 0.1% of all data, were removed. Any events occurring within a few blocks of the bus storage depot were removed, as operators may have generated pedestrian danger zone warnings while conducting walk-around inspections. As routes were rarely logged in the CAWS, these were reconstructed during post-processing and were assigned placeholder numbers (e.g., in this study, "route 1" for a particular transit agency is not necessarily the same route as that agency's Route 1). For each day and vehicle, the latitudes and longitudes of all events were plotted and compared with other days and vehicles. These plots were then matched to transit agency route maps based on visual comparison. Bounding boxes were drawn around geographic areas unique to a specific route or area with frequent events. For each analysis day, any bus with alerts generated within the geographic bounding box was assigned to that route and area for analysis, thereby controlling for buses that were assigned to different routes on different days. Buses occasionally switched routes midday, creating a partial misassignment, but these events were rare and did not significantly affect the results.

For larger agencies with equipped buses operating on more than 10 routes, specifically HRT and WMATA, routes of a similar type were grouped together. For HRT, routes that passed through a 2-mile zone covering downtown Norfolk were categorized as urban and other routes were categorized as non-urban. For WMATA, routes were classified as passing through either Washington, D.C. (urban), urban Arlington or the Pentagon (Virginia urban), or neither of those areas (Virginia suburban).

For the transit agencies operating in towns with large university populations (i.e., Lynchburg, Harrisonburg, and Blacksburg), data were categorized according to whether students were on campus, defined as days with classes in session according to university academic calendars. As most routes passed through the campus, this maximized the number of pedestrian interactions and bus in-service time and ensured consistent traffic patterns and service schedules for stealth and live modes.

Finally, any dates after February 29, 2020, were removed to minimize the effect of travel restrictions and closures related to COVID-19.

Collecting Qualitative Data From Transit Agency Staff

To inform survey development, two informal in-person feedback sessions were held with transit operators: one at WMATA during its stealth mode period and one at DASH when its buses were in live mode. Operator surveys were then conducted at all agencies with the exception of Virginia Regional Transit. Managers and maintenance staff at some agencies provided additional feedback, which was documented to assess overall impressions of the CAWS.

Initial Operator Feedback Sessions

So that the research team could obtain informal in-person feedback prior to finalizing operator surveys, transit agency managers suggested that a researcher be stationed in a drivers' lounge/break room to interact with bus operators as they arrived for or returned from their shifts. An operator feedback session at WMATA was held during WMATA's stealth mode period in the early afternoon on a Wednesday in October 2019. A session at DASH, which had an earlier CAWS installation date than WMATA's, was conducted in the early afternoon on a Tuesday in April 2019 after alerts had gone live on its equipped buses. Sessions were guided by discussion questions but were informal; i.e., operators were encouraged to share feedback in any order they chose. The following discussion questions were used for the WMATA (stealth mode) session; questions for the DASH session were similar but were adjusted to reflect that its operators had begun receiving CAWS alerts.

1. What advantages of the Mobileye system do you see for drivers? For the transit agency?

2. Was the training you received sufficient to help you understand the meanings of the alerts and why the system is in use?

3. How do you think driving with the system will change your behavior as a driver?

4. How concerned are you about false alarms (pedestrian alerts or collision warnings when no pedestrians/bicyclists/etc. are present)?

5. How concerned are you about the system failing to detect a pedestrian/bicyclist/etc. and alert you?

6. Do you expect the system to be helpful, distracting, or both?

7. Based on what you've heard so far, which features sound the most useful to you? Are there missing features?

8. How would you feel if system data were used to compare your driving performance with that of other drivers, either as private feedback to you or visible to all drivers?

9. Anything else we should ask about when we send written surveys to drivers?

Operator Survey

A survey was designed for transit agencies to distribute to their bus operators who had used the CAWS in live mode. The survey was designed to document several aspects of the system: how operators perceived the CAWS, whether their perceptions of changes in their own driving behavior aligned with trends suggested by the CAWS event logs, whether operators perceived the alerts as distractions, what implementation hurdles were present, and opinions on the usefulness of training. Agencies could request a mobile-friendly online (Google Forms) format, paper, or both.

Designing the Survey

Examples of previous operator surveys regarding CAWS were reviewed and adapted, with a goal of limiting the length of the paper version of the survey to a single page. The initial operator feedback sessions further informed survey development. An introductory paragraph was composed to introduce the research study and explain how survey data would be used.

The resulting survey included questions on the usefulness of training in aiding operator comprehension of alerts; the perceived frequency of false positives and missed detection; and how helpful and/or distracting the system was. Several questions allowed for open-ended answers to enable operators to respond freely. Employee identification numbers were used to avoid duplicate responses without identifying operators by name. Contacts at each transit agency reviewed the survey content prior to distribution. The final survey instrument is provided in the Appendix.

Distributing the Survey

In distributing the survey, the objective was to provide an opportunity for input from every bus operator who had driven an equipped bus recently. Transit agency contacts worked with researchers to determine an agency-appropriate working definition of "recently," which was typically between 1 week and 1 month; to identify operators who had driven equipped buses (two agencies gave all operators the opportunity to complete the survey); and to distribute the survey to their agency's operators in online and/or paper formats.

DASH initially had 2 buses equipped in 2018, then an additional 17 in 2019; these 17 buses did not operate in stealth mode. In total, about 22% of the bus fleet was equipped with the CAWS. Because DASH administration was dedicated to adapting operations due to COVID-19, the operator survey was delayed until summer and fall 2020. All of DASH's roughly 150 operators were given a paper version of the survey, and 49 responses were received.

Because most of its operators had driven one of its five equipped buses, Blacksburg Transit chose to distribute a link to the online version of the survey to all 130 of its operators via its online work scheduling platform. Eighteen Blacksburg Transit respondents completed the survey in February and March 2020, before the onset of COVID-19 restrictions in Virginia.

BRITE, with three equipped buses, requested paper surveys and returned five responses in May 2020.

Three buses at Fredericksburg Regional Transit were equipped in winter and spring 2020. Paper versions of the survey were distributed to operators in fall 2020, and 10 responses were received.

Greater Lynchburg Transit Company initially had one equipped bus, which had special branding because it was used on a downtown circulator route. After that route was discontinued in June 2019, the bus was out of service for a time, but a second bus was also equipped. The agency chose paper surveys and distributed them to 20 operators who had driven an equipped bus in April 2020. Eighteen responses were received.

HRT, based in Norfolk, had 10 buses equipped. Alerts went live in summer 2019, and the agency distributed paper surveys to operators in summer 2020; 32 responses were received.

The Harrisonburg Department of Public Transportation opted for the online version of the survey. Rather than surveying all operators, it chose to survey only those who had driven one of its two equipped buses within 1 month prior to the date the survey completion link was distributed. In addition, its survey was initiated after the onset of COVID-19 restrictions, which resulted in the shutdown of campus routes where the equipped buses had typically been used, so there were only seven such operators. Five of them completed the survey in April and May 2020.

Virginia Regional Transit had two trolley-look buses equipped in the towns of Culpeper and Front Royal. The buses had not been taken out of stealth mode as of spring 2020, and as of the following winter, administrators at the rural transit provider were unsure if operators had received training or if the systems were functional. For these reasons, operator surveys were not conducted for this agency.

WMATA was the largest transit agency included in the pilot, and it equipped 5 of its more than 1,300 Metrobuses in fall 2019. Although WMATA operates across state lines, the equipped buses were based at the Four Mile Bus Garage in Arlington and were to be used mostly on Virginia routes. The agency distributed hard-copy operator surveys in two rounds spaced approximately 1 year apart, in winter 2019-2020 and winter 2020-2021. One purpose of this strategy was to investigate how the opinions of individual operators might change over time. In the end, all of the Round 2 responses were from different operators than the Round 1 responses, so that sub-analysis was not practical; the Round 2 responses were added to the others. Overall, 14 responses from WMATA operators were included in the analysis: 5 from Round 1 and 9 from Round 2. Table 2 summarizes the survey collection details for each agency.

Table 2. Survey Collection Details by Agency

Transit Agency	Survey Dates	Survey Recipients	Completed Surveys Received	Survey Method
Alexandria Transit Company (DASH)	Summer and fall 2020	All operators (about 150)	49	Paper
Blacksburg Transit	February and March 2020	All operators (about 130)	18	Online
Central Shenandoah Planning District Commission (BRITE) (Staunton)	May 2020	N/A[a]	5	Paper
Fredericksburg Regional Transit	Fall 2020	N/A[a]	10	Paper
Greater Lynchburg Transit Company	April 2020	20 operators	18	Paper
Hampton Roads Transit	Summer 2020	N/A[a]	32	Paper
Harrisonburg Department of Public Transportation	April and May 2020	7 operators	5	Online
Washington Metropolitan Area Transit Authority (Washington, D.C., region)	Winter 2019-2020	N/A[a]	5	Paper
	Winter 2020-2021	N/A[a]	9	Paper

[a] These agencies did not confirm how many operators received the survey.

Analyzing Quantitative and Qualitative Data

Quantitative Telematics Data

The primary metric for evaluating the performance of the CAWS is the difference in mean events per 100 vehicle-kilometers traveled between stealth and live mode operation.

Differences were compared for all events, collision warning events, danger zone events, dangerous driving events, and aggressive driving events. Within these categories, several scenarios were compared: weekdays only, weekends only, classes in session (for systems with substantial university populations), first week live vs. all stealth, and first month live vs. all stealth. The two-tailed Welch's t-test (Welch, 1947), a variant of the Student t-test designed to accommodate unequal variances and sample sizes, was used to test significance.

Qualitative Survey Response Data

Survey responses were compiled into a spreadsheet for analysis. Online responses automatically transferred to the spreadsheet, and paper survey responses were entered manually. Because respondents could write comments next to any question on the paper version, any such comments on questions that were not free-response in the online version were moved to the general comments question during data entry. One agency that supplied its operators with hard-copy surveys returned some that had been created by printing out the online form, resulting in a four-page layout rather than the single-page layout that was typically used for the hard-copy survey. It is possible that the additional pages induced the respondents with this survey layout to provide more comments or longer comments than were typical.

For multiple-choice questions, pie charts were employed to provide visualization of responses. Answers to free-response questions were categorized based on their content to enable visualization.

Any incomplete responses were analyzed for the questions that had been answered (e.g., if a survey response contained only a response to Question 1, that response was added into the analysis of Question 1 only). When a free-response answer to a question referred to a respondent's earlier answer (e.g., "Read answer to #7"), the earlier response was duplicated for that question.

RESULTS AND DISCUSSION

Literature Review

The results of the literature review focus on the items most relevant to this study, i.e., evaluations of the selected CAWS in transit buses (as opposed to other large vehicles such as commercial trucks). Publications related to other CAWS technologies may also provide useful background, but because the literature review of Staes et al. (2020b) in TCRP Synthesis 145 summarizes them, they are not repeated here. Studies of related topics such as automation in transit vehicles are presented next, followed by a summary of other media related to pedestrian interactions with transit buses.

CAWS in Transit Buses

Several recent studies have evaluated transit bus use of the same Mobileye CAWS evaluated in this study. These studies indicated that the system has been deployed or pilot-tested in locations including Los Angeles, California; Seattle/King County and Spokane, Washington; Dallas, Houston, and College Station, Texas; Miami-Dade County, Florida; New York City; and London, England.

Staes et al. (2020a) summarized seven projects initiated in 2016 under the federal Safety Research and Demonstration Program including an 18-month, $1.45 million Mobileye CAWS deployment on up to 60 buses with the Los Angeles County Metropolitan Transportation Authority. The agency initially selected a second vendor for testing, but during deployment, it became evident that the technology was not ready. The interim report indicated that a stealth mode was used, but that evaluation was not complete; as of the report date, the project team had identified bus routes for deployment. Even so, the authors reported the following lessons learned:

- Technology maturity is not a given, which can affect capabilities and unit costs.
- Quality control and assurance vary by vendor, and product capabilities and costs continue changing.
- The CAWS market for heavy-duty vehicles is limited compared to what is available for other vehicle types, and CAWS solutions for heavy vehicles require further testing in the transit operating environment.
- CAWS prototype testing revealed quality control issues with some parts, which had to be replaced. This, in turn, led to integration issues that were being addressed as of the report date.

Along with examining non-technology approaches to transit safety, Staes et al. (2020b) sought to determine whether transit agencies found onboard technologies including CAWS to be effective at avoiding transit bus crashes and incidents. Of 44 transit agencies that responded to a survey, 23% had implemented pedestrian warning technologies. Responding agencies were a range of sizes, with buses operating in urban (86%), suburban (52%), and rural (29%) environments. One response noted that rural transit agencies often rely on statewide contracts, so they purchase only the technology that comes on vehicles that are on those contracts. Implementation barriers across agencies included costs or return on investment, challenges retrofitting buses, and resistance from unions and operators.

Another challenge identified in the study was documenting safety improvements resulting from CAWS. Agencies typically provided ways for operators to offer input concerning onboard technologies, and for most agencies that had surveyed operators, electronic forms did not result in high response rates. Agencies reported mixed feedback from employees regarding CAWS; the 14% of agencies that had received mostly negative feedback highlighted concerns about distraction and effectiveness. In a separate survey distributed to transit operators through the Amalgamated Transit Union, only five respondents had driven a bus with audible pedestrian warnings. All five respondents found the warnings distracting, and most cited excessive false alarms as a cause.

Staes et al. (2020b) also interviewed participants from seven deployments that used CAWS. Houston METRO had piloted CAWS on five buses starting in 2017. Researchers reported challenges from low lighting, operator complaints about the alerts ("beep fatigue"), and installation delays. At the time of the study's publication, the transit agency had not yet seen a significant reduction in collisions. Case example agencies had generally received positive employee feedback, tempered somewhat by complaints of false positives and other issues with system alerts. Dallas Area Rapid Transit began its pilot in 2018, and the system was in place on seven buses. A 4-week stealth mode period was instituted to allow for data comparisons to live mode, and the system vendor planned to disseminate an electronic questionnaire for operators to provide feedback. The agency was recognizing its safest operators at an annual safety event, using driving performance data (e.g., speed, braking profile, and turning data).

Spears et al. (2017) described CAWS testing on 38 buses in the state of Washington, where operator acceptance was mixed: 37% of survey respondents said the system was helpful, 33% said they would prefer to drive with it, 63% said it was distracting, and 67% said they would prefer not to have it. A high rate of false positives was the most frequent operator complaint, especially for alerts when buses either approached stops with people waiting or passed pedestrians on sidewalks. A video analysis found an overall false-positive rate of 3.21% and a false-negative rate of 0.30%. The lane departure warning feature was disabled after complaints that it was annoying (Lutin and Ke, 2018). In contrast to some of the operators' dislike of the system, a comparison of telematics data from one agency with two buses that remained in stealth mode vs. live mode data from other agencies indicated large differences in near-miss event rates per mile (328 vs. 93 alerts per mile for FCWs and 62 vs. 35 for PCWs). A benefit-cost framework suggested positive returns after year 6 of an equipped bus being in service, and an examination of past insurance claims suggested that about two-thirds of them could have been prevented by CAWS. The authors concluded that although the majority of drivers did not like the system, it did change their driving performance, even if they were simply adjusting their driving to minimize how often they had to hear alerts (Lutin and Ke, 2018).

Hadi et al. (2019) described a Florida DOT effort to evaluate the Mobileye CAWS on bus routes in Miami-Dade County. Ten buses were equipped, and during the comparison period, 5 of them remained in stealth mode. As with the Washington State pilot, a general conclusion was that although operator acceptance was low, telematics data indicated that the system had positive effects on driving behavior across various performance measures. Video clips were used to augment telematics data for examining operator reactions and false alarms. False alarm rates for pedestrian alerts were as high as 45% but varied by route and sensor position. Examinations of videos to investigate causes of PCW alerts resulted in differing findings for each sensor, but people at bus stops and on sidewalks generated a substantial portion of the alerts. In an operator acceptance survey with 57 responses, slightly more than one-half of respondents responded negatively to questions of the system's ease of use, overall usefulness, and accuracy. Slightly less than one-half of respondents responded negatively to questions about FCW and PCW effectiveness and whether the system contributed to changes in their driving behavior. A benefit-cost analysis suggested that system-wide installation (at a per-bus cost of \$6,900 for hardware, \$2,000 for installation, and \$239.88 for an annual telematics subscription fee) might not result in a positive return on investment but that targeted installation on buses serving high-crash-frequency routes could.

Staes et al. (2020b) summarized two other Mobileye CAWS deployments. The larger one, on 66 buses in London, resulted in a reported 29% reduction in observed collisions. A 27-day pilot in 2016 at Texas A&M University in College Station found no false alarms but a desire for nighttime warnings. Fitzpatrick et al. (2018) reported that in the Texas A&M pilot, operators and dispatchers confirmed that the locations of frequent PCW alerts were known conflict points between buses and vulnerable road users. That study also noted that pilot projects had occurred in New York City and Seattle, Washington.

Deployments of Other Pedestrian CAWS on Buses

Staes et al. (2020b) included several case examples that used a different CAWS than the one selected for the DRPT demonstration project. Two older pilot projects (2014 and 2015) of pedestrian detection systems were terminated after the technology was not successful at distinguishing pedestrians. A 6-month pilot in Cleveland, Ohio, of a pedestrian detection system from another manufacturer found that operator opinions were split between CAWS being distracting and being helpful, although less than 2% of operators responded to the emailed survey and a stealth-mode-type comparison found an 18.8% improvement in operator reaction time. A Seattle pilot of a version of CAWS with autonomous emergency braking was halted in part because of false positives. In addition, audible pedestrian alerts were disabled “because of operator fatigue and feedback from the public,” but there was anecdotal positive feedback from operators for a prototype blind spot video display system. Other overall findings from Staes et al. (2020b) included delays in procurement, testing, and deployment being typical; vendors being unable to address false positive alerts; and challenges for agencies in using large amounts of data. The authors recommended further research on safety aspects and associated liabilities of bus CAWS along with documentation of additional feedback from operators and other staff.

Staes et al. (2020a) reported interim results of the deployment of another manufacturer’s pedestrian avoidance CAWS with automated braking at Pierce Transit in the Tacoma, Washington, region. Light detection and ranging (LiDAR) sensors were integrated with the use of existing bus braking functionality that was normally used to keep a bus from moving when doors had been opened. The full study was to include track testing of a bus on the Virginia Smart Road, testing of how the braking affected passenger motion, and eventual installation of systems on 30 buses, to be followed by analyses in stealth and active modes and driver surveys. After completion of the track testing and installation on four buses, challenges and lessons learned included administrative needs (executive-level support, time for vendor contract negotiation and transit board approval, and additional testing due to scope changes); installation challenges when equipment was retrofitted onto existing buses; and the obtaining of consistent data for analysis.

Retrofitting CAWS Onto Buses

Nasser et al. (2018) explored 13 automation technologies that could be transferred from light-duty vehicles and commercial trucks to diesel transit buses and the associated implementation challenges. The study’s closest analog to the CAWS described in the present study was termed “Object Detection and Collision Avoidance,” which was the only technology given a grade of “Green” (vs. “Yellow” or “Red”), indicating that only minor modifications to foundational bus systems were required and that safety concerns were minor. Building upon these systems to automate steering and braking fell into the Yellow and Red categories, respectively. The study noted the strengths of each of three sensor types that could be employed: only cameras did well at detecting pedestrians, only radar detected moving objects and differential speeds at various distances, and only ultrasonic sensors detected objects very close to the vehicle and in poor weather conditions.

Chiarenza et al. (2018) focused on trucks and suggested retrofitting FCW systems, which were readily available as an aftermarket product, for vehicles not scheduled for replacement in the near future and incorporating advanced driver-assistance systems into new vehicle procurement. The study found that FCW and automatic emergency braking (AEB) systems in large vehicles were limited in their ability to detect pedestrians and bicyclists, with only one system capable of detecting a moving person, and only in daylight, and none reliably able to detect a stationary person. The authors noted that the lack of nighttime functionality could lead to "mode confusion, wherein the driver either assumes that AEB is active when it is not, or forgets that the AEB is active."

Lutin et al. (2016) analyzed bus collision claims in the states of California, Ohio, and Washington and estimated that FCW with AEB systems could prevent 61% of claims greater than $100,000; 46% of such claims were collisions with pedestrians, bicyclists, and motorcyclists. The authors acknowledged the need to consider effects of deceleration on passengers, balancing that tradeoff with the benefit of AEB removing the typical bus driver's 2-second perception-reaction time.

User Surveys

Godavarthy (2019) surveyed U.S. transit agencies about eight types of bus transit automation technologies including collision avoidance. The survey received 157 responses from rural transit agencies, 67 from small urban agencies, and 34 from urban agencies. Respondents in rural and smaller communities tended to have lower levels of knowledge about and interest in transit automation technologies than their peers in urban agencies, and the report listed some challenges unique to agencies in rural areas and those in small urban areas. Collision avoidance was generally the technology that transit agencies favored most for near-term implementation, and respondents desired implementation resources such as websites and webinars, face-to-face assistance, and example requests for proposals.

Mangones et al. (2017) solicited expert opinions on the potential risk reduction from bus CAWS, which varied substantially (e.g., experts estimated FCW systems could reduce fatalities by 2% to 50% and injuries by 2% to 65% and that side-collision warning could reduce fatalities by 1% to 40% and injuries by 1% to 45% in New York City).

Quantitative Telematics Data and Analysis

For the statistical analysis, events per 100 kilometers were calculated on a daily basis for each bus. Event rates by route and event type are shown in Figures 2 through 7. For systems with substantial university populations (Lynchburg, Harrisonburg, and Blacksburg), black bars indicate dates when classes were in session and gray bars indicate dates when classes were not in session. Red dashed lines indicate when live mode was activated and operators began receiving collision warning and danger zone alerts. Precise dates are shown in Table 1. From a visual inspection, the clearest trends are visible in Figure 4 for Lynchburg's route 1 and in Figure 7 for WMATA, where collision warnings and danger zones decreased substantially when live mode was activated.

The results of statistical tests are shown in Tables 3 through 8. For each route, the event rates per 100 kilometers in stealth and live mode were compared with samples consisting of daily bus event rates. Negative changes indicated a reduction in the alert rate in live mode. Several routes had inadequate before/after sample sizes to support statistical analysis across all metrics, but differences are included for consistency across agencies. P-values less than 0.05 suggest strong evidence to reject the null hypothesis that there is no difference in means between stealth mode and live mode.

In nearly all comparisons with p-values less than 0.05, event rates were lower in live mode than in stealth mode, suggesting that operators were generally responding to the alerts by allowing more space around pedestrians and reducing speeds and longitudinal/lateral accelerations that triggered dangerous and aggressive behavior events. In only a handful of cases in Lynchburg and Hampton Roads did dangerous and aggressive behavior rates increase with live mode. Although a conclusive determination of reasons for this result was not possible with the data available, one possibility is that operators engaged in hard braking or steering maneuvers in an attempt to avoid getting alerts or in response to alerts. Other explanations could include changes in operators on the routes or physical changes along the routes.

To determine generalized trends across all systems and routes, alert rates for each agency were calculated after all routes for equipped buses that reported data in both stealth and live modes were aggregated. The agency-level analysis is shown in Table 8. Most agencies saw live mode reductions in danger zone warnings and dangerous behavior. Changes in collision warnings and aggressive behavior were mixed, with four agencies showing reductions and two agencies showing increases.

Table 9 shows the changes in events per kilometer from stealth to live mode for all equipped buses statewide.

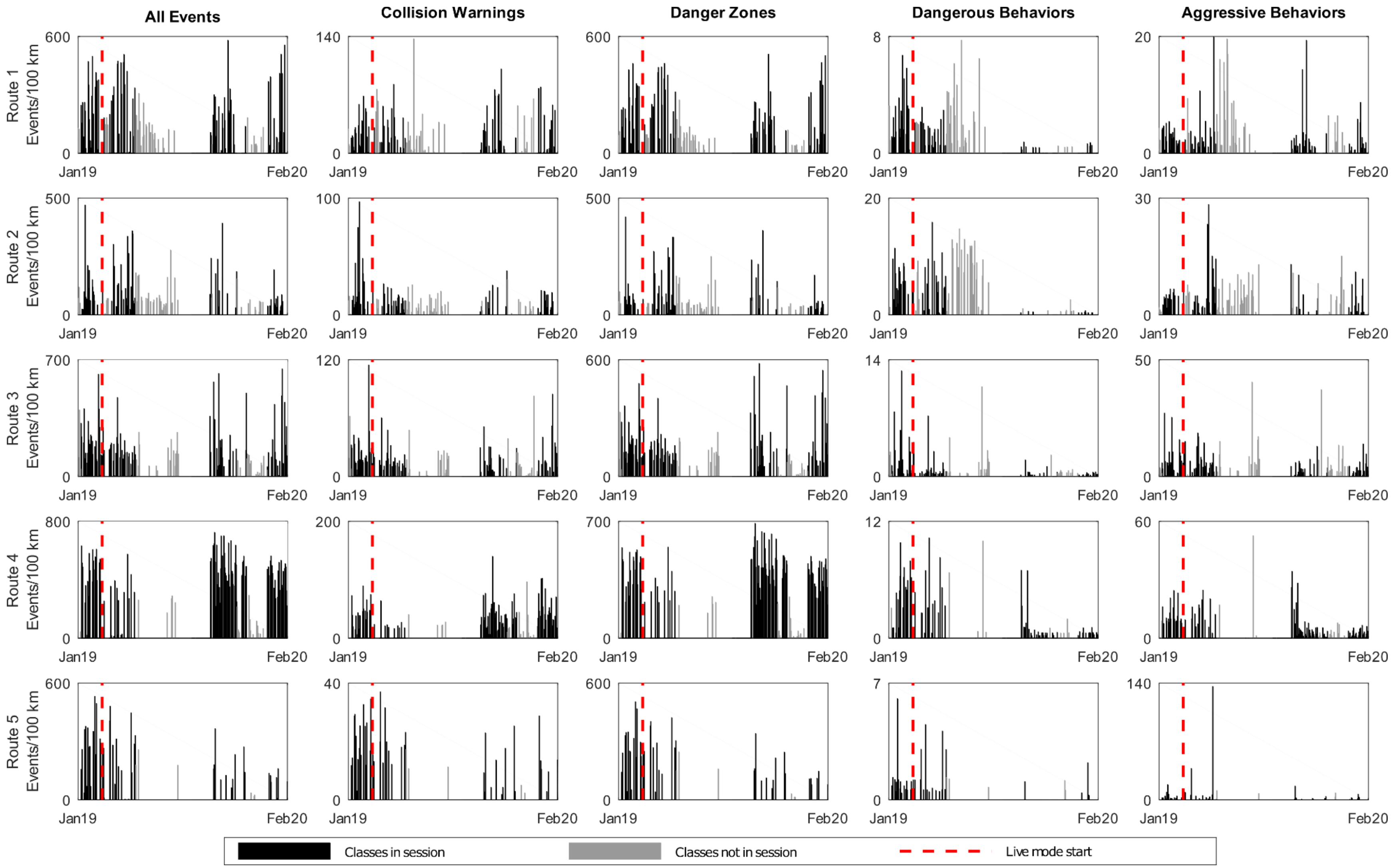


Figure 2. Events per 100 Kilometers for Blacksburg Buses by Route and Event Type Between January 2019 and February 2020

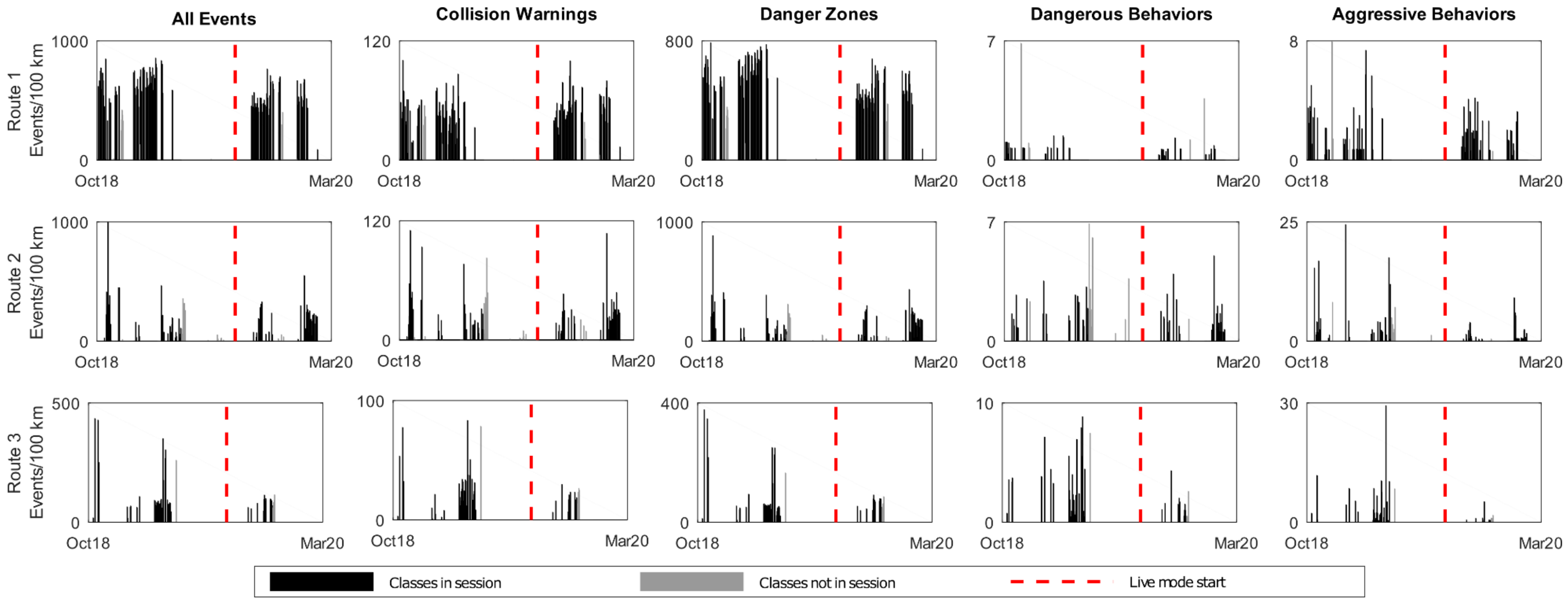


Figure 3. Events per 100 Kilometers for Harrisonburg Buses by Route and Event Type Between May 2018 and February 2020

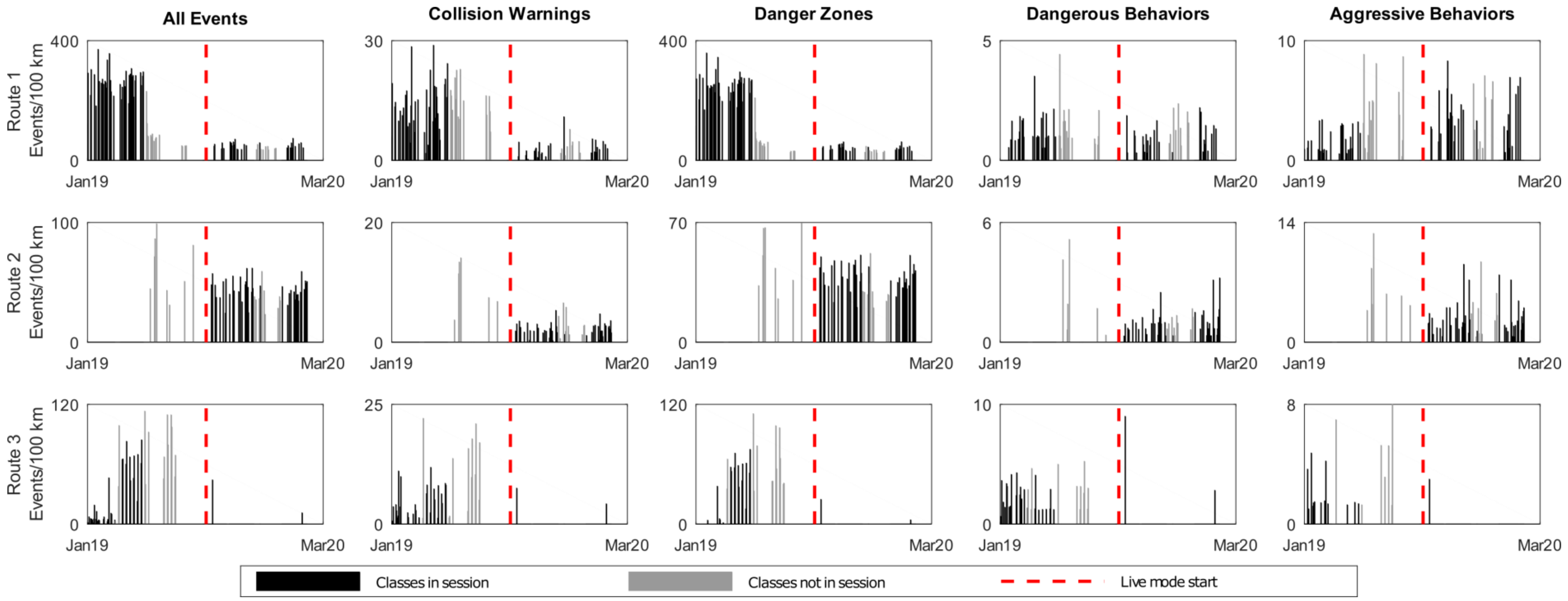


Figure 4. Events per 100 Kilometers for Lynchburg Buses by Route and Event Type Between October 2018 and February 2020

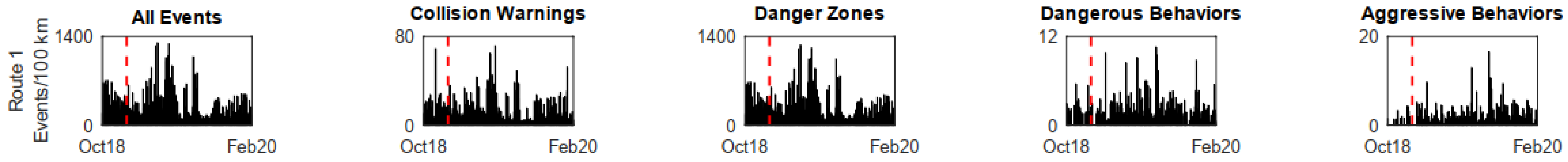


Figure 5. Events per 100 Kilometers for Alexandria Buses by Route and Event Type Between October 2018 and February 2020

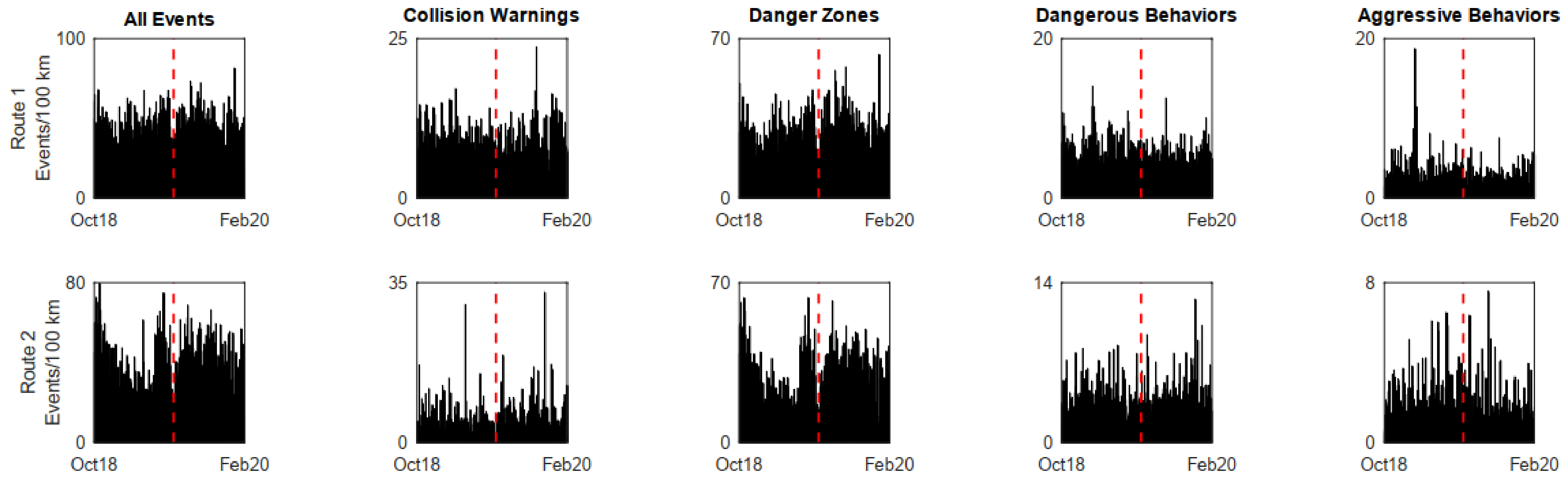


Figure 6. Events per 100 Kilometers for Hampton Roads Buses by Route and Event Type Between October 2018 and February 2020

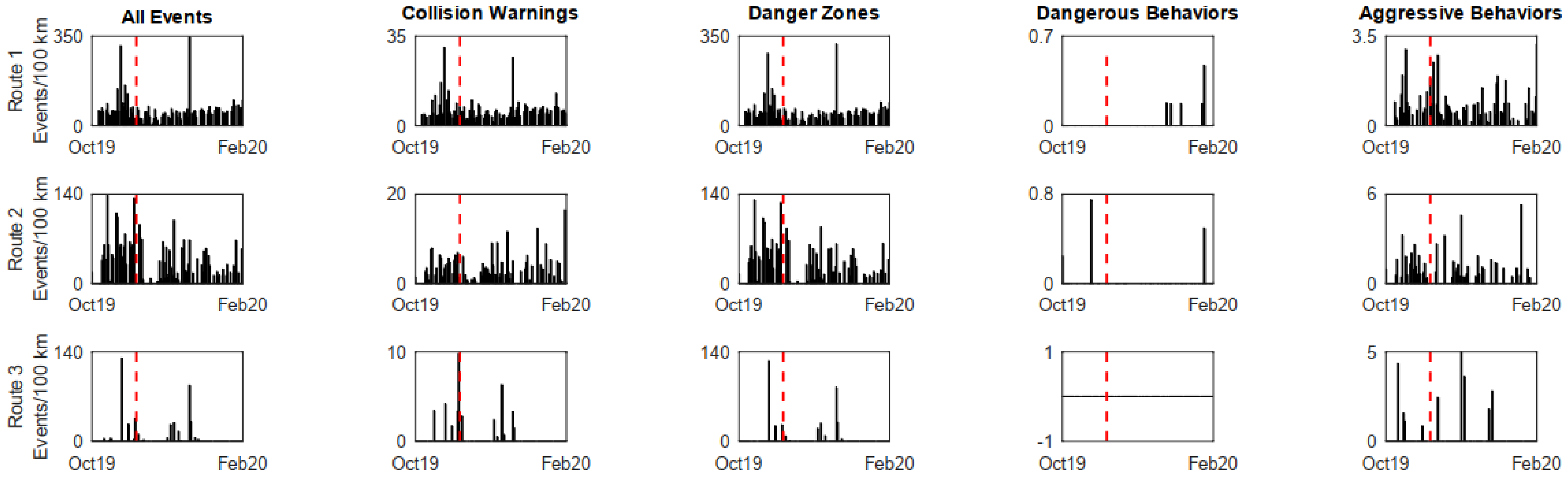


Figure 7. Events per 100 Kilometers for WMATA Buses by Route and Event Type Between October 2019 and February 2020. WMATA = Washington Metropolitan Area Transit Authority.

Table 3. Change in Events per Kilometer From Stealth to Live Mode for Blacksburg Buses

		All Events		Collision Warnings		Danger Zones		Dangerous Beh.		Aggressive Beh.	
Comparison	**Route**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**
All Days	1	-20.2%	0.15	4.9%	0.98	-24.1%	0.13	-46.8%	*0.00	30.5%	0.06
	2	4.5%	0.84	-50.3%	*0.02	24.3%	0.74	-16.9%	0.27	26.3%	*0.03
	3	-30.6%	*0.01	-37.6%	*0.00	-30.4%	*0.02	-52.1%	*0.01	4.4%	0.66
	4	-11.3%	0.25	-20.9%	0.13	-8.1%	0.44	-77.6%	*0.00	-56.0%	*0.00
	5	-35.3%	*0.01	-43.0%	*0.01	-35.6%	*0.02	-37.1%	0.68	45.8%	0.29
Weekdays	1	-18.0%	0.13	13.7%	0.58	-22.9%	0.10	-40.1%	*0.03	33.9%	0.08
	2	-9.8%	0.68	-56.2%	*0.03	4.7%	0.95	-25.7%	0.34	34.5%	*0.04
	3	-32.0%	*0.02	-38.1%	*0.01	-32.0%	*0.02	-52.1%	*0.02	4.0%	0.87
	4	-12.1%	0.09	-21.6%	0.07	-9.0%	0.20	-77.4%	*0.00	-55.8%	*0.00
	5	-37.0%	*0.01	-42.4%	*0.01	-37.7%	*0.01	-31.6%	0.76	56.7%	0.20
Weekends	1	25.9%	0.16	-18.9%	0.40	34.1%	0.14	-71.0%	*0.04	41.9%	0.29
	2	-1.8%	0.67	-51.7%	0.28	23.4%	0.93	-32.5%	0.25	-14.8%	0.46
	3	5.4%	0.34	-24.4%	0.23	11.2%	0.49	-39.2%	0.16	32.3%	0.43
	4	1263.5%	-	346.5%	-	-	-	-100.0%	-	-78.0%	-
	5	48.6%	0.54	-50.2%	0.61	85.3%	0.34	-86.0%	0.51	-45.4%	0.56
Classes in	1	-9.0%	0.49	1.7%	0.84	-9.9%	0.50	-69.1%	*0.00	-10.2%	0.56
	2	30.0%	0.46	-43.3%	0.04	65.3%	0.19	-49.3%	*0.00	12.8%	0.25
	3	-27.0%	0.06	-36.0%	*0.01	-26.1%	0.10	-59.1%	*0.00	-9.1%	0.26
	4	-7.3%	0.55	-21.2%	0.13	-3.5%	0.92	-78.6%	*0.00	-56.8%	*0.00
	5	-32.2%	*0.03	-40.3%	*0.02	-32.3%	*0.03	-42.2%	0.75	39.4%	0.31
First Week	1	-21.4%	0.23	11.4%	0.83	-26.1%	0.31	-6.1%	0.81	-20.0%	0.25
	2	-25.7%	0.44	-33.2%	0.46	-29.4%	0.38	-26.7%	0.62	74.3%	0.31
	3	-27.8%	0.11	-42.8%	*0.01	-28.5%	0.11	28.9%	0.94	57.9%	0.28
	4	-42.9%	-	-44.6%	-	-44.1%	-	8.9%	-	-18.0%	-
	5	-33.0%	0.40	-54.0%	0.15	-33.1%	0.42	7.8%	0.64	113.5%	0.35
First Month	1	-17.3%	0.37	28.7%	0.45	-23.9%	0.28	-18.0%	0.32	0.1%	0.99
	2	22.2%	0.84	-41.5%	0.07	46.3%	0.67	0.9%	0.95	26.2%	0.15
	3	-31.0%	*0.01	-37.5%	*0.00	-32.1%	*0.02	-28.3%	0.12	40.5%	0.43
	4	-48.6%	*0.03	-48.6%	0.10	-50.0%	*0.04	-21.6%	0.41	-11.4%	0.58
	5	7.8%	0.93	-17.0%	0.81	7.5%	0.87	35.5%	0.44	197.4%	0.32

* Welch's t-test p-value < 0.05. "-" indicates that the sample size was insufficient to conduct a Welch's t-test.

Table 4. Change in Events per Kilometer From Stealth to Live Mode for Harrisonburg Buses

		All Events		Collision Warnings		Danger Zones		Dangerous Beh.		Aggressive Beh.	
Comparison	**Route**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**
All Days	1	-17.8%	*0.00	2.5%	0.44	-19.5%	*0.00	-23.4%	0.36	-21.6%	0.31
	2	18.0%	0.56	14.5%	0.69	22.0%	0.49	-37.0%	0.06	-71.6%	*0.00
	3	-9.3%	*0.03	-16.1%	*0.02	-1.5%	0.07	-55.0%	*0.00	-81.2%	*0.00
Weekdays	1	-17.7%	*0.00	2.6%	0.41	-19.5%	*0.00	-28.8%	0.14	-21.5%	0.31
	2	37.5%	0.05	14.9%	0.40	45.1%	*0.03	-47.5%	0.09	-61.5%	*0.04
	3	-14.7%	*0.01	-28.5%	*0.00	-8.1%	*0.03	-50.7%	*0.04	-62.8%	*0.04
Weekends	1	34.8%	-	-19.1%	-	-	-	-	-	-	-
	2	-51.5%	0.17	5.5%	0.52	-60.5%	0.16	-7.6%	0.42	-84.6%	0.06
	3	-6.5%	0.53	16.9%	0.88	1.9%	0.92	-53.9%	0.12	-91.4%	*0.01
Classes In	1	-20.6%	*0.00	1.5%	0.56	-22.5%	*0.00	-30.2%	0.21	-19.0%	0.38
	2	12.9%	0.84	12.4%	0.81	16.2%	0.93	-24.5%	0.24	-74.5%	*0.01
	3	-4.4%	0.05	-16.1%	*0.02	5.2%	0.13	-49.0%	*0.02	-83.4%	*0.00
First Week	1	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-
First Month	1	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-

* Welch's t-test p-value < 0.05. "-" indicates that the sample size was insufficient to conduct a Welch's t-test.

Table 5. Change in Events per Kilometer From Stealth to Live Mode for Lynchburg Buses

		All Events		Collision Warnings		Danger Zones		Dangerous Beh.		Aggressive Beh.	
Comparison	**Route**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**
All Days	1	-71.9%	*0.00	-78.2%	*0.00	-73.9%	*0.00	2.9%	0.53	60.4%	*0.00
	2	-39.9%	*0.05	-74.4%	*0.05	-31.5%	0.08	-55.9%	0.29	-54.2%	0.09
Weekdays	1	-71.3%	*0.00	-79.4%	*0.00	-73.3%	*0.00	0.8%	0.63	64.9%	*0.00
	2	-36.3%	0.09	-73.7%	0.09	-29.2%	0.15	-39.9%	0.58	-44.7%	0.14
Weekends	1	-84.1%	-	-77.1%	-	-86.0%	-	-32.7%	-	-	-
	2	-48.4%	-	-69.3%	-	-36.7%	-	-81.4%	-	-73.6%	-
Classes in	1	-80.5%	*0.00	-79.0%	*0.00	-82.3%	*0.00	26.1%	0.36	262.8%	*0.00
	2	-	-	-	-	-	-	-	-	-	-
First Week	1	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-
First Month	1	-72.9%	*0.00	-84.4%	*0.00	-73.5%	*0.00	9.2%	0.76	-2.2%	0.39
	2	-35.9%	0.05	-73.0%	*0.04	-24.6%	0.14	-68.2%	0.15	-65.3%	*0.04

* Welch's t-test p-value < 0.05. "-" indicates that the sample size was insufficient to conduct a Welch's t-test.

Table 6. Change in Events per Kilometer From Stealth to Live Mode for Alexandria Buses

		All Events		Collision Warnings		Danger Zones		Dangerous Beh.		Aggressive Beh.	
Comparison	**Route**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**
All Days	1	-40.97%	*0.01	-45.32%	0.12	-41.49%	*0.01	58.72%	0.07	327.14%	*0.00
Weekdays	1	-40.06%	*0.01	-43.51%	0.10	-40.66%	*0.01	52.78%	0.08	381.29%	*0.00
First Week	1	-0.33%	0.82	8.93%	0.58	-0.47%	0.83	-58.21%	0.51	-100.00%	*0.00
First Month	1	-42.89%	*0.00	-43.93%	*0.02	-43.35%	*0.00	1.50%	0.19	273.78%	0.16

* Welch's t-test p-value < 0.05. "-" indicates that the sample size was insufficient to conduct a Welch's t-test.

Table 7. Change in Events per Kilometer From Stealth to Live Mode for Hampton Roads Buses

		All Events		Collision Warnings		Danger Zones		Dangerous Beh.		Aggressive Beh.	
Comparison	**Route**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**
All Days	1	6.52%	*0.01	8.10%	0.06	10.84%	*0.00	-6.28%	*0.00	-16.37%	*0.00
	2	6.38%	*0.01	8.36%	0.06	10.90%	*0.00	-7.66%	*0.00	-18.93%	*0.00
Weekdays	1	5.66%	0.58	4.72%	0.67	8.55%	0.33	-0.58%	0.32	-5.37%	0.29
	2	6.52%	*0.01	8.10%	0.06	10.84%	*0.00	-6.28%	*0.00	-16.37%	*0.00
Weekends	1	-21.66%	*0.01	-18.47%	0.10	-23.34%	*0.02	-17.40%	*0.03	-22.00%	0.18
	2	-0.96%	0.54	-11.70%	*0.04	5.07%	0.58	-7.68%	0.11	-17.79%	*0.03
First Week	1	18.07%	*0.00	27.37%	0.05	20.32%	*0.01	1.03%	0.55	8.62%	0.46
	2	15.68%	*0.00	13.11%	*0.04	19.30%	*0.00	6.48%	0.11	-12.77%	0.08
First Month	1	-27.64%	*0.00	-34.41%	*0.00	-34.27%	*0.01	1.01%	0.61	32.39%	0.84
	2	-4.08%	0.49	-1.99%	0.66	-6.70%	0.45	2.64%	0.96	15.82%	0.43

* Welch's t-test p-value < 0.05. "-" indicates that the sample size was insufficient to conduct a Welch's t-test.

Table 8. Change in Events per Kilometer From Stealth to Live Mode for WMATA Buses

		All Events		Collision Warnings		Danger Zones		Dangerous Beh.		Aggressive Beh.	
Comparison	**Route**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**	**Diff.**	**p-value**
All Days	1	-19.89%	*0.01	2.48%	0.59	-22.15%	*0.01	-	-	-3.25%	0.90
	2	-16.09%	*0.02	6.69%	0.94	-18.41%	*0.01	-	-	3.03%	0.96
	3	-52.99%	0.37	-29.70%	0.56	-55.46%	0.36	-	-	-22.01%	0.81
Weekdays	1	-19.89%	*0.01	2.48%	0.59	-22.15%	*0.01	-	-	-3.25%	0.90
	2	-26.75%	0.07	-12.39%	0.27	-29.11%	0.07	-	-	73.34%	0.42
	3	-40.37%	*0.00	-10.70%	0.29	-43.48%	*0.00	-	-	-2.91%	0.70
Weekends	1	-36.50%	*0.00	-15.70%	0.45	-38.38%	*0.00	-69.79%	0.28	-21.18%	0.82
	2	-43.89%	*0.00	-26.27%	0.21	-45.76%	*0.00	3.50%	0.65	-27.86%	0.86
	3	-18.67%	0.40	60.06%	0.18	-21.88%	0.34	-100.00%	0.35	-13.12%	0.72
First Week	1	-36.50%	*0.00	-15.70%	0.45	-38.38%	*0.00	-69.79%	0.28	-21.18%	0.82
	2	-1.31%	0.30	-27.72%	0.10	1.14%	0.33	-100.00%	0.16	-19.16%	0.86
	3	-39.99%	*0.00	-28.69%	*0.04	-41.33%	*0.00	-100.00%	0.16	-14.93%	0.75
First Month	1	-42.86%	0.42	-62.77%	0.13	-41.58%	0.51	-	-	-0.73%	0.81
	2	-61.99%	0.46	-5.19%	0.44	-69.83%	0.49	-	-	40.79%	0.91
	3	-23.89%	0.64	-87.51%	0.39	-8.85%	0.85	-	-	-39.11%	0.66

WMATA = Washington Metropolitan Area Transit Authority.

* Welch's t-test p-value < 0.05. "-" indicates that the sample size was insufficient to conduct a Welch's t-test.

Table 9. Change in Events per Kilometer From Stealth to Live Mode for All Equipped Buses Statewide

Comparison	Status	Transit System					
		Blacksburg	Harrisonburg	Lynchburg	Alexandria	Hampton Roads	WMATA
All Events	Stealth	236.1	357.6	140.2	333.3	36.1	58.4
	Live	208.2	327.9	45.8	196.9	39.5	44.1
	Diff.	-11.8%	-8.3%	-67.4%	-40.9%	9.4%	-24.4%
Collision Warnings	Stealth	27.0	34.3	11.7	15.0	5.9	4.6
	Live	21.0	36.6	2.8	8.2	6.6	4.6
	Diff.	-22.2%	6.6%	-76.4%	-45.2%	10.8%	0.2%
Danger Zones	Stealth	201.3	319.4	125.0	317.0	23.9	53.0
	Live	180.9	289.6	38.6	185.6	27.0	38.9
	Diff.	-10.1%	-9.3%	-69.1%	-41.5%	12.9%	-26.6%
Dangerous Behavior	Stealth	2.6	1.2	1.3	1.0	4.1	0.0
	Live	1.4	0.6	1.1	1.5	4.0	0.0
	Diff.	-45.6%	-46.9%	-15.6%	57.8%	-1.4%	-3.9%
Aggressive Behavior	Stealth	5.1	2.6	2.4	0.4	2.1	0.8
	Live	4.8	1.1	3.3	1.6	1.9	0.6
	Diff.	-5.8%	-59.5%	40.5%	325.9%	-13.2%	-17.5%

WMATA = Washington Metropolitan Area Transit Authority.

Qualitative Data and Analysis

Initial Operator Feedback

WMATA

WMATA bus operators who had received training on the CAWS but had not yet operated buses displaying live alerts shared their feedback. They expected the system to help avoid pedestrian crashes, help drivers gauge proximity of bicyclists and pedestrians, and keep operators aware of what was around the bus beyond what they would ordinarily observe (e.g., one noted that it could help with awareness in between regular scans of mirrors). Some thought the system would be well suited for the congested conditions in which WMATA routes operated. Operators described the training they received as quick but sufficient and noted that because a very small percentage of the agency's buses had the system, most operators did not receive the training. They recalled from the training that the New York City transit system had good results with CAWS.

In terms of expected behavior change, the expectations of WMATA operators were mixed. Some expected the system to increase operator awareness of how close the bus was to vehicles, pedestrians, and bicycles; they noted that it was not uncommon for them to see bikes squeezing between buses and other vehicles. Others expected no behavior change—because on routes with speed limits of predominantly 20 to 25 mph, bus operators already gave other road users sufficient space—or were unsure, expecting some operators might like it and some might not.

The WMATA operators were curious as to how frequent false alarms would be. Some noted that given congested road conditions, their buses were often near other vehicles, pedestrians, and bicyclists, so alerts based on the proximity of the bus to these other road users might be too frequent. For example, an operator wondered if the following distance alerts would be a nuisance if they beeped every time the bus inched forward in stop-and-go-traffic: "I don't need the bus to tell me how close to be to another vehicle." Regarding what might happen if the system failed to provide an alert (i.e., a false negative), two operators stated that they did not expect to depend on the system and thus were not overly concerned.

Opinions were mixed on whether the system would be mostly helpful, mostly distracting, or both, with noise and brightness mentioned as specific anticipated concerns, especially if passengers became alarmed by seeing and/or hearing the alerts. Another concern was CAWS displays potentially creating additional blind spots. One of the operators who expected the system to be mostly helpful noted that this was the perspective of a relatively new driver with 9 months on the job. Opinions were similarly mixed on the validity and fairness of using the CAWS data to provide operators with feedback on their driving performance. One operator pointed out that such data should not become a substitute for supervisors conducting ride-along observations. Some operators, including a union representative, were concerned that the system could track operators but had not been advertised to them that way, building on the distrust some operators had expressed after cameras were installed inside buses. Others noted that the system should improve conditions overall and that private reports to each operator could be useful.

DASH

DASH bus operators who had driven equipped buses provided feedback on the system and its alerts. Opinions varied on whether the CAWS was helpful, effective, or distracting. Some operators reported mixed reactions: the system was helpful but too sensitive or effective but distracting.

For the pedestrian detection feature, some found it to have functioned appropriately, with one long-time operator reporting that the system had been a lifesaver, especially when entering a bus stop as people were moving toward the bus. Several drivers mentioned false or too frequent pedestrian detection alarms, especially in areas with high pedestrian volumes such as Old Town Alexandria. Unnecessary alerts for pedestrians on sidewalks when the bus is going straight ahead (mostly on the right-hand side but sometimes across the street) were mentioned, along with false alarms when the bus is turning and the system detects stationary objects as pedestrians. One driver advised that the pedestrian alert sometimes appeared for a motorcycle and noted that this was not necessarily a problem. Fewer operators reported false negatives (missed detections), although one thought the system had worked at some crosswalks and not at others. One driver found the system inconsistent because it would display alarms for pedestrians far away but miss a bicyclist passing close to the bus. Two drivers found the pedestrian alerts to be too slow, activating after they had already seen a pedestrian.

Most operators who mentioned the FCW feature found it too sensitive for the congested traffic conditions of DASH routes. One suggested that the alarm should cease when the brake is applied. Two operators reported missed FCW detections, especially when the bus was not centered on the vehicle it is following.

Five operators did not recall receiving any training but said they figured out the system on the road (although one mentioned ignoring the beeping FCW display, not knowing what it was). Others reported that the training was sufficient. Perceived behavior change varied, with two drivers claiming their behavior had not changed as a result of receiving the alerts.

Desired features were noted. Two DASH operators expressed a desire for nighttime functionality, especially in the rain, and two desired more consistency in speed limit recognition (an example was the system displaying a 70 mph speed limit on a 25 or 35 mph street). One wanted pedestrian alerts to work when the bus was stopped, noting that people often dart in front of a bus just as it is about to move, and one suggested changing the alert tones to distinguish the alerts from the passenger stop request chime.

Operator Survey Results

Across the eight transit agencies, 151 operator survey responses were received. As noted earlier, some agencies distributed the survey to all operators and others selected only those who had driven an equipped bus recently. In addition, some but not all agencies advised the researchers of how many of their operators were invited to complete the survey. For these reasons, an overall response rate is not available and would likely not be particularly meaningful. The input from these 151 responses should not be used to assess the deployment of the CAWS at a particular agency but can be informative in terms of assessing DRPT's overall statewide CAWS demonstration project.

More than two-thirds of respondents reported that they received training that was somewhat or very effective at helping them understand the meaning of the system's alerts, as shown in Figure 8a. Slightly more than one-fourth of respondents indicated either that training was not very effective or that they never received training.

Operators reported frequent false alarms, as shown in Figure 8b. More than 40% of respondents reported pedestrian alerts or collision warnings occurring often when no pedestrians, bicyclists, etc., were present, and another one-third reported that they occurred sometimes. As seen in Figure 8c, operators reported that missed detections (false negatives) were less frequent, with roughly similar proportions of respondents indicating that they had to take action to avoid a conflict often, sometimes, rarely, and never when the system failed to provide a warning.

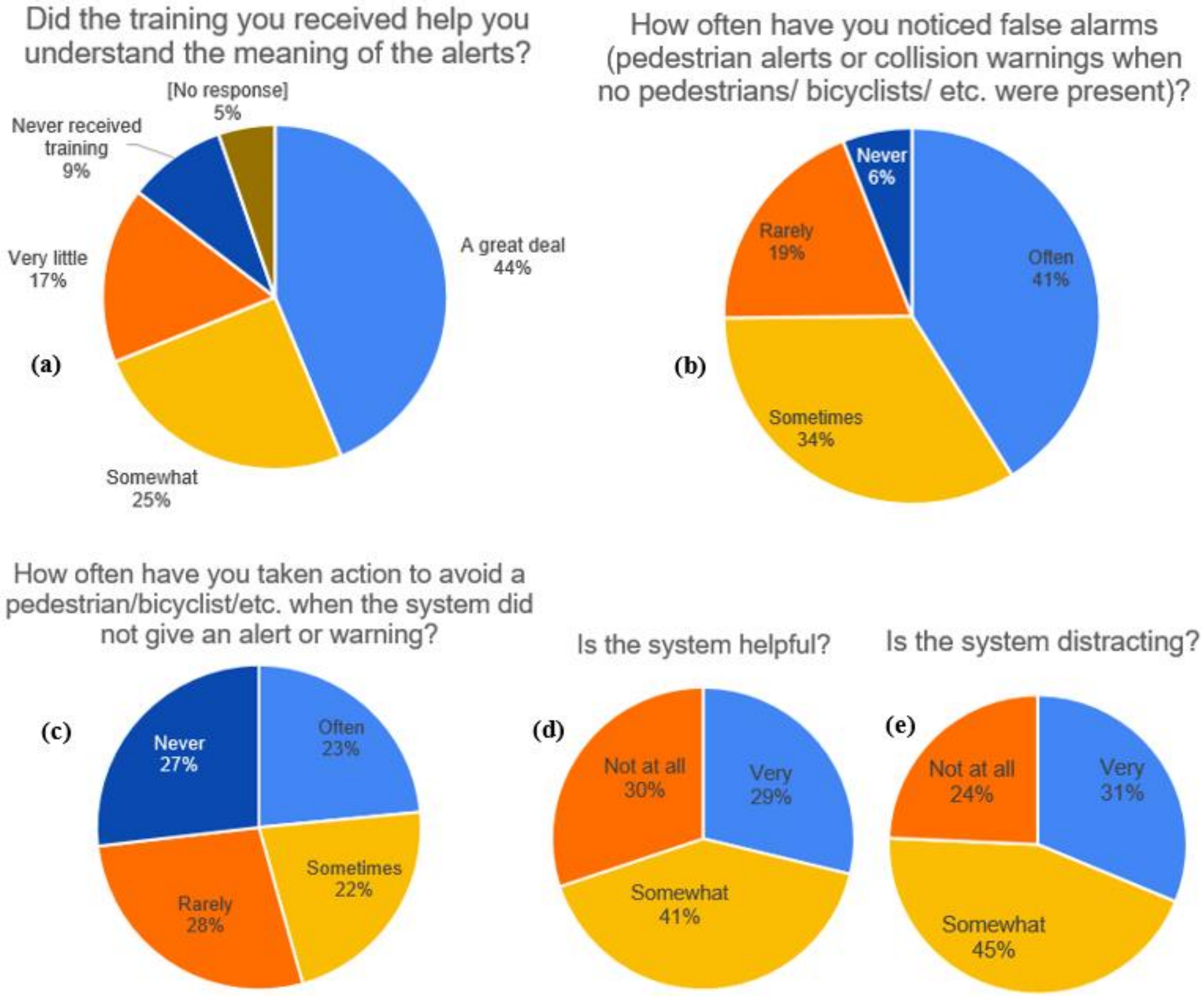


Figure 8. Operators' Perceptions of CAWS Effectiveness. CAWS = collision avoidance warning system.

Respondents had mixed opinions about the system's helpfulness and distractions from alerts, shown in Figures 8d and 8e. Most found the system at least somewhat helpful, but 30%

found it not at all helpful. Three of four respondents found the system distracting, with nearly one-third reporting it to be very distracting.

The remainder of this section discusses the categorized results of free-response survey questions. Because free-response answers could address multiple categories of responses, in many cases the total number of categorized responses exceeds the total number of respondents. For example, in Figure 9, the verbatim response "It has not changed my behavior because I cannot trust it" was recorded under both the *Not much/no change in behavior* and the *Negative comments* response types.

Many bus operators reported no perceived change in their driving behavior as a result of the system, as shown in Figure 9. Some reported improved awareness. As one operator responded: "The system changed my behavior being more aware, and made me better at my job. The light and the alert noise keep me informed of what's around the bus." The 16 negative comments centered on distraction and false alarms. A representative response from this perspective was: "I'm more comfortable driving without the system because the alarms that go off are often scarier (read: more startling) than whatever hazard might be in the road or around the bus." The neutral comments all accompanied reports of little or no behavior change; e.g., "I follow the training I received and it covers all of what the sensors were telling me."

Figure 10 shows operator perspectives on the CAWS advantages and disadvantages. Although several operators stated that there were no advantages of the system, to either them or their agencies, others identified various outcomes consistent with the goals of the CAWS.

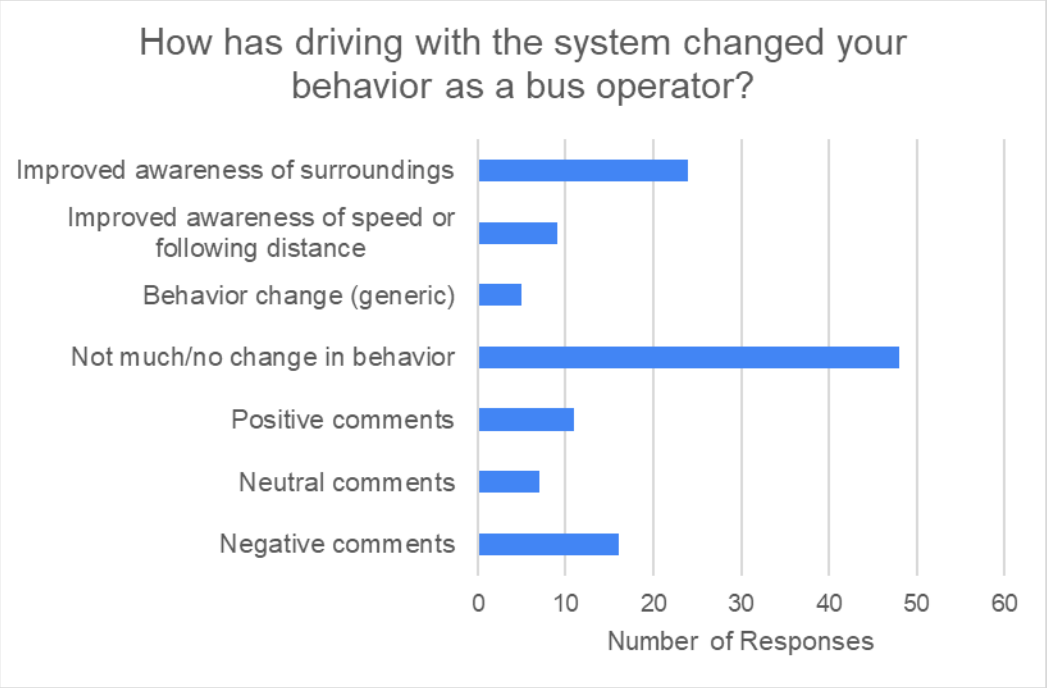
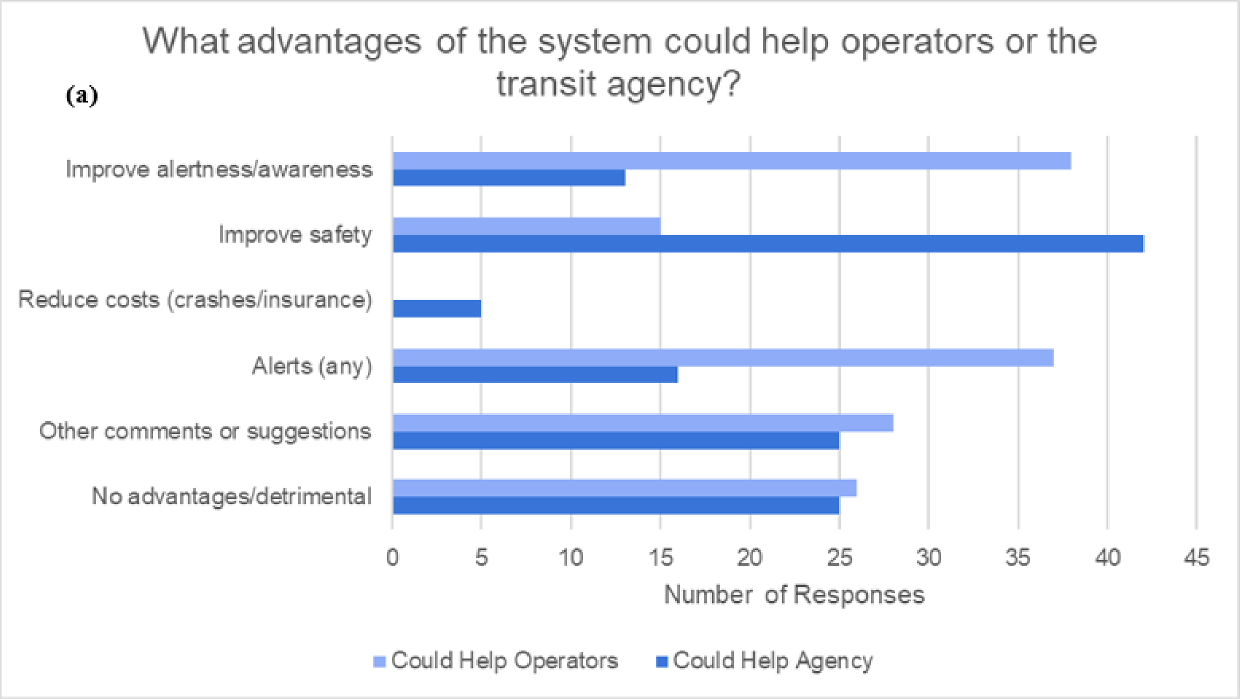


Figure 9. Operators' Perceptions of Changes in Their Driving Behavior (120 Comments From 97 Respondents)



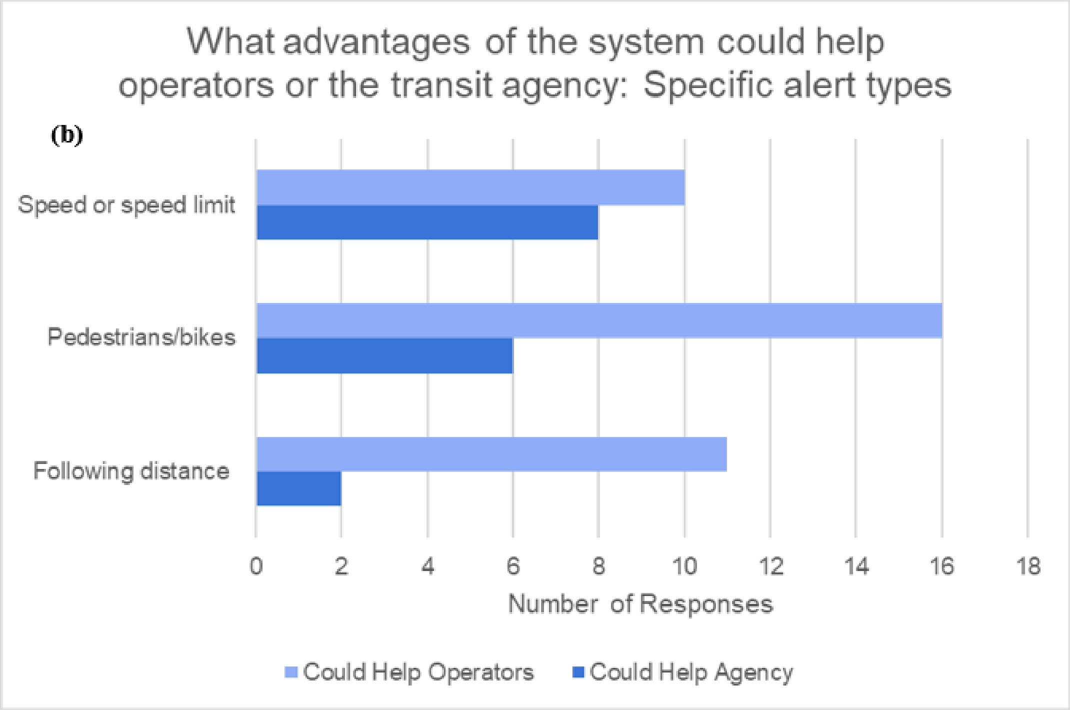


Figure 10. Operators' Perceptions of Advantages of CAWS (270 Comments From 126 Respondents). CAWS = collision avoidance warning system.

Items that some respondents saw as advantages that could help bus operators included improved situational awareness and help with blind spots, general improvements in operator safety, and alerts (disaggregated in Figure 10b). As far as advantages to the transit agency, improved safety was the most frequently mentioned category. Several other comments and specific suggestions were provided; e.g., “The speed sensor is somewhat useful for those that have not become familiar enough with the roads. However, the system did not handle the school zone speeds with any consistency.” For Figure 10b and the following topic of useful system features, the alert category *following distance* likely includes or conflates FCW and headway monitoring because respondents did not use those precise terms in their free-response answers.

As the most useful CAWS features, respondents most frequently cited the alerts overall and the pedestrian/bicycle alerts specifically, as shown in Figure 11. Several respondents also mentioned following distance and speed or speed limit alerts. Twenty-eight respondents stated that the system had no useful features (this includes only those who entered responses of “none,” “not useful,” etc., and does not include another 21 blank responses). As shown in Figure 12, 46 respondents indicated that there were no additional features they wished the system had whereas other respondents provided a range of general and specific suggestions.

Some transit agencies provide feedback on operators’ driving performance using the CAWS data. Figure 13 shows operators’ stated levels of comfort with receiving feedback privately or along with everyone else’s. Many operators stated that they would feel comfortable receiving such feedback, both privately and in a situation where all operators could see everyone’s feedback. Five of the 71 respondents who said they would be comfortable viewing their driving feedback along with everyone else’s elaborated that they were comfortable with that only if operators remained anonymous. Several respondents added comments expressing discomfort with the concept of assessing driving performance using the CAWS data, typically suggesting that such assessments might be invalid based on what they saw as a high level of inaccuracy and/or false alarms.

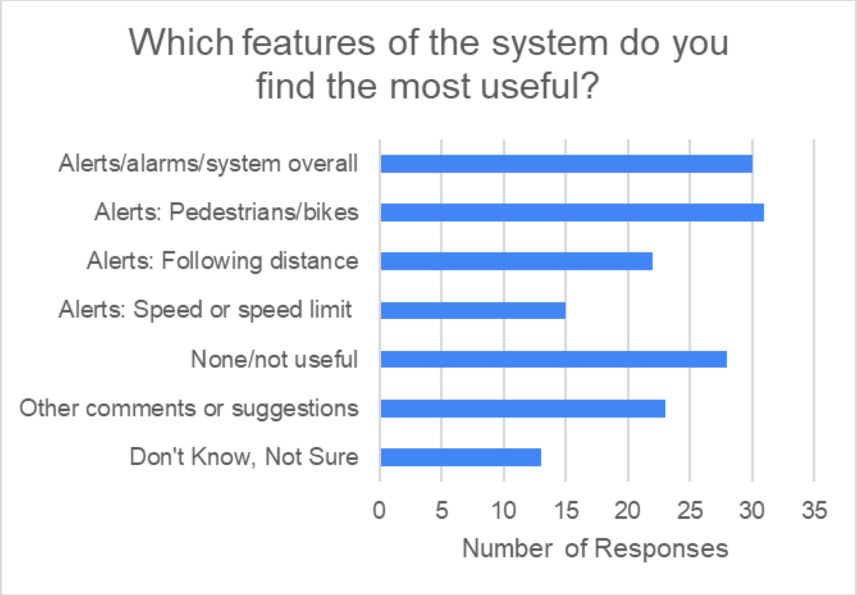


Figure 11. Operators’ Perceptions of CAWS’s Most Useful Features (162 Responses From 130 Respondents). CAWS = collision avoidance warning system.

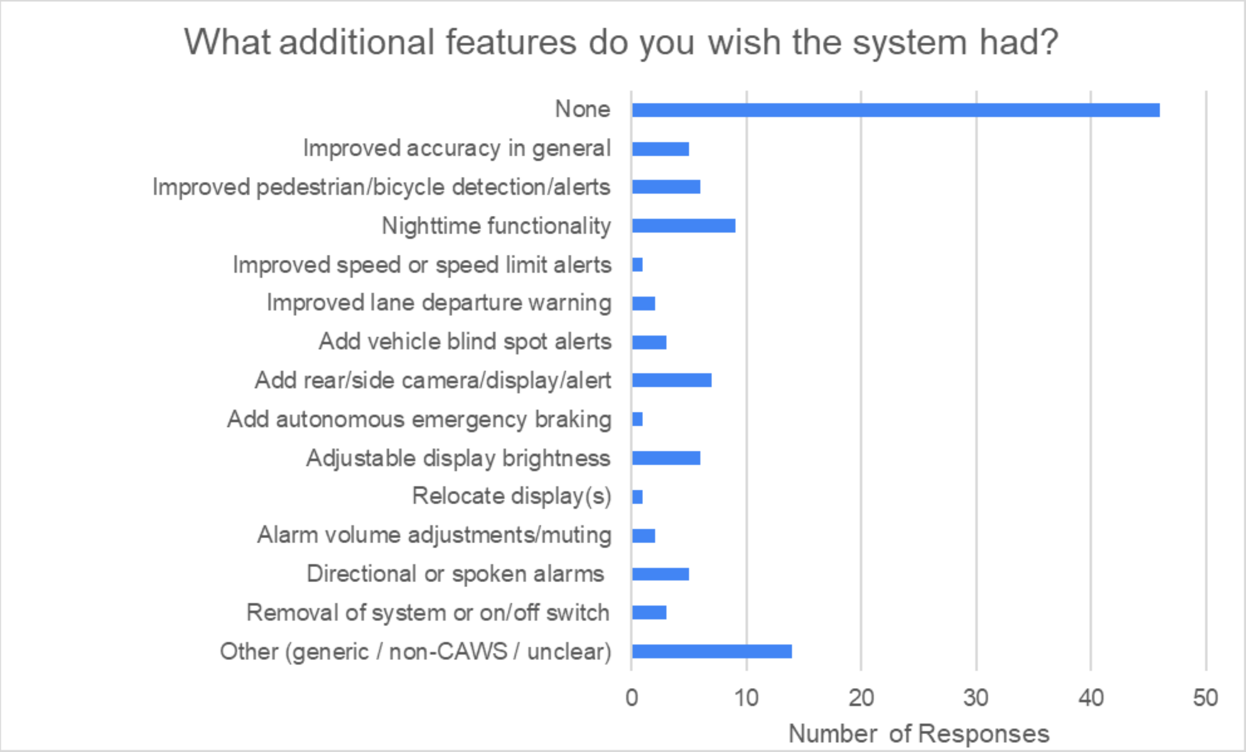


Figure 12. Operators' Perceptions of Desired Additional CAWS Features (111 Responses From 107 Respondents). CAWS = collision avoidance warning system.

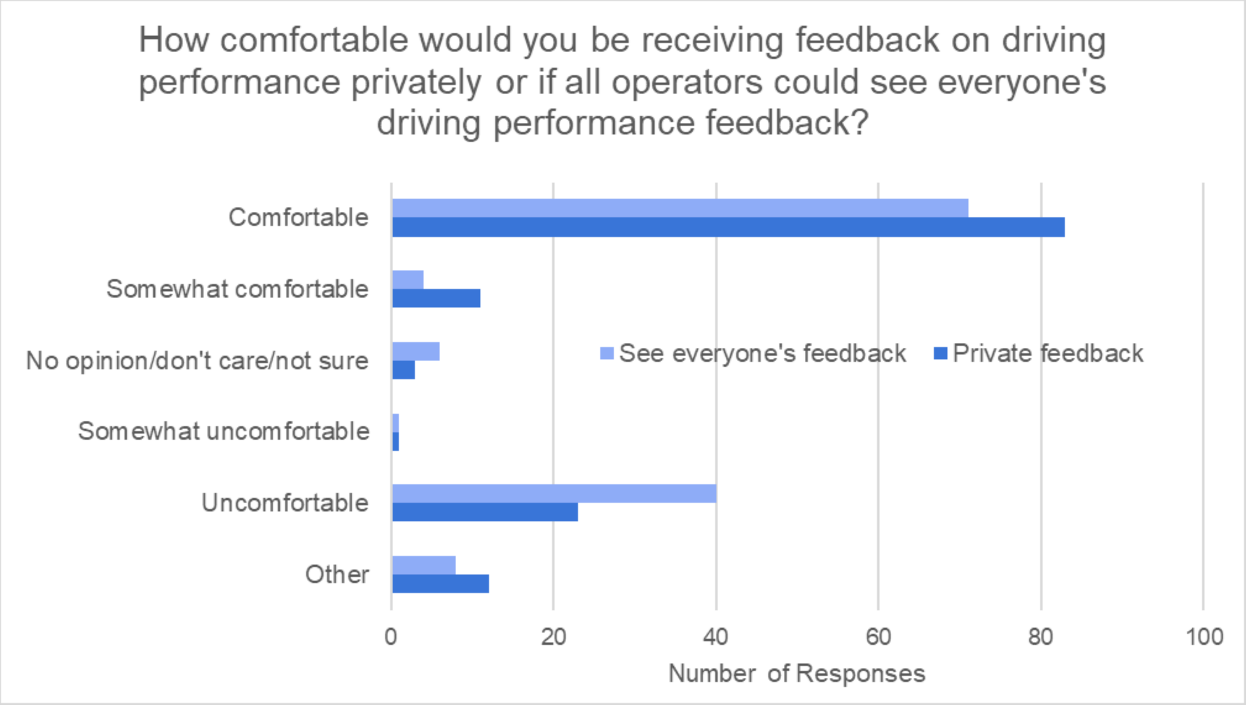


Figure 13. Comfort Levels With Receiving Private or Public Feedback on Driving Performance (263 Comments From 134 Respondents). CAWS = collision avoidance warning system.

The final survey question was open-ended, inviting respondents to provide any other comments. About one-half of respondents entered comments, which are summarized in Figure

14. As might be expected, most of the respondents who took the time to enter comments had complaints, criticisms, and other negative feedback about the system in general or specific elements of it. Others, however, expressed general support for the system or offered positive or neutral observations. Because a categorization of comments cannot fully reflect the breadth and detail of the opinions, several examples of open-ended comments are included in Table 10.

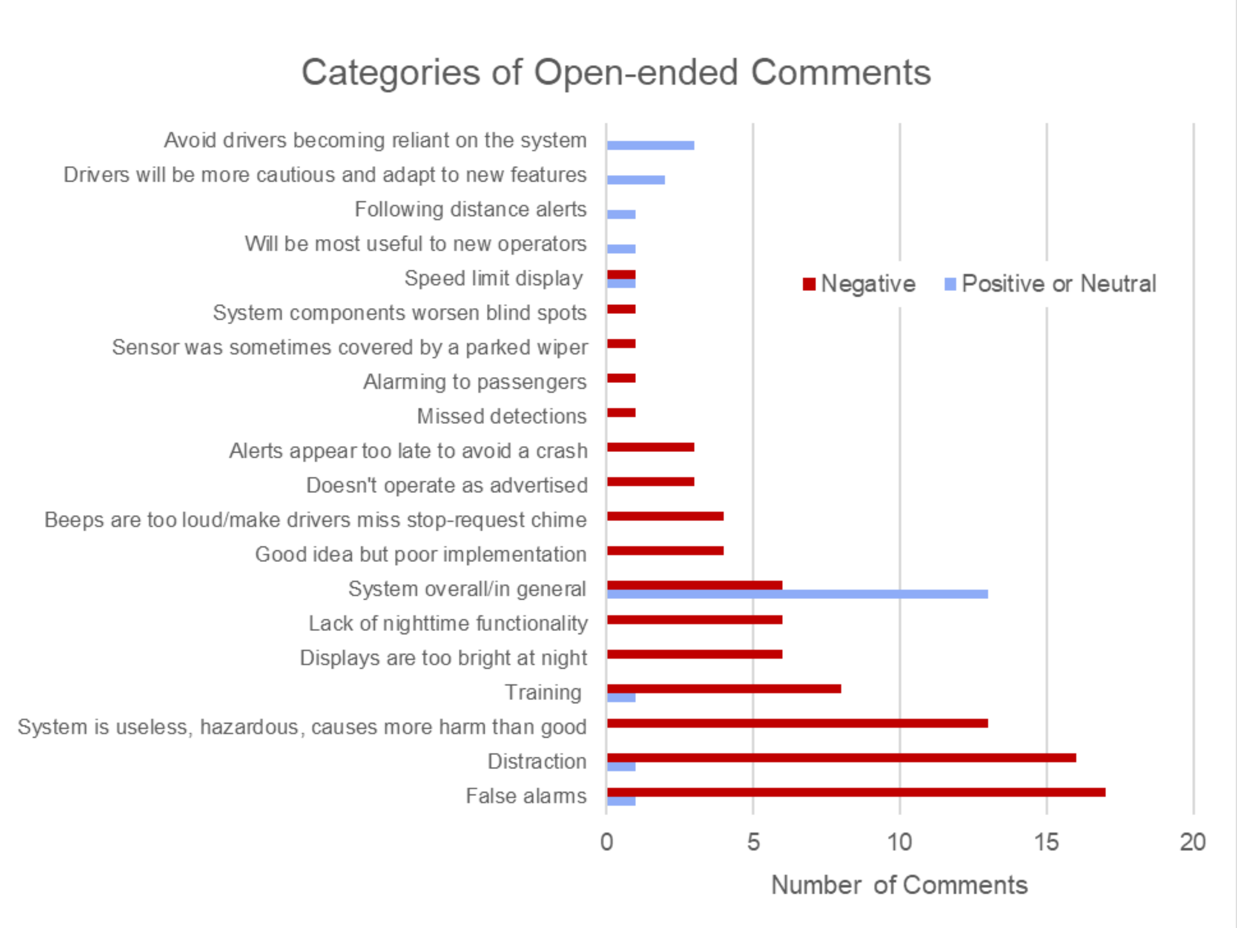


Figure 14. Categorized Free-Response Comments (115 Comments From 82 Respondents). CAWS = collision avoidance warning system.

Table 10. Examples of Open-Ended Operator Survey Responses Regarding the Collision Avoidance System

Comments (Verbatim)
"Alerting to people on the opposite sidewalk is a very poor design, causing many false alerts. If the system took into account which way people were moving, it might be better."
"I have noticed that many 'false alarms' are when turning left around traffic circles or when turning left around a median. As stated above, I have learned to ignore these alarms, as annoying and distracting as they can be, but I always check to make sure there was actually no pedestrian. These false alarms defeat the stated purpose of the system, and until they can be resolved, I feel the system is more a hazard to pedestrian safety than a benefit. Thank you for letting us be a part of this study and for listening to our feedback!"
"I would be very very disappointed if this system was implemented in our units. I strongly feel that there were no benefits to me as an operator. I am grateful that I had no incidents while this system was screaming and flashing when I should have been watching mirrors and ahead rather than looking at flashing lights. If I were to have an incident with this system activated I would feel very strongly that it would have played a negative part as a distraction to my attention and a delay in my response."
"I think this is a good safety item. Help keep you focus."
"When I drove a vehicle with this system on a crowded campus or on a crowded game day shuttle, the amount of false positives were mind boggling. When the system beeps at you constantly, all that does is makes the driver jittery, on edge, and nervous which means a net result of a less safe operator in my opinion. Beeping and blinking things that go off like that are not helpful at all. If the system truly just went off when there was actual imminent danger, that would be helpful. It cannot go off every time someone walks within 15 feet [4.6 m] of your bus or it will never stop, which, again, just makes you nervous and more likely to make a mistake. Also, as I've already said, making work at night when you actually have visibility issues would make a lot of sense."
"The only training was a poster to look at. It is not unusual for a false alarm when entering a bus stop. The light from the system is bright enough to hurt my eyes, especially at night. There have been times when I've questioned why the system didn't alert, i.e., a skateboarder going between me and the curb."
"Somewhat distracting but a good distraction."
"I think any driver who relies on this is more at risk for an accident than if they were to just use good habits."
"Good system needs a little adjusting distance wise."
"I am comfortable in my skills and ability but do not trust the accuracy of this device. A lot of time it gives false or misleading sign."
"System no good at night. The idea is good; system not so much. Lot of faults."
"Bells are annoying and interfere with passenger buzzer. Bells start going off unnecessarily when vehicles slow suddenly to turn right in front of our vehicle, or change lanes."
"I also really like the feature that warns me of vehicles in front of me & the number of seconds between the bus & the vehicle ahead. Also the speed limit indicator is helpful!! The only feature I wish it had was some kind of infrared or night vision technology. Although the vehicle distance indicator and the speed limit indicator continue to work in low to no light conditions the pedestrian indicator does not work at night or pre-sunrise darkness. This is very important & would be helpful if the pedestrian indicator worked through the night. Pedestrians rarely wear reflective indicators & often jaywalk during after rush hour & night to low light conditions when there is less traffic."
"I feel the Mobileye system would be a great addition to [agency] and our goal towards providing the best and safest ride in the nation and though I feel it's a great tool for all operators its benefit to new operators would be paramount to helping them become more aware of surroundings."
"Training on the system would assist us better with understanding it and allow us to give better feedback."
"I have not had proper training with this (gadget)."
"This device is more of a safety hindrance than a help. It has never worked correctly. A major distraction while driving."

Additional Feedback From Managers and Maintenance Staff

Blacksburg Transit operations staff summarized several of the CAWS-related challenges after about 1 year of operation in live mode. Although the vendor advised that the system was functioning as designed, two of their five equipped buses seemed to produce more alerts than the others. False positives had been an issue, to the extent that supervisors had observed apparent attempts by operators to cover the CAWS displays or to remove their mounting hardware. Operations staff hypothesized that the number of false positives was high in part because many of the agency's routes operated where sidewalks were immediately adjacent to the roadway and where pedestrian volumes were high. Some locations that appeared as hot spots—areas with frequent pedestrian alerts—were at turns where buses rarely interacted with pedestrians. One of these was a roundabout, where many alerts appeared for pedestrians that were not at risk, and another was a T-intersection, where alerts for pedestrians on the left-hand sidewalk appeared after the bus completed a left turn from the stem of the T to the cap of the T.

At WMATA, maintenance staff provided feedback after the CAWS had been installed but before drivers began receiving system alerts. Their overall impressions of the system were positive, with the exception of some elements not functioning at night, and they reported that during a test ride, the alerts were the right volume, used appropriate tones, and functioned properly. They did not expect the CAWS to affect materially their maintenance workload but were curious to see how well the external sensors held up under frequent bus washing.

An administrator at HRT provided feedback during its stealth mode period. Training on the system had occurred for mechanics and operators, but many operators remained confused about the purpose of the system, so the agency planned to add the CAWS to its overall training program. Equipped buses were intended to be deployed on specific routes but were not all based at the same depot. With only about 10% of its bus fleet equipped with the system, many of its drivers would never or only rarely drive an equipped bus.

Discussion

It is clear that the CAWS performance was mixed, with fewer warnings in most categories after live mode was begun; some operator survey respondents indicated that the system was helpful, and 75% of operator survey respondents indicated that they often or sometimes noticed false alarms (Figure 8b). Although less than one-half of survey respondents often or sometimes had taken action to avoid a vulnerable road user that the CAWS had not detected (i.e., false negatives; Figure 8c), this may not be an indicator of success. When CAWS is considered as a precursor to full automation, and with safety in mind, the only acceptable response to the false-negative question is "never"—because a successful fully automated bus must always detect and avoid vulnerable road users. By that metric, 73% of respondents indicated that the system was not successful.

Several avenues of improvement for CAWS technologies could increase system effectiveness and driver acceptance. CAWS technologies require refinement in the transit operating environment, particularly regarding pedestrian detection and operator alerts/distraction. Dynamic (e.g., location-based) sensitivity adjustments could be especially useful for routes that traverse both pedestrian-heavy areas (e.g., major university campuses) and areas with far less pedestrian activity. This could reduce the number of nuisance alerts in locations where drivers are already well aware of pedestrian presence.

CAWS could be further improved by leveraging feedback from transit operators. Examples from the survey conducted in this study include operators requesting brightness adjustment controls for the in-vehicle displays and lower sensitivity for detection of pedestrians walking along sidewalks.

Agencies may wish to consider providing training to operators both before and after the operators start seeing CAWS alerts. Some operators found training to be sufficient and the system to be intuitive, but some desired more training (and others provided comments suggesting that they did not fully understand some aspects of the system). Recurring training could help avoid over-reliance on the system (Chiarenza et al., 2018).

CAWS alerts for driver aggressiveness appear to be based on lateral and longitudinal acceleration, but the precise factors and thresholds were proprietary and could not be shared with transit operators. Without clear thresholds for what constitutes an alert, it was difficult for transit agencies to train operators to drive in such a way as to minimize alerts. CAWS could be improved by providing clear, specific guidance on ways operators can avoid aggressive driving alerts.

CAWS may be one data source transit and roadway agencies could use for decision-making. Some transit agencies have evaluated operators' driving performance based on CAWS data. Although many bus operators said they would be comfortable receiving such performance feedback, the quantity of negative feedback suggests that some operators would question the validity of an evaluation based on CAWS data. Roadway agencies could use clusters of CAWS alerts (e.g., PCWs) to represent near misses to identify safety hot spots proactively. However, two caveats identified in this study were the high frequency of false alarms that operators reported and the fact mentioned by one transit agency that the discernable hot spots were already known problem areas. Thus, making decisions based on CAWS data alone may not be advisable, but including CAWS data as one of many data sources could help in visualizing high-risk locations, as research has suggested (e.g., Chiarenza et al., 2018; Jahangiri et al., 2019).

The level of federal funding available to agencies may affect the value proposition for this type of technology. Increased federal investment in transit capital expenses may reduce the cost burden for state and local stakeholders for new technologies. With additional funds, agencies can begin to consider innovative technologies such as electric buses (George, 2021). A similar trend could also support the purchase of buses with advanced safety features as long as those features did not increase operating costs. That is, the features come with a risk that operating costs could increase due to increased staff turnover if bus operators resign because of frustration with the systems' false alarms and objections to use of the systems' data in performance evaluations. The input obtained from operators in this study did not necessarily suggest that such frustration was severe enough to warrant resignations. Agencies that can provide sufficient training, manage driver expectations, and use driver feedback to make improvements to CAWS are likely to minimize this risk and will thus be best able to benefit from investing in CAWS.

Still, predicting monetary savings is challenging for at least two reasons: (1) transit agencies typically implement safety technology and supporting measures such as training enhancements holistically rather than one at a time, making it difficult to isolate the effects of the technology alone; and (2) although near-miss events may help indicate risk even in areas with no crashes, reducing the number of near-miss events would not clearly reduce costs the way reducing actual crashes would (Staes et al., 2020b). In addition, Peirce et al. (2019) attempted to assess the business case for transit agencies (not a full societal benefit/cost analysis) of partial and full automation. Although the study found a strong business case for partial automation, that case was based on an assumed crash reduction value of 45% despite estimates for crash reductions that ranged from 1% to 71%.

Technology improvements on the horizon are likely to address some of the shortcomings of CAWS for large vehicles. For example, augmented reality projections could address the complaint of CAWS displays creating additional blind spots and possibly reduce distraction, and thermal cameras capable of detecting pedestrians in the dark could resolve the issue of nighttime functionality (Barry, 2021). Many transit operators mentioned the latter shortcoming, and their concerns are supported by crash data: from 2010 to 2019, pedestrian fatalities increased 54% at night but increased 16% during the daytime, and three of four pedestrian fatalities in 2019 were at night (Governors Highway Safety Association, 2021). Despite the promise of improved technology and its rapid pace, institutional hurdles could prevent its adoption: nearly three-fourths of the transit agencies that responded to a survey by Staes et al. (2020b) said they did not have contractual means to upgrade their onboard bus technologies. A counterbalancing effect could occur if CAWS features started to become standard equipment on buses, in which case implementation could occur gradually over time via fleet turnover rather than via additional retrofits.

A potential area for future research is the use of CAWS data to identify areas of high crash potential, i.e., hot spots. Locations with frequent pedestrian alerts might indicate areas for potential safety countermeasures, particularly at mid-block crossings without crosswalks. Similarly, aggressive driver behavior warnings might serve as crash surrogates for identifying areas of improvement. Warning indications could be cross-referenced with Virginia's Pedestrian Safety Action Plan map to identify potential areas of heightened risk for pedestrians. Local and regional safety planning efforts could also cross-reference these data.

Another potential direction for future research could be exploring how the opinions of bus operators regarding CAWS, as well as their driving behaviors that are logged by the system, change over time or as they log more hours driving equipped buses. This study considered exploring operator opinions over time via repeated surveys but ultimately did not do so because of the number of agencies involved; at one agency where two rounds of surveys were conducted, different drivers completed the first and second rounds of surveys, so comparisons were not possible. Changes in driving behavior over time could be evaluated if driver identification numbers were logged in the CAWS, but that feature was not enabled in the demonstration project.

CONCLUSIONS

- *The benefits of the CAWS in a transit operating environment are mixed.* Although most empirical measures showed improvement as evidenced by fewer alerts and warnings after the live mode was initiated, survey results indicated excessive false alarms and unnecessary alerts in areas with high volumes of pedestrians. This reinforces prior findings documented in the literature.

- *The driving performance of operators, as measured by event rates in the CAWS data, generally improved after they began receiving system alerts.* When results were statistically significant, nearly all metrics substantially improved after system alerts were activated.

- *A substantial number of bus operators had negative experiences with the CAWS.* Although alert logs suggested that driving safety improved, 75% of operator survey respondents reported that they often or sometimes noticed false alarms, which was also the most frequent type of open-ended survey comment, followed by distraction.

- *Transit and roadway agencies should exercise caution when using the CAWS data for decision-making.* The quantity of negative feedback from bus operators and the high frequency of false alarms suggest that job performance evaluations or safety hot spot maps based solely on the CAWS data might not be valid. Using the CAWS data as one of many data sources might be more appropriate.

RECOMMENDATIONS

1. *DRPT's Public Transportation Division should support transit agencies' interests in deploying bus CAWS through offering matching funds, training, and expertise.* The mixed results of this study suggest that at present, the decision of whether to deploy CAWS is best left to each transit agency, but agencies choosing to do so may benefit from support. This could include providing matching funds, offering training, coordinating information exchanges, and/or making ongoing technical assistance available to ensure the system continues to function properly and the telematics data are accessible to the agency.

2. *DRPT's Public Transportation Division should monitor bus CAWS technology as it continues to develop through an annual scanning review of new technology and attendance at national transit conferences.* The rapidly changing nature of driver assistance technologies means that some of the challenges evident in the Virginia demonstration project (e.g., lack of nighttime functionality) may be resolved in future iterations. Substantial advances in technology could merit a future evaluation. At present, DRPT may wish to ensure that transit agencies are familiar with both the benefits and challenges of CAWS technology.

IMPLEMENTATION AND BENEFITS

Researchers and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and to determine the benefits of doing so. This is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

With regard to Recommendation 1, by fall 2022, DRPT’s Statewide Transit Planning Manager will identify a plan for supporting transit agencies that wish to deploy bus CAWS. The plan could include updating DRPT’s technical assistance and demonstration grant processes, developing statewide contracts for technology system procurement, and providing examples of how CAWS data can be used to support local and regional safety planning efforts. For example, a process could be considered to provide technical assistance to demonstration grant recipients beyond the 1-year period of the demonstration grant itself.

With regard to Recommendation 2, by August 2022, DRPT’s Statewide Transit Planning Manager will provide Virginia transit agencies with a technology summary that includes current CAWS technology. Each August through 2025, DRPT’s Statewide Transit Planning Manager will communicate with VTRC regarding developments in bus CAWS technology to consider the merits of additional study.

Benefits

The benefits of implementing Recommendation 1 will depend on the specifics of the plan to be identified by DRPT. Funding support will increase the likelihood that agencies will choose to deploy CAWS, which could have safety benefits. Other types of support such as training and technical assistance can maximize the value of state and agency technology investments by helping individual transit agencies achieve the benefits of CAWS while mitigating and managing the challenges.

The benefits of implementing Recommendation 2 are as follows. Providing a technology summary to Virginia transit agencies will support local decision-making by allowing each agency to consider its unique context as it weighs the benefits and challenges of this and other technologies. Communicating annually with VTRC regarding technology advancements will position DRPT to invest in CAWS technology when its benefits more clearly outweigh its challenges while avoiding allocating state resources to a technology that could rapidly improve. Performing these activities each August can support agencies’ decisions entering the fall grant-application season.

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APPENDIX

BUS OPERATOR SURVEY INSTRUMENT

The following overview and survey are representative of the paper survey instrument; minor modifications were made for the online version.

[Agency] Mobileye Operator Survey Overview

[Agency] is doing this survey for the Virginia Transportation Research Council, which is helping the Virginia Department of Rail and Public Transportation evaluate the Mobileye Collision Avoidance System. Part of the evaluation is finding out what bus operators think of the system.

Your individual responses will be associated with your employee ID, which will assist the researchers to see how comfortable you are with using the system throughout the research process. Researchers will summarize responses from all operators in a research report, which will not identify individual operators in any way.

Thank you for your time and honest feedback on this survey!

[Agency] Mobileye Operator Survey

Your honest feedback is highly appreciated and valuable to us! You may add comments with any question; if you need more space, please use the back of this survey and note the question number.

1. Employee number: ______________________

2. Did the training you received help you understand the meaning of the alerts? *(select one)*

   Very little   Somewhat   A great deal

3. How often have you noticed false alarms (pedestrian alerts or collision warnings when no pedestrians/bicyclists/etc. were present)? *(select one)*

   Never   Rarely   Sometimes   Often

4. How often have you taken action to avoid a pedestrian/bicyclist/etc. when the system did not give an alert or warning? *(select one)*

   Never   Rarely   Sometimes   Often

5. How has driving with the system changed your behavior as a bus operator?

6. (a) Is the system helpful? *(select one)*

   Not at all   Somewhat   Very

   (b) Is the system distracting? *(select one)*

   Not at all   Somewhat   Very

7. What advantages of the system could help operators?

8. What advantages of the system could help [Agency] as a transit agency?

9. Which features of the system do you find the most useful?

10. What additional features do you wish the system had?

11. Some transit agencies provide feedback on operators' driving performance using Mobileye data.
    a. How comfortable would you be receiving such feedback privately?

    b. How comfortable would you be if all operators could see everyone's feedback?

12. Any other comments? Use the back of this survey if necessary.