Analysis of Advanced Driver Assistance Systems in Police Vehicles: A Survey Study

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Abstract

Few studies have examined the impact of advanced driver-assistance systems (ADAS) on police officers to improve driver safety and prevent crashes. This is in spite of police officers having higher driving-related mortality rates than average civilians. To fill this gap, a survey study was conducted on 73 police officers to assess their opinions on various ADAS features as well as their recommendations for improvement. Results of the correlation analyses indicated that officer behavior and opinion on ADAS features were influenced by the trust officers had in the available ADAS systems among other key factors such as ADAS training and perceived usefulness. On this basis, guidelines for future research and development of ADAS were provided to improve officer driving safety in police operations. The guidelines need to be further validated in future driving simulation or naturalistic studies.

Keywords: Police, Vehicle, Technology Acceptance Model, Accident Prevention

1.0 Introduction

Crash reports from various states in the U.S. have revealed high numbers of emergency vehicle crashes, especially in law enforcement situations. The national safety council (NSC) report from 2010 to 2018 (NSC, 2018) indicated 138 fatalities in fire truck crashes, 252 deaths in ambulance–related crashes and 805 fatalities in police vehicle crashes. Furthermore, crash rates of police vehicles were found to be 2.5 times higher than the national average among all occupations (Maguire, 2002).

Motor vehicle crashes are among the leading causes of law enforcement officer deaths and injuries (Tiesman and Heick, 2014). From 2011 to 2015, police vehicle crashes accounted for almost one-third of all law enforcement fatal work injuries (Bureau of Labor Statistics, 2020). Although overall law enforcement fatalities in pursuit situations have decreased moderately from over 160 per year in 1980 to under 120 per year in the late 2000s, deaths caused by motor vehicle crashes have steadily increased (Lambert, 2016). According to the Federal Bureau of Investigation (FBI), the leading cause of accidental police officer fatalities from 2015 to 2019 was motor vehicle crashes, accounting for 156 police officer deaths (FBI, 2009).

Advanced driver-assistance systems (ADAS) are expected to mitigate road fatalities and reduce the number of road accidents and injuries. Some ADAS such as forward collision warning (FCW) systems and low-speed autonomous emergency braking (AEB) can reduce property damage and liability claims (Lund, 2013). A study conducted by Cicchino (2017) revealed that rear-end striking crash involvements were reduced by 27% with implementation of FCW alone, 43% with low-speed AEB alone, and 50% with both. Furthermore, rates of rear-end striking crash involvements with third-party injuries were reduced by 18%, 44%, and 59%, respectively. Wu et al. (2018) found that driving with FCW resulted in quicker reaction times (shorter throttle release and brake time) and larger response intensity (larger maximum brake pedal force and larger maximum lane deviation) as compared to driving without FCW. In addition, FCW was found to reduce the number and severity of crashes. It is estimated that if all vehicles were equipped with FCW and AEB,

almost 1 million US rear-end police reported crashes and 400,000 crashes with injuries would be prevented annually (Cicchino, 2018). In another study, it was found that a combination of FCW, pre-crash brake assist (PBA), and autonomous pre-crash braking (PB) could reduce the change in velocity during the crash by 34%, decrease number of passenger fatalities or injuries by 50%, and prevent 7.7% of collisions (Kusano & Gabler, 2011). Accident involvement rates in lane-change crashes were also found to be 14% lower among vehicles with blind spot monitoring (BSM) as compared to those without (Cicchino, 2018).

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 (Gietelink, 2006). Technologies that fit under the umbrella of ADAS can represent high level autonomous vehicles such as self-driving cars or lower level technologies such as backup cameras. For the purpose of this study, the primary focus was on currently available ADAS in civilian and by extension police vehicles. Though previous work has emphasized the potential of ADAS for reducing accidents in civilian drivers (Davidse, 2006), very few studies focused on potential benefits of ADAS use in police vehicles. Prior studies focused specifically on older drivers found that many of the most highly recommended systems such as collision warning systems and automated lane change systems still require extensive research before public acceptance and manufacturing are able to create acceptable versions of these systems for the public. Examples of these factors that need to be accounted for include: Trust (Najm et al., 2006, Ghazizadeh et al., 2012), which is defined as "*the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability*" (Lee & See, 2004, p.51), and training. Training has been found as one of the most important factors that contributes to greater user acceptance and system success (Scherer et al., 2019). Coughlin & D`Ambrosio (2012) and Koustanaï et al. (2012) suggested that training can lead to a better system understanding, including system capacities, benefits, and limitations. In addition, previous studies

have suggested that training can influence ease of use of information technology (Davis et al., 1989). Biassoni et al. (2016) investigated the effects of training with advanced collision warning systems on ADAS technology acceptance with 527 novice drivers. Results indicated that the quantity and quality of information on technology features can significantly change the initial acceptability of the safety device. In addition, pleasantness of use and perceived benefits for safety were found to be the most critical factors for the novice drivers. Previous studies paid specific attention to the area of trust in information technology. It is widely accepted that users who trust in certain technology put themselves in a vulnerable position, and the trust relation might lead the user to take the potential risk of losing something important and instead using the technology (Mayer et al., 1995). For example, Xu et al. (2010) developed a technology acceptance model (TAM) to analyze why travelers accept or refuse advanced traveler information systems (ATIS) and to explain, predict, and increase travelers' acceptance of ATIS. They concluded that trust in ATIS significantly determines travelers' intention to accept and use it (Xu et al., 2010).

Despite the high risk posed to police officer safety by motor vehicle crashes, ADAS-related studies have remained almost strictly limited to investigating their potential uses for civilians. In order to better equip police officers to deal with the increased risk of accidents associated with their profession, it is necessary to investigate ways to improve ADAS use for police vehicles specifically as opposed to civilian drivers in general. In our prior study, we have identified a list of the most prevalent ADAS available for police officers based on a review of literature on police vehicles, patents, and review of scientific research studies (Nasr et al., 2021). Some of the features include rear view cameras, emergency braking, adaptive cruise control, etc. A complete list of these features is provided in Nasr et al., (2021). The findings of this study provided a list of ADAS features, which is incorporated into the questions for this survey. Additionally, recommended features from the review to be added into future police vehicles such as Front Vehicle Detection

Systems, Intersection Collision Avoidance, and Evasive Steering Assist were found to be the most potentially useful ADAS features for crash mitigation for police officers. To evaluate the findings of our previous literature survey, this study aimed to collect the opinions of officers on both recommended and existing ADAS in police vehicles.

1.1 Research Objective

The objective of this study was to understand police officers' opinions and needs regarding ADAS in police vehicles. To achieve this objective, we conducted an online survey and identified correlations and trends between officer opinions on ADAS features in their vehicles.

2.0 Method

2.1 Survey

An online survey composed of 19 questions of four different types was distributed among the officers. The question types included: (1) yes/no questions with space for elaboration, (2) Likert scale response questions with ranges of responses between 1 (represents the lowest reported frequency or the lowest possible trust in the technology) and 5, (3) checkbox questions with choices selected based on the findings of our previous literature review (Nasr et al., 2021), and (4) free response questions. The questions for the study were selected to conform to one of several overarching categories of questions for the purpose of correlation analysis. The three primary categories included *perceived usefulness, perceived ease of use,* and *trust,* with two other questions focusing on *training* and *past behavior*. As the final question merely asked for additional suggestions, it was not placed in a category. Table 1 outlines the survey questions and the response type.

The questions were based on the ADAS widely available in police vehicles in the U.S. and were designed to understand which features were available in police department vehicles, whether they were used by police officers for their work operations, and how useful officers perceived the features. The available ADAS features used in this survey were based on the findings of our

previously completed literature review (Nast et al., 2021). The ADAS features included were: Bluetooth/Uconnect Communication Systems, Rear View Camera, Pre-Collision Assist, Emergency Braking, Lane Keep Assist, Lane Departure Warning, Patented Safety Seat, Adaptive Cruise Control, Hill Start Assist, Hill Descent Control, Reverse Brake Assist, Front Split View Camera, Gunshot Detection System, Automated License Plate Reader, Low-Speed Automated Driving, and Blind Spot Information System.

Participants were also asked to rank ADAS features (on their potential usefulness identified in Nasr et al., (2021)) that are currently not widely available in police vehicles. These potential features included: Front Vehicle Detection System, Intersection Collision Avoidance, Evasive Steering Assist, Left Turn Assist, Traffic Sign Detection Algorithm, Post Collision Braking, Traffic Jam Assist, Two Lane Detection, Lane-Ending Detection, Wrong Way Moving Vehicle Detection, Wrong Way Alert, and Autonomous Highway Driving. For descriptions of all mentioned features, please see Nasr et. al., 2021.

Table 1: Survey questions and their respective categories.

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
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

A copy of the survey used in this study can be found from

https://docs.google.com/forms/d/1w6Tk8tqIFi_RjotGoIXslEe9z6i3w0tw1VWGIK__nco/edit.

2.2 Survey Procedure

The survey was administered to participating precincts in Texas via email. Participants were first asked to fill out an online consent form and a demographic survey before completing the actual

survey. Responses were collected and organized using Google Forms between September 2nd, 2020 and September 17th, 2020.

2.3 Data Analysis

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. This test compromises a nonparametric statistic used in cross-tabulated table data where both variables are dichotomous (Frey, 2018). The assumptions of the phi test, including having samples randomly and independently selected from a defined population with expected values of at least 5, were met. 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 (Abdi, 2007). Finally, comparisons between yes/no and Likert scale responses employed the Wilcoxon rank sum correlation with the assumptions for the test met (Zaiontz, 2014). Free response questions were analyzed using conventional quantitative analysis separate from the analysis conducted on the other questions.

3.0 Results

3.1 Demographic information

Seventy-three participants completed the demographic questionnaire and the results are displayed in Table 2.

Table 2: Results of demographic survey.

Category	Results
Sex	68 males, 5 females
Age	*M* = 37.24 yrs., *SD* = 8.3 yrs.
Number of participants who attended police academy	73

Experience as police officer	*M* = 11.03 yrs., *SD* = 7.43 yrs.
Experience serving as a primary patrol officer	*M* = 8.63 yrs., *SD*= 6.14 yrs.
Number of participants who received additional training since the police academy (e.g., emergency vehicle operation courses)	63
Level of experience with ADAS (1 being no experience and 5 being an expert)	*M* = 2.74, *SD* = 1.19
Frequency of ADAS use	*M* = 46.11% and *SD* = 27.19%
Road types drove	Urban, rural, highways, and suburban roads

Note: *M*: Mean, *SD*: Standard deviation

In addition, 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 most uncommon features available.

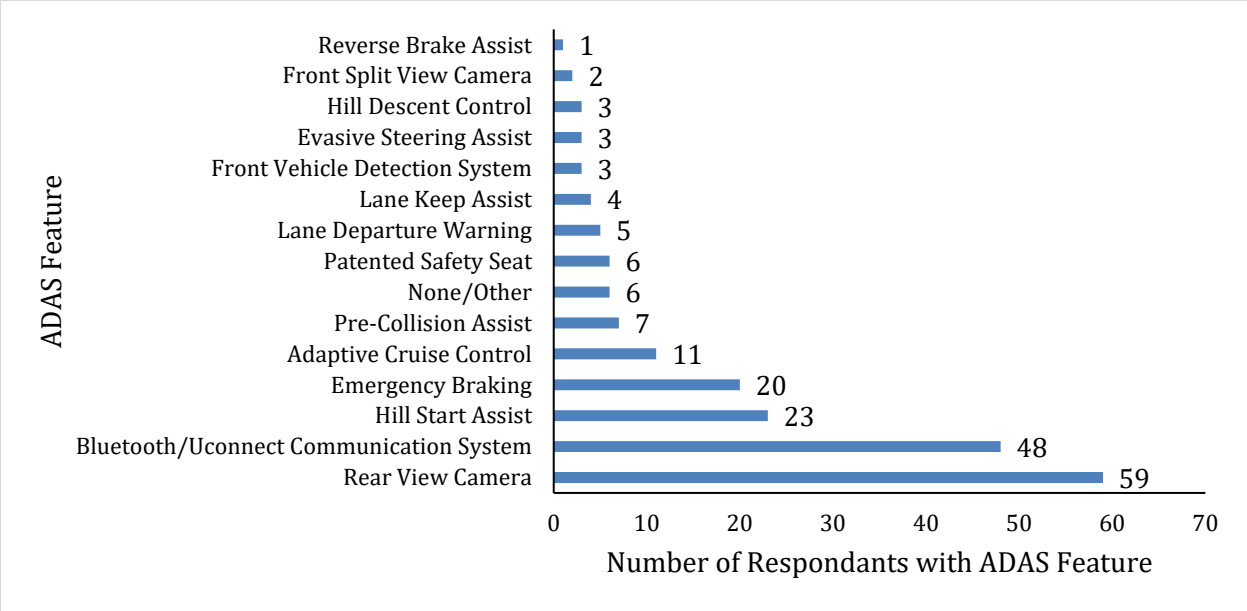

Figure 2: Existing ADAS in Police Vehicles

Participants were also asked to rank potential ADAS features, not currently available in police vehicles in the U.S., based on how useful they thought they could be (1 being the most useful and 12 being the least useful). The most useful potential ADAS features according to the surveyed police officers were as follows (starting with the most potentially useful): Intersection collision avoidance (M = 5.60, SD = 4.06), wrong way alert (M = 5.89, SD = 3.90), front vehicle detection system (M = 5.92, SD = 4.04), evasive steering assist (M = 6.51, SD = 3.69), wrong way moving vehicle (M = 6.59, SD = 3.89), post collision braking (M = 6.67, SD = 3.76), two lane detection (M = 6.59, SD = 2.92), left turn assist (M = 6.81, SD = 3.61), traffic jam assist (M = 6.85, SD = 3.33), traffic sign detection (M = 7.41, SD = 3.74), lane ending detection (M = 7.44, SD = 3.21), and autonomous highway driving (M = 7.64, SD = 3.86). The results indicated that police officers prioritized ADAS features with regards to avoiding collisions such as intersection collision avoidance over ADAS designed to reduce the mental burdens associated with driving such as traffic sign detection or autonomous highway driving.

3.2 Survey Results

From the initial number of participants who completed the demographic questionnaire, the data for seven participants were removed due to failing or choosing not to complete the online survey sent to them. Therefore, survey data analysis was conducted on the data from the remaining 66 participants. A summary of the responses to survey questions are shown in Tables 3 and 4 and Figures 3 and 4. For the Likert questions, participants were asked to rate their agreement with a variety of statements, with higher values being more positive responses.

Table 3: Descriptive statistics on Likert scale questions.

Question	Mean (Standard Deviation)
2. How often do you use available ADAS features in the police vehicle?	3.05 (1.29)
11. Do you think ADAS features can be useful in pursuit situations?	2.86 (1.35)
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?	2.58 (1.46)
14. How much do you trust ADAS features to improve your driving safety?	2.82 (1.20)
15. How much do you trust autonomous vehicles to improve your driving safety in police operations?	1.94 (1.15)
16. To what extent do you think that ADAS features reduce your workload?	2.15 (1.01)

Table 4: Summary of responses to Yes/No questions

Question	Percentage of "Yes" Responses (%)
4. Are there any ADAS features in your police vehicle that you don't use at all? If so, please explain.	9.09
7. Do you know how to easily turn on and off your ADAS features?	47
8. Is there any situation in which you'd prefer to have your ADAS features turned off? If so, please explain.	37.9
9. Would you use ADAS more if their functionality and advantages were clearly explained to you?	62.8
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.	59.1
18. Do you think that ADAS features improve your attention to the road and the surrounding environment? If yes, please explain how.	43.9

Figures 3 and 4 summarize the results gathered for questions 1 and 10 respectively. Figure 3 indicates what features officers believed to be most beneficial to them during their work. These features are available ADAS in the latest police vehicles in the U.S. (e.g., the 2020 Ford Police Interceptor Utility, the 2020 Chevy Tahoe Police Pursuit Vehicle, and the 2020 Dodge Charger Pursuit) but might have not been available in the vehicles of police officers surveyed in this study (which was illustrated in Figure 2). Similar to the responses to available ADAS features (Figure 2), the responses to question 1 suggested a strong preference of police officers for the rear-view cameras and the Bluetooth communication systems in comparison to all of the other ADAS

features. The responses to question 10 indicated officers' preference towards receiving alerts using a combination of visual and auditory modalities as compared to visual or auditory modality only or vibrotactile alerts.

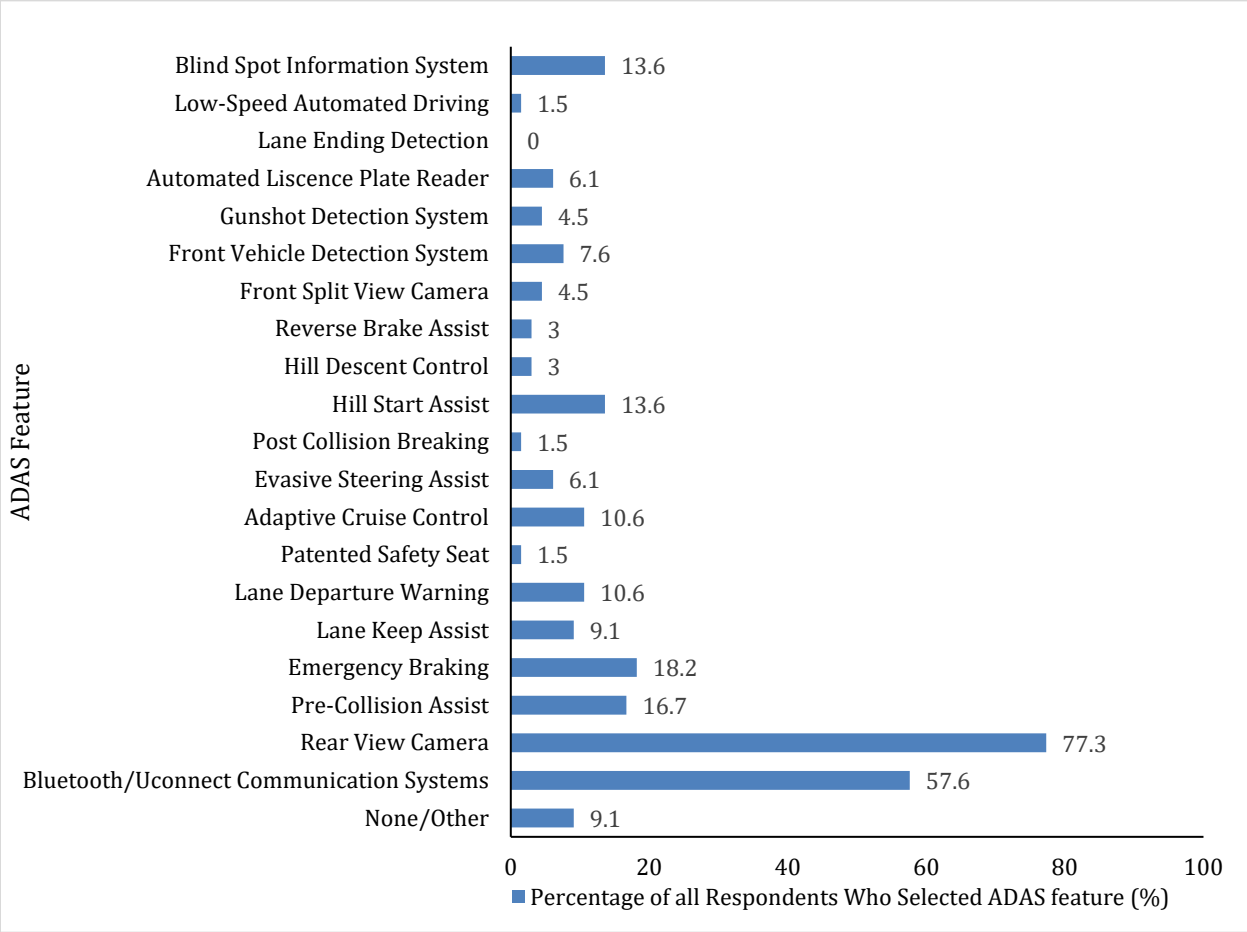

Figure 3: Beneficial ADAS Features

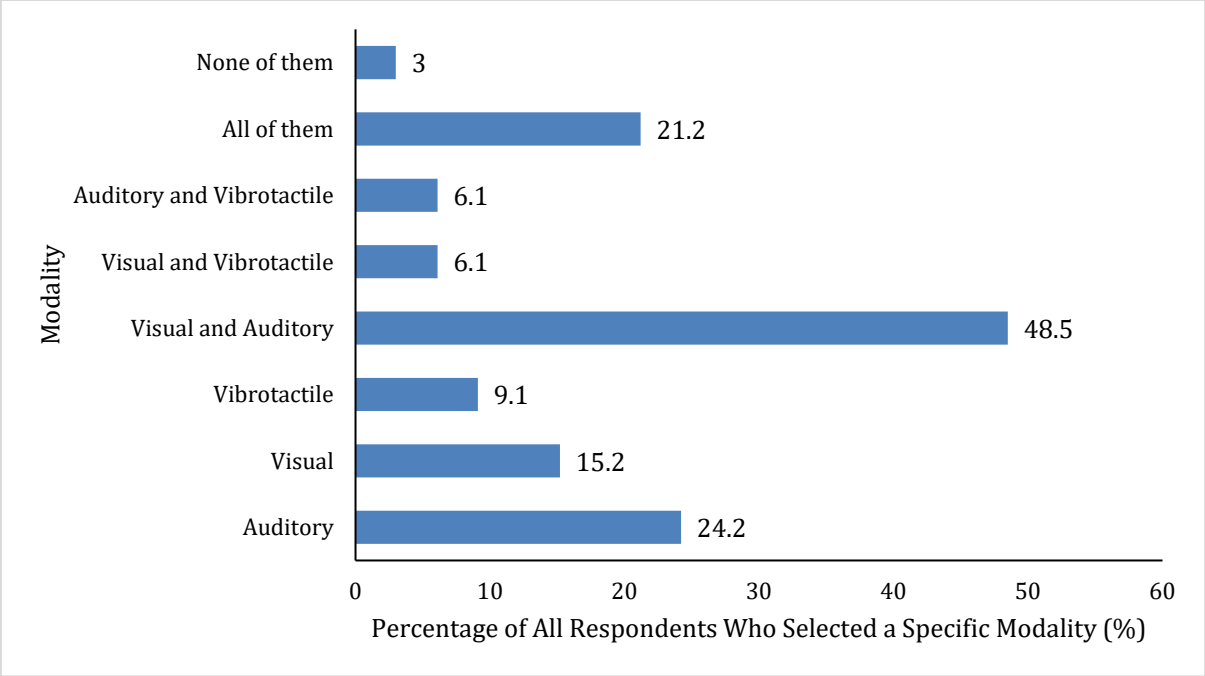

Figure 4: Officers' Preferred Sensory Modality to Receive Alerts

3.3 Correlation analysis

The significant correlations between different questions are shown in Table 5. 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".

Table 5: 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)

3.4 Responses to open-ended questions

Several questions were provided in the free response format in order to better retrieve individual opinions of participants. The notable results and implications for these questions are summarized in this section with the percentage of participants who reported the comments in the parenthesis.

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 blind spot information and cameras compromising 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 (Figure 2). This may reflect a strong desire of officers to have access to features they do not currently have access to.

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 requests from police officers to enhance existing ADAS features in police vehicles, included in 17.6% of responses. Specific examples officers cited include being able to enable and disable features such as front vehicle detection and lane assist easily, and clearly explaining 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?

Similar to question 3, 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, emergency braking systems, and blind spot monitoring 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 improve safety.

Question 19: Do you have any other suggestions to improve ADAS in police vehicles? Standardization of ADAS features and adaptability were cited as the most desired changes, comprising 27.8% and 10.7% of responses of those who responded affirmatively to this question respectively, though responses were more varied as 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 changed its settings based on the needs of the situation and police officers. 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 MCT interface and separate user interfaces for those ADAS features. This highlights a disparity between civilian drivers and police officers that creates a need for a unique approach to manufacturing and researching ADAS specifically designed for police vehicles.

4.0 Discussion

4.1 Survey Results Implications

A majority of officers (91.2%) indicated that there are several ADAS 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 that indicated that ADAS could be at least somewhat useful in pursuit situations and the 57.4% of surveyed officers that believed ADAS are helpful for improving driving safety and reducing crashes, a clear disconnect between officer ADAS use and their belief in its effectiveness is visible. In order to resolve this discrepancy, useful ADAS have to be identified and standardized to be used 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 the same 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 reduces 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 not sufficient. The easiest way to surmount this hurdle would be to design ADAS such that are intuitive 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 a clearer picture of which ADAS features are truly the most helpful for police officers would appear. Beyond this, 47.1% of officers indicated that they prefer a combination of visual and auditory alerts over single visual or auditory alerts and vibrotactile alerts for their police vehicles. Therefore, in order to improve ADAS access, manufacturers should take advantage of these multi-modal alerts.

4.2 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. (2018) 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 (2019) 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 in order 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 (FBI, 2009). In police pursuits, officers are engaged in hazardous situations, which require driving in high speed, close following behavior, sudden road maneuvers, and complex decision-making situations, which all can increase driver workload (Crundall et al., 2003). 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 is useful in pursuit situations and that ADAS improves attention to the road and surrounding environment. The findings are in line with the Hoyos et al. (2018) study that found 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 with civilian drivers when it comes to the effectiveness of exposure to ADAS on their willingness to use ADAS. Therefore, the way officers are informed of 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 in order to engage officer interest in ADAS while not appearing overwhelming or confusing.

4.4 Limitations

This study had some limitations. First, participants were recruited from police departments in the state of Texas. The findings might not directly be generalizable to agencies using different police vehicles. Second, many of the surveyed participants drove police vehicles that had a limited number of available ADAS. 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. Finally, 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 (Igbaria, 1995), 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.

4.5 Future Research and Recommendations

In order to encourage productive future research, several guidelines are presented here based on the results of this study. Though many general heuristics for vehicle ADAS design exist (e.g., Hansen, 2012; Inakagi, 2011; Nielsen, 1995; Stevens, 2002; Weinschenk & Barker, 2000) and our recommendations are by nature directly and indirectly tied to them, there are several key differences that separate police vehicles from civilian drivers and necessitate this more specific set of guidelines for future research and manufacturing. Our recommended guidelines emphasize

the heuristics that are most important for police officers rather than generalizing things for civilian drivers as a whole. These differences and the justification behind our proposed guidelines are elaborated on here.

Many guidelines that currently exist for designing ADAS for civilians emphasize the importance of reducing visual and auditory distractions in vehicles (Focus-telematics, 2006), which is not completely possible for police officers who have to complete multiple secondary tasks while driving to effectively carry out their job duties. As the officer is already going to be distracted by these secondary tasks, ADAS features for police vehicles have to be able to be quickly and effectively understood in a way that is intrusive enough to get the officer's attention when necessary so the officer can more safely accomplish secondary tasks that pull their attention away from the road. Another important distinction between current guidelines and what's presented here is the lower emphasis on training and training guidelines. As ADAS become more complicated and the issue of trust in ADAS continues to raise problems with its use, literature focused on describing how ADAS training should be carried out has grown (Manser, 2019). For police officers, however, the study found that the mental hurdles associated with extensive training can actually prevent officers from making full use of their ADAS features given how much they have to account for in their vehicles already. Thus, our guidelines put less emphasis on elaborating on extensive ADAS training or developing ADAS with more features and capabilities and more on intuitive, streamlined features that, though they might not be able to perform as many tasks as more complicated ADAS vehicles, will overall be more effective in encouraging use by police officers.

This is not to say that the presented guidelines go directly against all pre-existing heuristics for ADAS vehicle design. It has been shown through literature on modern vehicle design emphasizing the importance of designing safety features to account for the varying driving habits of users that there is a need for more specification in guidelines for drivers whose driving habits differ from the

average civilian (Happian-Smith, 2001). Police officers, by the nature of their profession, experience a higher workload while driving as compared to civilian drivers, meaning heuristics that may be established for design for civilian drivers will at least need to be justified for use for design of police officer vehicles.

Workload can be viewed as a direct source of stress from a job, caused by either the frequency of a task or the nature of the task itself (Stotland & Pendleton, 1989). Workload is a comprehensive organizational variable that can have many consequences on workers. Unfortunately, the workload of police officers has been found to be beyond the acceptable limits compared to other jobs (Sen, 2015). In addition, research on policing and stress suggests that police work is very stressful (Anderson et al., 2002). Sen (2015) conducted a survey study to evaluate police officers' workload. Results from 336 participants suggested that a majority of police officers have above normal workload perception (including heavy and unmanageable workload).

High workload is not the only differentiator between police officer and civilian drivers. Based on multiple resource theory, people have limited mental resources. If the task demands exceed resource capacity, information overload and degradations in task performance will occur, especially when the tasks compete for the same pool of attention (Wickens, 2008). Police officers are usually required to multitask when driving which leads to a higher workload as compared to civilian drivers who are not required to do non-driving related tasks. In addition, temporal demands placed on the officers due to the need for real-time information access and complexity of driving situations (e.g., driving in high speed and in pursuit conditions) can increase their workload as compared to the civilian drivers (Zahabi & Kaber, 2018).

To account for these differences between police officers and the general population, it is necessary to better advance the development of ADAS features to improve officer safety.

Therefore, the following list of guidelines has been determined in order 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 reasons cited by police officers with regard to situations 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 (Shupsky et al., 2020; Zahabi & Kaber, 2018). 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 the primary barriers towards using ADAS features for police officers. To combat this, researchers and manufacturers should focus on ADAS features, which 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 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 responders believed that ADAS can 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 (Shupsky et al., 2020; Zahabi and Kaber, 2018). The findings of this survey indicated that police officers might prioritize ADAS features with regards to avoiding collisions 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, which have 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. 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 to overcome the mental hurdles police officers face when taking on additional tasks while driving.

4.6 Conclusion

The objective of this study was to understand police officers' opinions on ADAS currently available in their vehicles as well as potential future ADAS. The findings helped to validate the authors' previously recommended ADAS features to be added in police vehicles while proposing

guidelines for future research to be conducted in the field. Several significant correlation results indicated that the perceived usefulness of ADAS features can be connected in some specific aspects to officer trust in ADAS features. This was expounded upon in the free response questions, where 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 that shift the needs of their proposed ADAS technologies as opposed to 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. If implemented, the guidelines proposed by this study have the potential to improve officers' and civilians' safety in police operations.

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References

Abdi, H. (2007). The Kendall rank correlation coefficient. *Encyclopedia of Measurement and Statistics. Sage, Thousand Oaks, CA*, 508-510.

Anderson, G. S., Litzenberger, R., & Plecas, D. (2002). Physical evidence of police officer stress. Policing: an international journal of police strategies & management.

Biassoni, F., Ruscio, D., & Ciceri, R. (2016). Limitations and automation. The role of information about device-specific features in ADAS acceptability. *Safety science, 85*, 179-186.

Barchéus, F. (2006). *Time analysis of ATC radio traffic in simulated free flight scenario.* Paper presented at the HFN conference on Human Factors and Economic Aspects on Safety.

B. J. Maguire, et al. (2002)."Occupational fatalities in emergency medical services: a hidden crisis," Annals of emergency medicine 40(6): pp. 625–632.

Biassoni, F., Ruscio, D., & Ciceri, R. (2016). Limitations and automation. The role of information about device-specific features in ADAS acceptability. *Safety science*, *85*, 179-186.

Bureau of Labor Statistics. “The Injuries, Illnesses, and Fatalities (IIF) program, Fatal Occupational Injuries to Emergency Responders,” December 5, 2019. Accessed on: March 6, 2020. [Online]. Available: https://www.bls.gov/iif/oshwc/cfoi/er_fact_sheet.htm

Cicchino, J. B. (2017). Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates. *Accident Analysis & Prevention, 99*, 142-152.

Cicchino, J. B. (2018). Effects of blind spot monitoring systems on police-reported lane-change crashes. *Traffic injury prevention, 19*(6), 615-622.

Coughlin, J.F., D'Ambrosio, L.A., Eds. (2012). Aging America and Transportation: Personal Choices and Public Policy. New York: Springer Publishing Company.

Crundall, D., Chapman, P., Phelps, N., & Underwood, G. (2003). Eye movements and hazard perception in police pursuit and emergency response driving. *Journal of Experimental Psychology: Applied*, 9(3), 163.

Dai, J., Li, R., & Liu, Z. (2020). Does initial experience affect consumers’ intention to use autonomous vehicles? Evidence from a field experiment in Beijing. *Accident Analysis & Prevention*, *149*, 105778

Davidse, R. J. (2006). Older drivers and ADAS: Which systems improve road safety?. *IATSS research*, *30*(1), 6-20.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, 319-340.

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management science*, *35*(8), 982-1003.

Federal Bureau of Investigation (FBI) (2009). Law enforcement officers killed and assaulted, 2008. Accessed on: March 6, 2020 Retrieved from https://ucr.fbi.gov/ leoka/2008

Federal Bureau of Investigation (FBI) (2020). Law enforcement officers killed accidentally. Accessed on: March 6, 2020 https://ucr.fbi.gov/leoka/2019/topic-pages/tables/table-65.xls

Focus-telematics, D. (2006). Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication Systems Including.

Frey, B. B. (Ed.). (2018). The SAGE encyclopedia of educational research, measurement, and evaluation. Sage Publications.

Ghazizadeh, M., Lee, J. D., & Boyle, L. N. (2012). Extending the Technology Acceptance Model to assess automation. *Cognition, Technology & Work*, *14*(1), 39-49.

Gietelink O, Ploeg J, De Schutter B, Verhaegen M. Development of advanced driver assistance systems with vehicle hardware-in-the-loop simulations. Vehicle System Dynamics. 2006;44(7):569-90.

Gregg, A. (2019). *Autonomous Police Vehicles: The Impact on Law Enforcement*. Naval Postgraduate School Monterey United States.

Hansen, J. H., Boyraz, P., Takeda, K., & Abut, H. (Eds.). (2012). *Digital signal processing for in-vehicle systems and safety* (p. 149). New York: Springer.

Happian-Smith, J. (Ed.). (2001). *An introduction to modern vehicle design*. Elsevier.

Hoff, K. A., & Bashir, M. (2015). Trust in automation: Integrating empirical evidence on factors that influence trust. *Human factors*, *57*(3), 407-434.

Hoyos, C., Lester, B. D., Crump, C., Cades, D. M., & Young, D. (2018, September). Consumer perceptions, understanding, and expectations of Advanced Driver Assistance Systems (ADAS) and vehicle automation. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 62, No. 1, pp. 1888-1892). Sage CA: Los Angeles, CA: SAGE Publications.

Igbaria, M., & Iivari, J. (1995). The effects of self-efficacy on computer usage. *Omega*, *23*(6), 587-605.

Inagaki, T. (2011). Technological and legal considerations for the design of interactions between human driver and advanced driver assistance systems. In *Proc. NeTWork Workshop: Control and Accountability in Highly Automated Systems*.

Khastgir, S., Birrell, S., Dhadyalla, G., & Jennings, P. (2018). Calibrating trust through knowledge: Introducing the concept of informed safety for automation in vehicles. *Transportation research part C: emerging technologies*, *96*, 290-303.

Kidd, D. G., Cicchino, J. B., Reagan, I. J., & Kerfoot, L. B. (2017). Driver trust in five driver assistance technologies following real-world use in four production vehicles. *Traffic injury prevention, 18*(sup1), S44-S50.

Koustanaï, A.; Cavallo, V.; Delhomme, P. (2012). Simulator training with a forward collision warning system: Effects on driver-system interactions and driver trust. In: Human Factors: The Journal of the Human Factors and Ergonomics Society, Oct 2012; vol. 54 (5), 709-21.

Kusano, K. D., & Gabler, H. C. (2011). *Potential Effectiveness of Integrated Forward Collision Warning, Pre-collision Brake Assist, and Automated Pre-collision Braking Systems in Real-world, Rear-end Collisions.* Paper presented at the 22st International Technical Conference on the Enhanced Safety of Vehicles (ESV 2011).

Lambert, D. (2016). Attributes of Police Vehicle Crashes.

Lee, C., Seppelt, B., Reimer, B., Mehler, B., & Coughlin, J. F. (2019). *Acceptance of Vehicle Automation: Effects of Demographic Traits, Technology Experience and Media Exposure.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Lee, J. D., & See, K. A. (2004). Trust in automation: Designing for appropriate reliance. *Human factors, 46*(1), 50-80.

Lund, A. K. (2013). Drivers and Driver Assistance Systems: How Well do They Match?

Manser, M. P., Noble, A. M., Machiani, S. G., Shortz, A., Klauer, S. G., Higgins, L., & Ahmadi, A. (2019). Driver training research and guidelines for automated vehicle technology.

Mayer, R. C., J. H. Davis, and F. D. Shoorman. An Integrative Model of Organizational Trust. Academy of Management Review, Vol. 20, 1995, pp. 709–734.

Najm, W., Stearns, M., Howarth, H., Koopmann, J., & Hitz, J. S. (2006). *Evaluation of an automotive rear-end collision avoidance system* (No. FHWA-JPO-06-055). United States. Department of Transportation. National Highway Traffic Safety Administration.

National Safety Council. “NSC analysis of NHTSA 2017 and 2018 FARS data and Traffic safety facts annual report tables.” Accessed on: March 6, 2020 from: https://cdan.nhtsa.gov/tsftables/tsfar.htm

Nasr, V., Wozniak, D., Shahini, F., & Zahabi, M. (2021, January 25-29). Application of Advanced Driver-Assistance Systems in Police Vehicles [Paper presentation]. In *Proceedings of Transportation Research Board Annual Conference*, Washington, DC.

Nielsen, J. (1995). How to conduct a heuristic evaluation. Nielsen Norman Group, 1, 1-8.

Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human factors, 39*(2), 230-253.

Portouli, V., Bekiaris, E., Boets, S., & Henriksson, P. (2008). *Comparative evaluation of training methods in improving drivers' understanding about the functionalities and potential limitations of ADAS.* Paper presented at the Proceedings of European Conference on Human Centred Design for Intelligent Transport Systems.

Reimer, B., Mehler, B., & Coughlin, J. F. (2010). An evaluation of driver reactions to new vehicle parking assist technologies developed to reduce driver stress. *Cambridge: New England University Transportation Center, Massachusetts Institute of Technology*.

Scherer, R., Siddiq, F., & Tondeur, J. (2019). The technology acceptance model (TAM): A meta-analytic structural equation modeling approach to explaining teachers' adoption of digital technology in education. *Computers & Education*, *128*, 13-35.

Sen, Y. F. (2015). A Research on Workload Perception of the Police Officer; The Case Study of Erzurum Police Department in Turkey. IJAR, 1(11), 241-244.

Shupsky, T., Lyman, A., He, J., & Zahabi, M. (2020). Effects of Mobile Computer Terminal Configuration and Level of Driving Control on Police Officers' Performance and Workload. *Human factors*, 0018720820908362.

Stotland, E., & Pendleton, M. (1989). Workload, stress, and strain among police officers. Behavioral Medicine, 15(1), 5-17.

Stevens, A., Quimby, A., Board, A., Kersloot, T., & Burns, P. (2002). Design guidelines for safety of in-vehicle information systems. *TRL Limited*.

Sullivan, G. M., & Feinn, R. (2012). Using effect size—or why the P value is not enough. *Journal of graduate medical education, 4*(3), 279-282.

Tiesman, H. M., & Heick, R. J. (2014). Law enforcement officer motor vehicle safety: findings from a statewide survey.

Weinschenk, S., & Barker, D. T. (2000). *Designing effective speech interfaces*. John Wiley &

Sons, Inc..

Wickens, C. D. (2008). Multiple resources and mental workload. Human factors, 50(3), 449-455.

Wu, X., Boyle, L. N., Marshall, D., & O'Brien, W. (2018). The effectiveness of auditory forward collision warning alerts. *Transportation research part F: traffic psychology and behaviour, 59*, 164-178.

Xu, C., Wang, W., Chen, J., Wang, W., Yang, C., & Li, Z. (2010). Analyzing travelers' intention to accept travel information: structural equation modeling. *Transportation Research Record, 2156*(1), 93-100.

Zahabi, M., & Kaber, D. (2018). Effect of police mobile computer terminal interface design on officer driving distraction. *Applied ergonomics*, 67, 26-38.

Zaiontz, C. (2014). Wilcoxon Rank Sum Test for Independent Samples. *Real Statistics Using Excel*.https://www.real-statistics.com/non-parametric-tests/wilcoxon-rank-sum-test/