Analysis of Advanced Driver-Assistance Systems in Police Vehicles

July 2023 | Final Report

SAFE-D
SAFETY THROUGH DISRUPTION

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16. Abstract

Motor vehicle crashes are the leading cause of death for police officers. Advanced driver assistance systems (ADAS) have the potential to improve officer safety by removing some of the driver's vehicle control responsibilities. This project included two phases: (1) an ADAS needs and implementation analysis in police vehicles; and (2) an evaluation of police ADAS in a driving simulation study. The first phase included a systematic review of literature and an online survey with officers to understand their ADAS needs and current systems in police vehicles. The second phase evaluated ADAS in high-demand situations using a high-fidelity driving simulator. Results indicated that officer behaviors and opinions on ADAS features were influenced by the trust officers had in the available ADAS, as well as other key factors such as ADAS training and perceived usefulness. ADAS features, including forward collision warning, automatic emergency braking, and blind spot monitoring had a positive effect on police officers' driving performance and in reducing workload. The outcomes of this project provide guidelines regarding effective ADAS features/types to automotive companies supplying police vehicles and can improve officer safety in police operations.

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Abstract

Motor vehicle crashes are the leading cause of death for police officers. Advanced driver assistance systems (ADAS) have the potential to improve officer safety by removing some of the driver's vehicle control responsibilities. This project included two phases: (1) an ADAS needs and implementation analysis in police vehicles; and (2) an evaluation of police ADAS in a driving simulation study. The first phase included a systematic review of literature and an online survey with officers to understand their ADAS needs and current systems in police vehicles. The second phase evaluated ADAS in high-demand situations using a high-fidelity driving simulator. Results indicated that officer behaviors and opinions on ADAS features were influenced by the trust officers had in the available ADAS, as well as other key factors such as ADAS training and perceived usefulness. ADAS features, including forward collision warning, automatic emergency braking, and blind spot monitoring had a positive effect on police officers' driving performance and in reducing workload. The outcomes of this project provide guidelines regarding effective ADAS features/types to automotive companies supplying police vehicles and can improve officer safety in police operations.

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Introduction

Motor vehicle crashes (MVCs) are the leading cause of death for police officers [1]. Among all public safety workers, police officers are involved in a significantly higher number of fatal MVCs as compared to firefighters and emergency medical services workers [2]. MVC rates for officers are also estimated to be 2.5 times higher than the national average among all occupations [3]. Some of these crashes have been attributed to officers' use of in-vehicle technologies and multi-tasking while driving [4]. Police officers are often required to use in-vehicle technologies and engage in secondary tasks while driving due to the need for real-time information. Prior studies have found in-vehicle technologies, especially mobile computer terminals (MCTs), to have a negative impact of officers' driving performance, visual attention to the roadway, mental workload, and situational awareness [5-7].

Advanced driver-assistance systems (ADAS) are technologies that automate/adapt/enhance vehicle systems for drivers. Some ADAS are designed to warn the driver if they are at risk of an impending crash, while others are designed to take action to avoid a crash. A list of ADAS technologies is provided in [8]. ADAS can improve driver safety by removing some of the driver's vehicle control responsibilities [9]. In addition, ADAS can reduce the demands of driving by automating some portions of the driving task, which might free up driver cognitive, perceptual, or motor resources to perform secondary tasks. It is not currently clear how ADAS can reduce the demands of driving and mitigate crashes involving police vehicles during emergency and non-emergency situations [10] while the officer is engaged in secondary tasks (e.g., using MCT). Therefore, it is critical to understand what types of ADAS are most effective in protecting driver safety to improve ADAS design and implementation in police vehicles.

Background

ADAS are vehicle control systems that improve driving comfort and traffic safety by using vehicle sensors (e.g., radar, laser), helping the driver identify and react to potentially hazardous traffic situations [11]. A statistical survey covering 2,025 crashes using the German Insurers' data revealed that ADAS such as Collision Mitigation Braking Systems (CMBS) reduced crashes and driver injuries by 17.8%. It was also found that a vehicle equipped with both CMBS and lateral guidance systems (i.e., systems that support drivers with lane keeping and lane changing) can prevent up to 25.1% of vehicle crashes [12]. Other ADAS features, such as forward collision warning (FCW) systems were also found to reduce near-crash events under fog conditions by 35% [13]. ADAS can relieve drivers from some driving-related activities, allowing them to engage in secondary tasks more safely and/or can reduce stress by allowing the driver relief from constant multiple cognitive tasks [14]. Another study indicated that ADAS improved driver safety from 2% (by using a blind spot monitoring [BSM] system) to almost 45% (by using an emergency brake assist system) [15]. FCW along with automatic emergency braking (AEB; which warns the driver and brakes autonomously when a frontal collision is imminent) have shown the potential to prevent up to 70% of rear-end crashes and 20% of all passenger vehicle crashes [16]. Another study found that rear-end striking crash involvement rates (where the driver crashes into the vehicle in front of them) were reduced by 27%, 43%, and 50%, respectively by a FCW system, low speed AEB, and FCW with AEB [9]. It is estimated that by including FCW and AEB in all vehicles, almost 1 million U.S. rear-end crashes and 400,000 crashes with injuries could be avoided annually [9]. Recently, the National Highway Transportation Safety Administration proposed a rule that would require AEB and pedestrian AEB systems on all passenger cars and light trucks [17].

While prior studies have reviewed ADAS used by civilian drivers in non-emergency vehicles [e.g., 14, 15], there has been no investigation on if/how ADAS can be useful for police vehicles. There are several differences in driver and vehicle states between police and civilian drivers, including temporal demand, travel speeds, and the level of driver training. Police officers often use in-vehicle technologies such as MCTs and police radios while driving. Additionally, officers must frequently perform their duties in high stress driving conditions, such as pursuit situations, that civilian drivers would not experience under normal conditions. Due to these differences in driving conditions, the benefits that ADAS provide for civilian vehicles may not be as effective for police vehicles. Therefore, the objectives of this project were to: (1) identify ADAS features that can be implemented in police vehicles to improve officer safety, and (2) understand the impacts of ADAS features on officer's driving performance, workload, and trust.

This project included two phases. Phase 1 included a systematic review of literature to determine the existing ADAS features in police vehicles and an online survey with law enforcement officers to identify the most beneficial features in police operations. The findings of Phase 1 study were used to select the ADAS features to be tested in Phase 2. Phase 2 included a driving simulation study to assess the impact of ADAS technologies on officers' driving performance, workload, and trust.

Phase 1

Method

Systematic Literature Review

A six-step approach was used to conduct the systematic literature review [18]. First, the literature review topic was defined as follows to improve the search process efficiency and outcome: *the effects of ADAS in police vehicles on officers' driving safety*. Second, the resources to conduct a comprehensive review of patents and prior studies on ADAS features in police vehicles were determined. Five databases were searched, including Google Scholar, Compendex, Web of Science (WOS), Transport Research International Documentation (TRID), and Google Patents. Patents were included as they provide information on existing ADAS features that might not be broadly implemented in police vehicles yet but have the potential to improve officer safety. Third, the search terms were selected based on keywords; these included *assistance features, automation, safety, driving, advanced driver-assistance systems, police, officer, car,* and *vehicle*. Fourth, a search strategy was established and executed. The search words were divided into three groups based on their relation to each other. Group one included *assistance features, automation, advanced driver-assistance systems,* and *safety.* Group two included *police* and *officer*. Group three included *car, driving,* and *vehicle*. One word from each group was used in every search, with each combination of group words being used for each database [18]. The search process initially uncovered 6,951 papers and 1,741 patents published from the years 1980 to 2020 (Figure 1) [19]. In addition, the top three car models utilized by police were obtained through a manual search, and the available ADAS features in these vehicles were determined through the manufacturers' websites. Though other police vehicle makes and models exist, the following three models were selected since they are the most prevalent and latest models of currently available police vehicles that include the latest ADAS features: the 2020 Ford Police Interceptor Utility, the 2020 Chevy Tahoe Police Pursuit Vehicle (PPV), and the 2020 Dodge Charger Pursuit. Manual searches were also conducted to gain insight on the recommended ADAS features via patents and other websites. Steps five and six included reviewing and organizing the searched results. Further analysis of the relevance of the papers from the initial search was completed using the PRISMA methodology [19] (see Preferred Reporting Items for Systematic Reviews and Meta-Analyses for additional information on this methodology.)

Inclusion criteria for research studies consisted of investigations focused on the effects of ADAS on driver safety and performance. Patent inclusion criteria consisted of active and application granted patents regarding ADAS that were not currently being utilized in police vehicles but could be applied in this domain. Initially, relevance of literature and patents was determined through review of the titles and abstracts. Finally, the full text of the patents and articles deemed to have relevant titles and abstracts were assessed to confirm their inclusion in the review. Websites found through manual searches were included in the article count displayed in Figure 1. Gray literature was also included in our review, including government reports, newsletters and bulletins, fact sheets, theses, and dissertations.

Online Survey

An online survey was conducted to validate the findings of the literature review and the authors' recommended ADAS features in police vehicles and to understand police officers' opinions and needs regarding ADAS. The survey was conducted with 73 police officers (68 males and 5 females; age: M = 37.24 yrs., SD = 8.3 yrs.) from Texas and a few other states. All participants were experienced officers (M = 11.03 yrs., SD = 7.43 yrs.) who regularly drove police vehicles. Participation in the study was voluntary and the officers could leave the survey at any time. Texas A&M's Institutional Board (IRB) approved the study procedure.

Upon completion of the informed consent form and the demographic questionnaire, participants filled out the survey using Google forms. The questions were based on the ADAS widely available in police vehicles in the U.S. and were designed to gather a better understanding of which features were available in police department vehicles, whether the features were used by police officers for their work operations, and how useful officers perceived the features to be. The available ADAS features used in this survey were based on the findings of our literature review. Please see Appendix A for the list of survey questions.

Data Analysis

The recommended ADAS features were classified and ranked based on the impact-oriented approach using the authors' expert judgment and literature evidence [20]. In addition, officers' responses to specific questions were summarized using histograms. Correlation analysis was used to understand the relationships between the individual responses. For comparisons between two yes/no questions, the phi correlation coefficient test was used [21]. Comparisons between two Likert scale responses were conducted by the Kendall rank correlation. The Kendall rank test was the best alternative to the Spearman's rank correlation, as the results collected for the survey failed one of the assumptions of the Spearman's rank correlation in addition to having many tied ranks [22]. Finally, comparisons between yes/no and Likert scale responses employed the Wilcoxon rank sum correlation with the assumptions for the test met [23]. Free response questions were analyzed using conventional content analysis. These analyses provided information regarding the factors that could affect police officers' perceptions about ADAS usage and effectiveness in police vehicles (Objective 1).

Results

Systematic Literature Review

Thirty-eight (38) published articles and 7 patents met our inclusion criteria and were included in this analysis. To better determine the ADAS features available for police vehicles, the latest police vehicle models in the U.S. had to be identified. These include the 2020 Ford Police Interceptor Utility, the 2020 Chevy Tahoe Police Pursuit Vehicle (PPV), and the 2020 Dodge Charger Pursuit, with the Ford model being the most prevalent [24]. Many ADAS features common in civilian vehicles, such as AEB, pre-collision assist with pedestrian detection, and BSM systems were also found to be available in police vehicles [25]. Additionally, police vehicles are generally equipped with temporary disable switches so that officers can deactivate some features, such as AEB, in situations such as pursuit driving where ADAS would be more of a hindrance than an aid [26]. A full list of ADAS features available in police vehicles in the U.S. is provided in Appendix B along with their descriptions. It is important to note that not all manufacturers provide homogenous ADAS features. For example, the Chevy Tahoe PPV is equipped with General Motors' patented Safety Alert Seat, which uses vibrations to physically indicate the location of a potential threat to police drivers. However, this vehicle does not have the potential threat detection system that the other two manufacturers provide [27]. Knowing what features currently exist in U.S. police vehicles, it is important to focus on how the current list of available ADAS can be expanded upon to best assist police officers in the field.

Future Police ADAS Features

Based on the review of ADAS features and knowledge of police driving operations, we recommended 10 features that have the potential to improve road safety and can be implemented in police vehicles. Each feature and general description are displayed in Table 1. Some of these features, such as evasive steering assist or front vehicle detection system, are currently available in police vehicles but for the most part the listed technologies are based on patents or tech reports.

Table 1. Recommended Features for Police Vehicles

ADAS/ Automation Feature	Description	References
Front Vehicle Detection System	Detects and tracks the immediate leading vehicle in front of the driver	[28]
Intersection Collision	Assesses the intersection situation and warns the driver and/or actuates	[29]

ADAS/ Automation Feature	Description	References
Avoidance	driving assistance if a dangerous situation is detected	
Evasive Steering System	Warns and assists the driver to move around another vehicle or object if a collision is imminent	[30]
Left Turn Assist	Activates when the driver turns on the left turn signal, assesses surrounding traffic, and brings the vehicle to a stop in dangerous situations	[31]
Traffic Sign Detection System	Detects traffic signs and communicates information deemed important to the driver	[32]
Traffic Jam Assist	Warns drivers if they are approaching a traffic jam, controls braking and steering to follow the leading vehicle while in a traffic jam	[33]
Two Lane Detection	Determines the markings of two lanes to detect obstacles in front of the vehicle on the road	[34]
Lane-Ending Detection	Warns driver if current lane is ending, assesses surrounding traffic, assists driver to switch lanes if needed	[35]
Wrong-Way Alert	Determines if the vehicle is driving the wrong way based on road sign detection and GPS location, alerts the driver if they are driving the wrong way	[36]
Autonomous Highway Driving	Provides the capability to self-drive while on the highway	[37]

Ranking of Recommended ADAS Features

The 10 recommended features were classified based on the impact-oriented approach using the authors' expert judgment and literature evidence [20]. The impact-oriented approach yields the degree of road safety impact implemented by the ADAS features. The impact of these systems on road safety was established based on estimating the technologies' road safety impact using three criteria, including avoidance of inappropriate speed, keeping appropriate longitudinal and lateral distances, and support of driver awareness. The selected criteria are based on the international bibliography for measurements of road safety and correspond to road accident factors that are addressed by ADAS features [20]. The inappropriate speed criterion refers to the problem of inappropriate speed for the specific traffic and road conditions. Keeping appropriate longitudinal and lateral distances criterion corresponds to difficulties of coordinating with other vehicles and road elements within traffic conditions. The last criterion, support of driver awareness, aims to address the issues regarding driver fatigue and attention required to perform the driving-related tasks [20].

The research team assigned a high (H) or low (L) rating to each recommended ADAS feature based on their direct impact on the corresponding road safety criteria (Table 2). To ensure inter-rater reliability, two researchers first individually rated the features and then discussed the ratings together to come to a consensus. A third researcher rated the featured independently and those results agreed.

Table 2. Road Safety Impact of the Recommended ADAS Features

Recommended ADAS Feature	Avoidance of Inappropriate Speed	Keeping Appropriate Longitudinal and Lateral Distance	Support Driver Awareness
Traffic Sign Detection System	H	L	H
Front Vehicle Detection System	H	H	H
Autonomous Highway Driving	H	H	L
Traffic Jam Assist	H	H	L
Intersection Collision Avoidance	H	L	H
Left Turn Assist	H	L	H
Evasive Steering System	L	H	H
Two Lane Detection	L	L	H
Wrong-Way Alert	L	L	H
Lane-Ending Detection	L	L	H

The results of ADAS features' impact on road safety were used to rank our recommended features from 1 to 10 (1 being the most useful and 10 being the least useful). Table 3 shows the ADAS features ranked based on how many "high" road safety impacts criteria were met by the ADAS feature. In case of a tie, the authors' judgement was used to rank those features. This approach was used for ranking all the recommended features except the Autonomous Highway Driving feature. Although this feature yielded 2H impact criteria, it was ranked last, due to the authors' knowledge of the complexity of police operations and some of the concerns regarding the use of autonomous police vehicles such as cyberattacks, privacy issues, and legal considerations [38].

Table 3 also includes the results obtained from the online survey with police officers where they were asked to rank the features based on how useful they thought each feature would be in police operations. Officers also ranked Autonomous Highway Driving as the least useful feature, which further validates the authors' ranking. The mean and standard deviation of police officers' ratings (from 1 to 10) for each feature are included in Table 3. A one-way analysis of variance (ANOVA) test did not reveal any significant differences between the features in terms of police officers' ratings ($p > 0.05$). Therefore, the features were ranked based on the mean of police officers' ratings.

Officers' ranking of ADAS features were generally similar (with the maximum of two rank differences) to authors' initial ranking except for the Wrong-Way Alert feature. The authors' ranking of the usefulness of Wrong-Way Alert was based on the feature's road safety impact score; however, the officers' ranking was based on their expertise of operating police vehicles. Therefore, the police officers' ranking of Wrong-Way Alert should be considered with higher weight than the authors' ranking. This approach was taken to ensure that the recommended technologies are appropriate to use during police operations.

Table 3. Ranking of the Recommended ADAS Features

Feature	Total number of high safety impacts (H)	Authors' ranking	ADAS rating based on the online survey (Lower = more useful ADAS)	Ranking based on mean of police officers' ratings
Front Vehicle Detection System	3	1	Mean: 7.02 SD: 4.81	3
Intersection Collision Avoidance	2	2	Mean: 6.69 SD: 4.79	1
Evasive Steering System	2	3	Mean: 7.69 SD: 4.38	4
Left Turn Assist	2	4	Mean: 8.15 SD: 4.30	6
Traffic Sign Detection System	2	5	Mean: 8.87 SD: 4.49	7
Traffic Jam Assist	2	6	Mean: 8.16 SD: 3.96	8
Two Lane Detection	1	7	Mean: 7.91 SD: 3.56	5
Lane-Ending Detection	1	8	Mean: 8.94 SD: 3.81	9
Wrong-Way Alert	1	9	Mean: 6.95 SD: 4.65	2
Autonomous Highway Driving	2	10	Mean: 8.98 SD: 4.73	10

Online Survey Results

Participants were asked to indicate which ADAS features were available in their police vehicles. The findings of this question are displayed in Figure 2. It was found that rear view cameras and Bluetooth communication systems were the most common ADAS available in police vehicles, with nearly all survey respondents indicating that they had at least one of these features in their vehicles. Conversely, reverse brake assist and front split view camera were the least common features available.

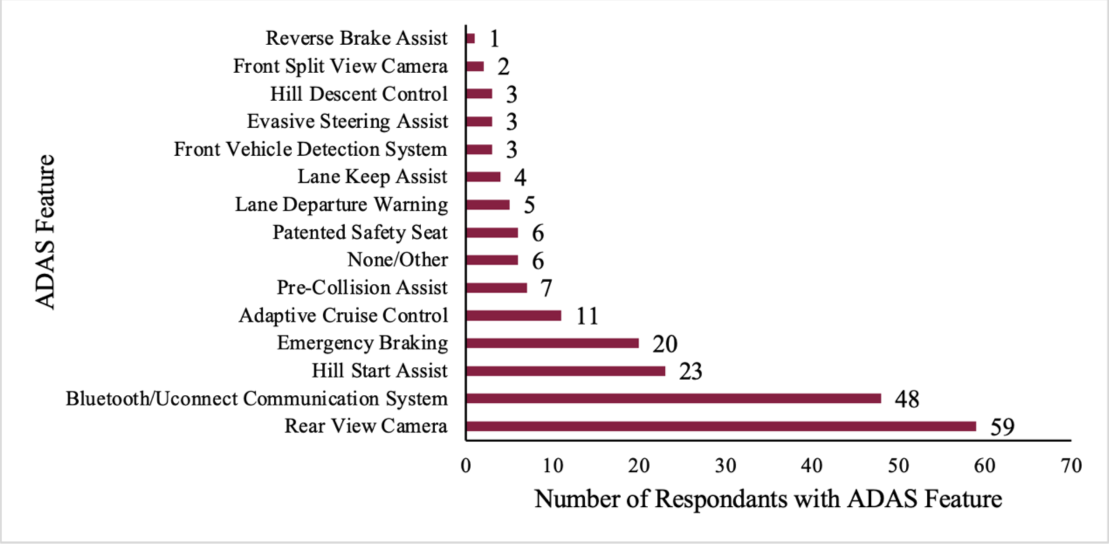


Figure 1. Existing ADAS in police vehicles.

The results also emphasized officers' preference towards receiving alerts using a combination of visual and auditory modalities as compared to visual or auditory modality only or vibrotactile alerts (Figure 3).

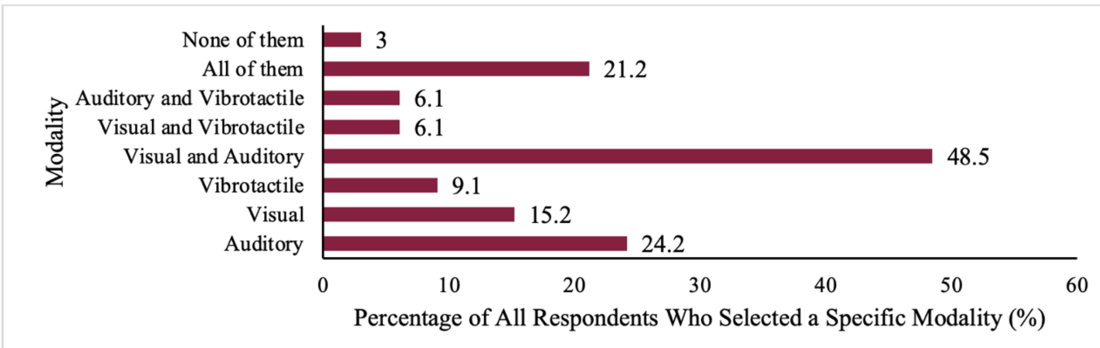


Figure 2. Officers' preferred sensory modality to receive alerts.

Correlation Analysis

The significant correlations between different survey questions are shown in Table 4. Note that all significant correlations were found to be positive, and all chi-square tests hypothesized that the proportion of people who responded "yes" would have significantly higher Likert scale responses than people who responded "no" (the list of questions is provided in Appendix A).

Table 4. Significant Correlations Among Survey Questions

Comparison Pair	Correlation Results
Q9 and Q18	ϕ = .28 (p = .024)
Q13 and Q18	ϕ = .36 (p = .003)
Q14 and Q16	τ = .41 (p < .001)
Q11 and Q16	τ = .35 (p < .001)
Q16 and Q15	τ = .34 (p =.0013)
Q14 and Q15	τ = .46 (p < .001)
Q12 and Q14	τ = .32 (p = .0017)
Q11 and Q14	τ = .35 (p < .001)
Q11 and Q12	τ = .33 (p = .0011)
Q9 and Q11	X^2(1, N = 66) = 9.11 (p = .0025)
Q14 and Q13	χ^2(1, N = 66) = 19.03 (p < .001)
Q14 and Q18	χ^2(1, N = 66) = 9.86 (p = .0017)

Note: Information on the question content is provided in Appendix A.

Responses to Open-ended Questions

Several questions were provided in the free response format to better capture participants' individual opinions. The most notable question answers and their implications are summarized in this section along with the percentage of participants who reported the comments.

Question 3: Are there any helpful ADAS features that your personal vehicle has that you would like to have in your police vehicle as well?

The responses for this question were similar to the responses to question 1 of the survey, with BSM and cameras comprising the highest percentage of responses of those who responded affirmatively to this question (25.8% response rate for both responses). Following these were collision assistance (22.6%) and cruise control (12.9%), which were not identified as prevalent features available in police vehicles by this survey. This may reflect a strong desire of officers to have access to features that are currently unavailable in their police vehicles.

Question 5: What are your recommendations to improve the current ADAS features in police vehicles?

Improvements to ADAS adaptability and usability were the most common police vehicle ADAS enhancement requests from police officers, included in 17.6% of responses. Specific examples officers cited include being able to easily enable and disable features such as front vehicle detection and lane assist, and having clear explanations of how the ADAS features work so they can be properly utilized. About 7% of officers requested the removal of ADAS without citing reasons. These responses justified the decision to categorize this question within the perceived ease of use category, as many officers expressed interest in improvements to existing ADAS features as opposed to suggesting new features entirely.

Question 6: If you were the manufacturer of police vehicles, what ADAS features would you add to the vehicle? Why?

Cameras were cited as critical to police officers when questioned on what they would add to police vehicles, comprising 19.1% of responses. Crash avoidance systems, such as collision and braking assistance, were also cited often (16.1% of responses). It is noteworthy that police officers favored ADAS that are designed to prevent crashes (e.g., rear-view cameras, AEB systems, and BSM systems) over systems that can improve their driver control responsibilities, even in free response questions. What this might indicate is that police officers prioritize the ability of ADAS to assist officers in dangerous/accident situations above any other ADAS feature quality when evaluating ADAS.

Question 17: What are the reasons/barriers that prevent you from using ADAS in police vehicles?

Lack of access was the primary reason cited for being unable to use ADAS in police vehicles, comprising 35.3% of responses. Some specific reasons mentioned included lack of department funding or unwillingness to purchase additional features for police vehicles. More importantly, perceptions of reliability and effectiveness filled the next two spots at 14.7% and 13.2% of responses respectively, indicating that a fundamental shift in the philosophy of manufacturers towards proper explanation and accommodation for police officers could potentially increase ADAS use among police officers and thus improve safety.

Question 19: Do you have any other suggestions to improve ADAS in police vehicles?

Of those who responded affirmatively to this question, standardization of ADAS features and adaptability were cited as the most desired changes, comprising 27.8% and 10.7% of responses respectively, though responses were more varied compared to other questions. Officers recommended that ADAS features should be compatible with existing police vehicles and technologies such as MCTs, and should be quickly activated, deactivated, or have settings changed based on the needs of the situation and police officer. Officers expressed discontent with the incompatibility between features unique to police vehicles, such as the MCT, and the ADAS available in their vehicles. This issue creates unnecessary barriers for police officers using ADAS while driving, as they have to interact with both the MCT interface and separate user interfaces for ADAS features. This reveals a disparity between civilian drivers and police officers and highlights the need for a unique approach to manufacturing and researching ADAS specifically designed for police vehicles.

Discussion

Systematic Literature Review

A comprehensive literature review revealed that several ADAS features and in-vehicle technologies are being utilized in police vehicles, including BSM systems, pre-collision assist, lane keep assist, and automated license plate recognition systems. Through the comprehensive review, no studies were identified that investigated ADAS features specifically in police vehicles. It is necessary to consider the differences in driver state between police officers and civilians when evaluating the effect of ADAS features on police driving performance, safety, and efficiency. While driving, police officers engage in secondary tasks (e.g., MCT, radio) and perform in high-demand situations (e.g., pursuit), unlike civilian drivers. These distinct differences have shown to negatively affect officers' driving performance, which makes studies of civilian drivers using ADAS not directly applicable to the police domain. However, some prior studies have indicated positive effects of automation and complementary technologies on police officer safety and driving performance. Based on the review of literature, the authors' knowledge and experience in the field, and the findings of an online survey with 73 police officers, 10 potentially useful police vehicle features were recommended. Future studies should further assess the impacts of these features in police vehicles using naturalistic and driving simulation studies.

Survey Study

A majority of officers (91.2%) indicated that there are several ADAS technologies in their police vehicles that they never use. Considering question 17, where officers indicated lack of budget as a primary barrier to implementation of ADAS in police vehicles, it is reasonable to conclude that the ADAS features that are implemented in police vehicles should be reconsidered. Coupled with the 58.5% of officers who indicated that ADAS could be at least somewhat useful in pursuit situations and the 57.4% of surveyed officers who believed ADAS are helpful for improving driving safety and reducing crashes, a clear disconnect between officers' ADAS use and their belief in its effectiveness is visible. To resolve this discrepancy, useful ADAS have to be identified and standardized for use in police vehicles. As multiple officers indicated in question 19, manufacturers have to be able to consider what features are useful for police vehicles specifically instead of treating them in the same way as civilian vehicles.

As indicated in responses to question 1, Bluetooth, rearview cameras, and emergency braking were the most beneficial ADAS features in police vehicles, yet over 60% of respondents rated their belief that ADAS reduce their workload as 2 or less on a scale of 5. Furthermore, roughly 40% of officers indicated that they almost never use ADAS while they are performing a secondary task. When coupled with the 67.6% of respondents who indicated that they would use ADAS more if the functionality and advantages were more clearly explained to them, it can be concluded that the education of officers in ADAS use is either ineffective or insufficient. The easiest way to surmount this hurdle would be to design ADAS such that they are intuitive in order to reduce the need for ADAS training and reduce confusion on the part of officers. In doing so, officers would make better use of the features available to them and it would be possible to get a clearer picture of which ADAS features are truly the most helpful for police officers. Beyond this, 47.1% of officers indicated that they preferred a combination of visual and auditory alerts over single visual or auditory alerts and vibrotactile alerts for their police vehicles. Therefore, to improve ADAS access, manufacturers should take advantage of these multi-modal alerts.

Correlation Implications

Trust

Questions 14 and 15 were the only questions designed to measure officer trust in ADAS features and subsequently autonomous vehicles, and the responses were positively correlated. Khastgir et al. [39] found that trust in ADAS and automated driving features, while important to ensuring the effectiveness of said features, must be moderated such that drivers do not trust ADAS features too much or too little. Gregg [38] discussed the effects of autonomous police vehicles on law enforcement and found that although the potential benefits of implementing autonomous vehicles is promising, drawbacks beyond the lack of trust in autonomous vehicles, such as susceptibility to hacking, could slow the speed at which these technologies are accepted by law enforcement. One way to build trust in autonomous vehicles might be to improve ADAS in current police vehicles to increase officer trust in ADAS as a whole.

Perceived Usefulness

Questions 11 and 16 have the most interesting significant correlation among the correlations comparing perceived usefulness questions. While other significant correlations in this category served to validate the category selection for the model questions, the correlation between questions 11 and 16 implied that ADAS have the potential to reduce officer workload in pursuit situations. According to the statistics on police motor vehicle crashes from the FBI, pursuit situations are one of the leading causes of accidental motor vehicle related deaths [40]. In police pursuits, officers are engaged in hazardous situations, which require driving at high speed, close following behavior, sudden road maneuvers, and complex decision-making situations, all of which can increase driver workload [41]. ADAS can remove some of the driver control responsibilities in these situations and therefore reduce officers' mental workload.

Trust vs. Perceived Usefulness

There were multiple question pairs that displayed a significant correlation between trust and perceived usefulness. For example, there was a positive correlation between questions 12 and 14, questions 14 and 16, and questions 14 and 18, which indicated that officers who trust ADAS to improve their driving safety also use ADAS while they are performing secondary tasks, believe that ADAS reduce their workload, and can improve their attention to roadway. However, these correlations were based on police officers' opinions and need to be further evaluated using objective measures of trust (e.g., gaze behavior), mental workload (e.g., physiological measures such as heart rate variability), and visual attention allocation (e.g., eye-tracking measures such as off-road glance duration).

Perceived Usefulness vs. Perceived Ease of Use

The desire to use ADAS more following further explanation of the features was significantly correlated to both believing ADAS are useful in pursuit situations and that ADAS improve attention to the road and surrounding environment. The findings are in line with [42], who found that more extensive exposure to ADAS features with more detailed explanation led to a heightened appreciation for ADAS features in civilian drivers. Therefore, it is reasonable to conclude that police officers might be similar to civilian drivers when it comes to the effect of exposure to ADAS on officers' willingness to use ADAS. Accordingly, the way officers are informed about how to use ADAS and the extent of what ADAS can do is just as important as educating officers about the ADAS features themselves. Manufacturers should emphasize clarity in the purpose of their design and future research should explore how to succinctly convey the benefits of existing features to engage officer interest in ADAS while ensuring that the systems do not appear overwhelming or confusing.

Phase 2

Method

The objective of the Phase 2 study was to assess the impact of ADAS technologies, including FCW, AEB, and BSM, on law enforcement officers' driving performance, workload, and trust. The results obtained from Phase 1 were utilized to inform the design of this driving simulation study [43-45]. Three hypotheses were formulated in this phase. The first hypothesis stated that driving with ADAS would result in a significant improvement in driving performance [46]. The second hypothesis proposed that officers would report a lower level of workload when driving with ADAS as compared to the manual driving condition. The third hypothesis posited that ADAS would increase officers' trust in the vehicle in safety-critical situations.

Participants

Eighteen (18) male police officers from Texas police agencies, with a mean age of 37.82 years (SD = 5.41), participated in the study. All participants had 20/20 vision and regularly drove police vehicles. Their experience with FCW (M = 28.26%, SD = 31.27%) and BSM systems (M = 34.49%, SD = 29.4%)

was assessed using a unidimensional visual analog rating scale ranging from 0 to 10. Participants read and signed an informed consent form before participating in the study. The study protocol was approved by the Texas A&M University IRB.

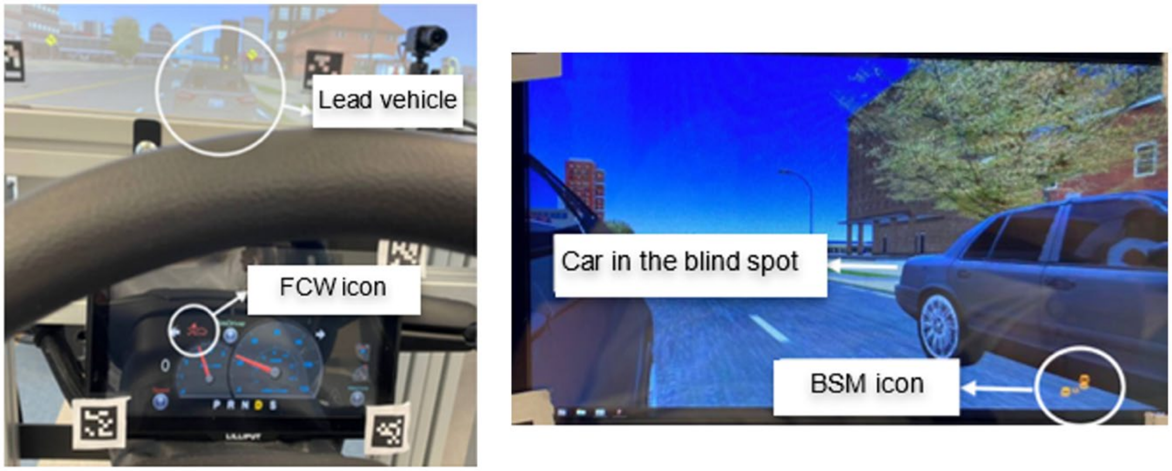
Experiment Setup

The experiment employed a fixed-based driving simulator (Realtime Technologies, Inc., Ann Arbor, MI) as depicted in Figure 4. The simulator was composed of a Ford Fusion mounted platform and projection screens that provided a 300-degree field of view, and data on driving behavior were collected at a rate of 60 Hz. The driving scenarios were created utilizing the SimCreator DX software. Participants interacted with the non-driving related task (NDRT) displayed on a laptop using a keyboard (as shown in Figure 4).

Figure 3. Driving simulator setup.

Design of Experiment

The experiment followed a within-subject design and included 12 driving scenarios. This study manipulated four independent variables: (1) hazard type (a braking lead vehicle [LB], a vehicle in the LV's blind spot [BS] while the officer was changing lanes, a combination of these two hazards [Combo]), (2) ADAS technology status (ON/OFF), (3) driving condition (normal vs. pursuit), and (4) NDRT status (ON/OFF). These independent variables were selected to assess the effect of ADAS in different police situations (e.g., pursuit) and workload conditions (e.g., while interacting with an NDRT). Furthermore, different hazard types were necessary to simulate the situations in which the BSM or FCW systems would be activated. Each scenario included two data blocks, with the NDRT randomly assigned to one of the blocks to avoid learning effects. The order of the scenarios was randomized. The LB scenarios were designed to simulate a rear-end pre-crash situation using a braking lead vehicle. A braking lead vehicle was used to simulate a common accident scenario based on previous studies [47-48]. The lead vehicle and the subject vehicle were in the same lane, with a fixed headway time of 2.5 seconds [49-50]. The FCW system activated with a warning beep sound and a visual icon on the dashboard when the leading car braked in front of the police vehicle (Figure 5a).



(a) (b)

Figure 4. ADAS features in the driving simulation study: (a) FCW icon, (b) BSM icon.

The BS scenarios included a vehicle in the driver's blind spot. Similar hazards were used in previous studies [51]. When the BSM was on, an icon appeared in the mirror if there was an object in the blind spot (Figure 5b). If blinkers were turned on, a warning sound was activated as well. The combo scenarios used both hazards (i.e., a lead vehicle and a vehicle in the blind spot) and warnings (i.e., BSM and FCW).

Driving Scenarios

Participants were instructed to drive a simulated urban roadway, follow traffic rules, stay in the middle of the right lane, and maintain a speed of 40 mph. They were also told to start chasing a fleeing vehicle at 60 mph when they heard an auditory message in the pursuit situation. The order of scenarios was randomized to prevent learning effects. The simulation represented a realistic urban environment with four lanes and followed regulations from the Texas Department of Transportation [52]. Each scenario lasted about 6 minutes and included two critical incidents; the location of the incidents varied to limit potential learning effects.

Non-driving Related Task

A plate number check task, which is the most frequently performed task by officers [53], was used as the NDRT. In this task, an automated voice from the simulator provided a question regarding a vehicle (e.g., "what is the plate status?"). Participants searched for information on the MCT and verbally provided the answer, which was recorded by the camera. The prototype was based on the MCT interface used by Texas police departments (Figure 6). The name and addresses shown in Figure 6 are fictional, created by the research team.

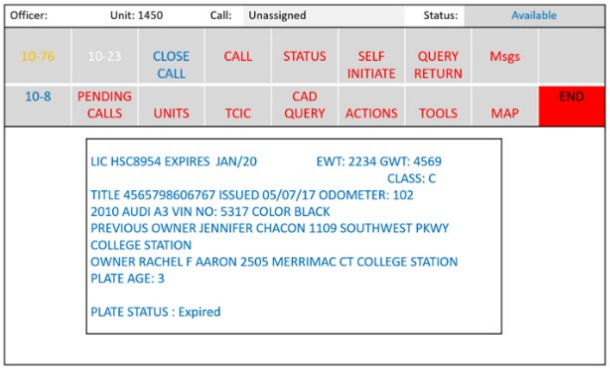


Figure 5. Non-driving-related task.

Dependent Variables

The driver performance measures for LB scenarios included brake reaction time [54], minimum time-to-collision (TTC), maximum lateral acceleration, and maximum longitudinal deceleration [55]. Lateral acceleration was used to evaluate driving performance and vehicle stabilization while passing the lead vehicle [47]. Maximum longitudinal deceleration was used to measure the severity of brake reaction. For BS scenarios, performance measures included number of collisions and time to change lanes [51]. Due to the page limitations of this report, only the significant driver performance responses are reported in the results section. Driver activity load index (DALI) was used to measure officers' subjective workload. Additionally, a trust questionnaire consisting of three subscales (i.e., trust performance, trust process, and trust purpose) was adopted from [56] to assess officers' trust in the ADAS system.

Data Analysis

A data screening process was conducted on driving performance data to detect any outliers. Diagnostics tests were performed on all dependent variables to satisfy parametric test assumptions of normality and equal variance. Residual normality was assessed by inspection of normal probability plots and Shapiro-Wilk's Goodness-of-Fit tests, and variance homoscedasticity was checked using Bartlett's tests. In case of parametric assumption violations, Box-Cox transformation was used. An ANOVA was conducted to investigate the effect of explanatory variables on response variables. Tukey's Honest Significant Difference post-hoc multiple comparison was applied to identify differences among levels of any significant effects, if applicable. A significance level of $p < 0.05$ was set as a criterion for the study. Error bars represent standard errors, and the letters (A and B) were used to uncover significant differences between the groups based on the post-hoc analysis. The driving simulator provided driving performance responses in seconds with accuracy up to two decimal digits. R studio was used to conduct the inferential statistics. The inferential analysis provided information regarding the effect of ADAS on officers' performance, workload, and trust (Objective 2).

Results

A significant effect of ADAS on drivers' minimum TTC was found ($F(1,172.35) = 7.03$, $p = 0.009$). Results indicated that officers exhibited a significantly longer minimum TTC when ADAS was activated compared to manual driving (Figure 7).

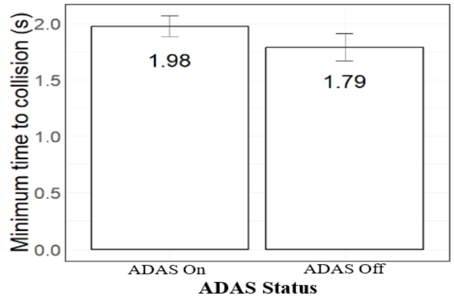


Figure 6. Effects of ADAS on minimum TTC.

Results indicated that in situations where the lead vehicle braked and another vehicle was present in the blind spot (i.e., the combo hazard type), officers demonstrated a larger maximum longitudinal deceleration when utilizing ADAS as compared to manual driving ($F(1,174.32) = 4.66$, $p = 0.03$) (Figure 8).

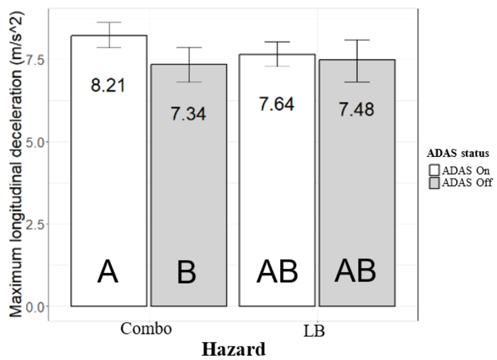


Figure 7. Effects of ADAS on maximum longitudinal deceleration.

The results also revealed a significant effect of ADAS on officers' trust ($F(1,323.16) = 17.56$, $p < 0.001$), as shown in Figure 9.

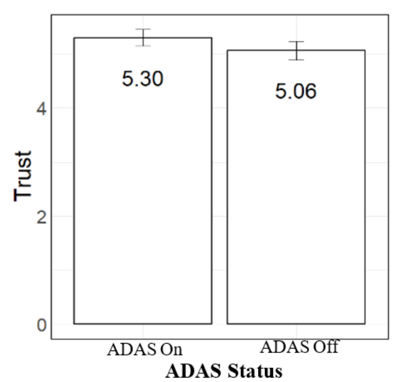


Figure 8. Effects of ADAS on trust.

An interaction effect between the ADAS status and hazard type was observed for the DALI score ($F(2,149.09) = 3.2$, $p = 0.04$). In the combo hazard situation, drivers reported significantly lower workload with ADAS ($M = 2.63$, $SD = 1.07$) compared to manual driving ($M = 2.97$, $SD = 1.07$).

Discussion

Hypothesis 1 posited that law enforcement officers would exhibit better driving performance with ADAS than during manual driving when negotiating the LB. Results partially supported this hypothesis. The results suggested that officers had a larger minimum TTC of 1.98 seconds with ADAS compared to 1.79 seconds without ADAS. In crash avoidance situations, a longer minimum TTC is generally considered to be a safer driving performance, as it provides drivers with more time to react. A longer minimum TTC with ADAS indicates that the officers had more time to perceive the danger, make a decision, and execute an evasive maneuver. This highlights the advantage that the FCW system affords officers' in perceiving and reacting to dangerous situations quickly and effectively.

The findings also suggested that in combo scenarios where FCW and BSM were both active and there was an LB and another vehicle in the driver's blind spot, officers demonstrated a higher level of maximum longitudinal deceleration as compared to driving without ADAS. This suggests that ADAS might be particularly effective in safety-critical driving situations, where there is a need for immediate and comprehensive information about surrounding vehicles. It is important to note that a larger maximum longitudinal deceleration does not inherently indicate a safer driving performance. However, when combined with the results of minimum TTC, this finding further supports the notion that providing drivers with appropriate and timely information about their surroundings through the use of ADAS technologies such as FCW and BSM can aid in making better decisions and executing safer maneuvers in crash avoidance scenarios.

In general, the results suggested that ADAS primarily influenced the longitudinal aspect of driving performance, demonstrating the effectiveness of FCW and AEB in enhancing safe driving. However, the impact of BSM was limited, possibly due to its low salience. The lack of an auditory signal unless the officers turned on their blinkers, and the fact that most participants did not use their blinkers, may have contributed to this. Thus, there is a need for improvement in the design of BSM warnings for officers to make them more noticeable.

According to Hypothesis 2, officers were expected to perceive a lower level of workload while driving with ADAS than during manual driving. Although the results did not fully support this hypothesis, it was found that officers reported a lower level of workload in the combo scenario with ADAS as compared to the driving without ADAS in normal driving conditions. The difference in workload scores in combo scenarios with and without ADAS can be explained by the effectiveness of these ADAS features in reducing cognitive load and increasing situational awareness. In the combo scenario, the presence of both an LB and a vehicle in the blind spot creates a more complex driving situation that requires the driver to monitor multiple sources of information and make quick decisions. FCW/AEB can alert the driver to a potential collision with the lead vehicle, while BSM can provide information about the presence of the vehicle in the blind spot. These systems can reduce the cognitive load on the officer by providing additional information and warnings, allowing the officer to focus on the task of driving in normal driving situations. In contrast, in the LB and BS scenarios, the driving situations are less complex and may not require the use of ADAS technologies to reduce cognitive load. This finding is consistent with the results of maximum longitudinal acceleration, which suggested that officers exhibited a larger maximum longitudinal deceleration with ADAS in similar scenarios.

However, there was no significant difference in DALI scores between driving with and without ADAS during pursuit driving situations. Wicken's multiple resource theory can explain this finding, as ADAS warnings require both auditory and visual resources, whereas pursuit driving demands high vigilance and involves the use of sirens and audio [57]. Per Wicken's theory, these two tasks may compete for the same resources and can overload officers, resulting in no significant difference in DALI score between manual driving and driving with ADAS. The use of ADAS may not have a significant impact on workload perception during pursuit driving, as the task itself already requires a high level of cognitive resources. Therefore, the effectiveness of ADAS may vary depending on the driving condition and the cognitive demands imposed on officers.

Hypothesis 3 stated that officers would have a higher trust in vehicle during the crash situation if the ADAS was in use. This hypothesis was supported by the results. This finding suggests that the use of ADAS can increase drivers' confidence in the safety of the vehicle and its ability to prevent or mitigate the impact of collisions. Increased trust in the vehicle is an important factor that can influence drivers' behavior and decision-making while driving. When drivers have greater trust in the safety features of their vehicle, they may be more likely to rely on these features to prevent collisions, which can lead to safer driving behavior overall [45]. Officers' knowledge of the ADAS technology is a significant factor that determines their trust in the ADAS [58] and their intention to use the technology [45].

Limitations

This study has some limitations. Regarding Phase 1, many of the surveyed participants drove police vehicles that had a limited number of available ADAS features. This could have led to biased results favoring the few ADAS features currently in the vehicles of the police officers surveyed due to lack of experience with all surveyed ADAS features. Also, the distribution of question types among the category of questions was unbalanced. Although having a balanced distribution of question types per each category is not required for the correlation analyses [59], it is possible that increasing or changing the category for some of the questions could have affected the results of the study. This issue needs to be further investigated in future studies.

Regarding Phase 2, participants in this study were all male, while 19.7% of law enforcement officers across the U.S. are women [60]. This might limit the generalizability of the findings to the overall officer population. Furthermore, the experiment simulated daylight driving, and cannot be generalized to night shifts. These limitations should be considered when interpreting the results of the study. Lastly, none of the covariates (e.g., age, experience, hours per week in the vehicle) were found to be a significant indicator of driving performance measures. The lack of significance for these covariates may be attributed to the limited range of these factors in our sample. We plan to address these limitations in our future studies by collecting data from a larger and more diverse sample of officers.

Conclusions and Recommendations

This study recommended some ADAS features to be added in police vehicles and proposed guidelines for future research to be conducted in the field. In addition, it was found that the perceived usefulness of ADAS features can be connected in some specific aspects to officer trust in ADAS features. Officers expressed a desire for improved adaptability and usability in their vehicles, emphasizing ADAS already implemented in police vehicles as areas for improvement (e.g., cameras, Bluetooth). The results highlighted the discrepancies between civilian and police officers, notably the higher workload and more difficult driving tasks police officers must accomplish, which shift the needs of their proposed ADAS technologies from those of civilian drivers. These findings were collected and summarized in a set of guidelines for future research and manufacturing to consider and validate in future driving simulation or naturalistic studies (Appendix C). If implemented, the guidelines proposed by this study have the potential to improve officers' and civilians' safety in police operations. The findings of the driving simulation study also suggested that driving with ADAS technologies would result in significant improvement in driving performance and reduce officers' perceived workload. Additionally, it was found that ADAS would increase officers' trust in vehicle safety with sufficient training on system capabilities. These findings provide evidence for the implementation of ADAS technologies in police vehicles to improve the driving performance and overall safety of law enforcement officers.

Additional Products

Link to the project on Safe-D website: https://safed.vtti.vt.edu/projects/analysis-of-advanced-driver-assistance-systems-in-police-vehicles/

Link to the Safe-D dataverse: https://doi.org/10.15787/VTT1/J3D2AK

Education and Workforce Development Products

- The Principal Investigator (PI) organized several open houses and lab tours, inviting middle school, high school, and undergraduate students to visit her lab and learn about human factors in transportation. Survey responses from about 50 students attending these events indicated that these activities helped the students become familiar with the human factors area (average rating of 4.4/5) and better understand the applications of computing and driving simulations in transportation (average rating of 4.5/5).
- In Fall 2021, the PI and her students gave an on-site demonstration to high school students to help them become more familiar with the human-systems engineering area and its applications in transportation. The students learned how to use eye-tracking glasses to capture eye movements to study driver distraction and workload.
- In summer 2022, the researchers' lab provided training for a K-12 teacher to familiarize them with the human-computer interaction area and its applications in transportation. These activities included (1) demonstration of the high-fidelity driving simulator and training on creating simple scenarios using graphical user interface and Java; and (2) data collection and analysis of physiological data using wearable devices including eye-tracking glasses and heart rate monitors.
- **Undergraduate engineering student training:** This project provided research training for three undergraduate students: Vanessa Nasr, David Wozniak, and Miguel Tovar. Two of these students worked on this project as their TTI internships during the summer 2020 and 2021. The students

were trained on conducting a systematic literature review, design of driving simulation-based experiments, data processing, data analysis, and manuscript writing.

- **Graduate student training:** This project provided training for one PhD student (Farzaneh Shahini) and provided the basis for her PhD dissertation study. Farzaneh successfully passed her PhD defense in May 2023.

Technology Transfer Products

- In 2020, the PI (Zahabi) gave a talk on "Law Enforcement and Advanced Driving systems: Effects on Road Safety (LEADERS)" as part of the human factors and ergonomics society (HFES) webinars. She presented the findings of the literature review and the survey (Phase 1 study) as part of this webinar. The audience was a mix of students, researchers, and practitioners in the area of human factors and ergonomics.
- In 2020, the PI (Zahabi) gave a virtual seminar on "Analysis of police in-vehicle technologies and their impact on officers' driving safety" in the Industrial and Systems Engineering Department at Virginia Tech University. She presented the findings of Phase 1 as part of this webinar. The audience was a mix of students, faculty, and researchers.
- In 2021, the PI (Zahabi) gave a seminar on "Analysis of Advanced Driver Assistance Systems in Police Vehicles" at University of Massachusetts Amherst. She presented the findings of Phase 1 as part of this seminar The audience was a mix of students, faculty, and researchers.
- In 2021, Vanessa Nasr (an undergraduate student worked on this project) presented the findings of Phase 1 at *the 100th Annual Meeting Transportation Research Board*, Washington, D.C.
- In 2021, the PI (Zahabi) gave a virtual seminar on "Analysis of police in-vehicle technologies and their impact on officers' driving safety" in the Industrial and Systems Engineering Department at University of Florida. She presented the findings of Phase 1 as part of this webinar. The audience was a mix of students, faculty, and researchers.
- The ADAS recommendations based on the findings of Phase 1 are now posted on the Safe-D researcher portal and Dr. Zahabi's research laboratory website (https://hsi.engr.tamu.edu/publications/)
- The findings of this project have been published in two journal articles [43-44] and one HFES conference proceeding [45]. We plan to submit a journal paper based on the findings of Phase 2 by the end of the Summer 2023.

Data Products

The dataset and data dictionary files are uploaded to the VTTI Dataverse: https://doi.org/10.15787/VTT1/J3D2AK

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Appendices

Appendix A

List of survey questions and their respective categories.

Note: The questions were designed based on the discussion with some police officers and were pilot tested before distribution to the police agencies.

Question	Response Type	Category
1. What are the most beneficial ADAS features in your police vehicle? Please select all that apply and provide a short explanation for your selection.	Checkbox	Perceived usefulness
2. How often do you use available ADAS features in the police vehicle?	Likert scale	Past Behavior
3. Are there any helpful ADAS features that your personal vehicle has that you would like to have in your police vehicle as well? Which ones?	Free Response	Perceived usefulness
4. Are there any ADAS features in your police vehicle that you do not use at all? If so, please explain.	Yes/No	Perceived usefulness
5. What are your recommendations to improve the current ADAS features in police vehicles?	Free Response	Perceived ease of use
6. If you were the manufacturer of police vehicles, what ADAS features would you add to the vehicle? Why?	Free Response	Perceived usefulness
7. Do you know how to easily turn on and off your ADAS features?	Yes/No	Perceived ease of use
8. Is there any situation in which you would prefer to have your ADAS features turned off? If so, please explain.	Yes/No	Perceived usefulness

Question	Response Type	Category
9. Would you use ADAS more if their functionality and advantages were clearly explained to you?	Yes/No	ADAS training
10. How do you prefer to receive alerts in your police vehicle? (please select all that apply)	Checkbox	Perceived ease of use
11. Do you think ADAS features can be useful in pursuit situations?	Likert scale	Perceived usefulness
12. How often do you rely on ADAS features while you are performing a secondary task (e.g. using the MCT, cell phone, talking on the radio) as compared to when you are driving without these distractions?	Likert scale	Perceived usefulness
13. Do you think the currently available ADAS features in police vehicles are helpful to improve driving safety and reduce crashes? If yes, please explain how.	Yes/No	Perceived usefulness
14. How much do you trust ADAS features to improve your driving safety?	Likert scale	Trust
15. How much do you trust autonomous vehicles to improve your driving safety in police operations?	Likert scale	Trust
16. To what extent do you think that ADAS features reduce your workload?	Likert scale	Perceived usefulness
17. What are the reasons/barriers that prevent you from using ADAS in police vehicles?	Free Response	Perceived usefulness
18. Do you think that ADAS features improve your attention to the road and the surrounding environment? If yes, please explain how.	Yes/No	Perceived usefulness
19. Do you have any other suggestions to improve ADAS in police vehicles?	Free Response	N/A

Appendix B

List of ADAS features in police vehicles.

ADAS feature	Description
Blind Spot Information Systems	Provides the driver with information about other vehicles in the driver's blind spot through sensor technology
Rear View Camera	Assists the driver while backing up, displaying what is behind the vehicle as well as indicating potential hazards
Pre-Collision Assist	Detects a potential collision with a vehicle or pedestrian directly in front of the vehicle and applies the brakes automatically if the drivers do not do so themselves
Pedestrian Detection	Detects human movements, particularly those near the car or on a collision course with the car
Emergency Braking	Detects an impending forward crash with another vehicle in time to avoid or mitigate the crash through the automatic appliance of breaks without driver input
Lane Keep Assist	Provides automatic steering and/or braking to keep a vehicle in its travel lane upon detection of drifting
Lane Departure Warning	Alerts the driver when the vehicle is about to veer out of lane and warns to get back into lane, precedes lane keep assist.
Safety Alert Seat	Communicates crash threat direction with the tactile sense
Adaptive Cruise Control	Automatically adjusts the vehicle speed to maintain a safe distance from vehicles ahead
Hill Start Assist	Maintains the brake pressure for a set amount of time as the driver switches from the brakes to the gas pedal in order to assist in hill ascension
Hill Descent Control	Uses traction control technology with anti-lock brakes to automatically promote safe hill decent without brake input from the driver
Reverse Brake Assist	Provides a complete stop if the driver does not react in time while reversing, emitting audible and visual warnings before the brakes apply
Front Split View Camera	Allows the driver to see a 180-degree view in front of the vehicle and provides warnings in case of detected dangers in blind spots when pulling out
Automatic Braking System	Anti-lock braking system and anti-skid braking system

ADAS feature	Description
Traction Control System	Prevents loss of wheel traction on differing road terrains
Electronic Stability Control	Consists of speed sensors on each wheel and the ability to brake individual wheels that are the basis of anti-lock brakes
Night Vision	Detects and alerts the driver of the pedestrians, cyclists, and deer beyond the reach of your headlamps
Collision Mitigation	Reduces the severity of a collision during and after the collision, performing brake application the driver is likely unable to do in the situation
Multisensor Platform	Helps prevent or mitigate rear-end crashes using techniques that involve multiple radars and cameras
Driver Drowsiness Detection System	Scenario dependent response with an increasing sequence of wakeup actions and/or automated driving actions
Curve Control	Senses a driver taking a curve too quickly and responds by rapidly reducing engine torque, applying four-wheel braking when needed

Appendix C

The following list of guidelines has been complied to guide future research and to improve ADAS in the next generation of police vehicles. These guidelines are meant for both researchers and manufacturers of ADAS features to consider when undertaking future development of ADAS, in particular for police vehicles.

Guideline 1: Emphasize clarity above everything else

One of the largest barriers to ADAS usage for police officers was identified as a lack of understanding of the ADAS features available. About 68% of respondents affirmed that they would make greater use of ADAS if the functionality and advantages were more clearly explained. Since ADAS training significantly impacts perceived usefulness of ADAS features, improving officers' knowledge of ADAS can potentially increase ADAS acceptance among police officers.

Guideline 2: Improve ADAS accessibility and usability

About 38% of police officers stated that there were situations where they preferred to have their ADAS features disabled. However, over half of the respondents identified that they were unable to easily turn on or off their ADAS features. Accessibility and usability, desired qualities according to the free response results, should be emphasized in the design of ADAS to account for individual differences and preferences of police officers when using ADAS features.

Guideline 3: Provide adaptive ADAS

Police driving conditions, including pursuit and emergency operations, are different from the situations that civilian drivers are involved in. Therefore, ADAS features for police vehicles should be easily adaptable to these situations or powered off effectively otherwise. Pursuits and other similar situations were the top scenarios cited by police officers where they preferred to have their ADAS features off. Thus, when designing or researching ADAS features, adaptability to the wide variability of driving scenarios police officers face is paramount.

Guideline 4: Investigate ways to integrate ADAS into existing police vehicle technology

Police officers already have multiple unique features (e.g., MCT, radio) in their vehicles compared to civilian drivers. These features, while necessary for police officers to perform their duties, significantly increase officers' mental workload and distraction while driving. Officers indicated that ADAS should be compatible with existing police in-vehicle technologies and should be easily activated or adjusted based on individual preferences, needs, and driving situations. This highlights a need for a unique approach to design and manufacture ADAS for police vehicles. Furthermore, research should be conducted on whether integrating ADAS into police vehicle technology would encourage higher ADAS use among police officers.

Guideline 5: Focusing on perfecting a few features is better than having many less elaborate features

Police officers experience higher levels of workload than civilian drivers. The survey indicated the lack of understanding regarding ADAS as one of police officers' primary barriers towards using ADAS features. To combat this, researchers and manufacturers should focus on ADAS features that target the factors specified above when designing for police vehicles, with future research validating the directions chosen for designing such features. Furthermore, building trust in ADAS requires that officers understand the nature of the features they are using. As officers, already have a high mental workload associated with their jobs; a few features that help them perform their duties effectively would be much easier to understand and trust than a multitude of complex features.

Guideline 6: Police vehicle ADAS features should focus on improving officer driving safety

Roughly a third of respondents rated the extent to which ADAS features reduce their workload as a 1 out of 5 on the Likert scale, as low as possible. However, more than half of the respondents believed that ADAS could improve their driving safety. While for civilian drivers, ADAS features may be effective in reducing their mental workload on the road, officers are already obligated to accomplish secondary tasks while driving and to drive in high-demand situations such as pursuit and emergencies. These situations have been found to significantly increase officers' mental workload as compared to driving without secondary tasks and in normal driving conditions. The findings of this survey indicated that police officers might prioritize collision avoidance ADAS features, such as intersection collision avoidance, over other ADAS such as traffic sign detection or autonomous highway driving, which might be due to the unique driving situations that they are involved in. Police vehicle manufactures should prioritize integration of those ADAS features with the greatest potential to improve officers' driving safety.

Guideline 7: Design to reduce the need for extensive ADAS training

The results indicated that ADAS training has a significant effect on perceived usefulness of ADAS. As useful as ADAS features are, the prospect of needing to undergo training to fully understand and utilize these features can be daunting to police officers already burdened with high mental workload and stressful jobs. To account for this while not sacrificing the trust gained from understanding how ADAS features work, future research should investigate ADAS features that require minimal training to understand, and manufacturers should endeavor to design intuitive ADAS that perform their duties with as little required attention or input from the driver as possible. This includes the activation and deactivation of these systems, in accordance with Guideline 2. Furthermore, the training should be delivered in the form of multi-media software tools or driver simulators when possible and should be simple enough to overcome the mental hurdles police officers face when taking on additional tasks while driving.