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FIELD OPERATIONAL TEST OF ADVANCED DRIVER ASSISTANCE SYSTEMS IN TYPICAL CHINESE ROAD CONDITIONS: THE INFLUENCE OF DRIVER GENDER, AGE AND AGGRESSION

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ABSTRACT−Although various Advanced Driver Assistance Systems (ADASs) have been developed to assist drivers, their performances and driver acceptances in China have not been well tested and analyzed. This study aims to examine how do driver gender, age, and aggression affect the performances and driver acceptances of typical ADASs by means of Field Operational Tests (FOTs), including FCW (Forward Collision Warning), LDW (Lane Departure Warning), and SBZA (Side Blind Zone Alert). Thirty-three participants were recruited to drive an equipped vehicle on the test route in and around Beijing City. Vehicle states, environmental information, and driver feedback were recorded by CAN bus, cameras, and post-drive questionnaires. The test results showed that the alert frequencies of FCWs and LDWs increase in higher speed traffic scenarios, whereas that of SBZA declines. Driver acceptance rate of SBZA ranks the highest, with FCW ranking the second and LDW being the last. Driver gender, age, and aggression effects were analyzed in details, showing their relationships with total alert times, alert times per 100 km, and driver acceptance rate of each system. The findings are helpful for future development of ADASs for automotive industry.

KEY WORDS : ADASs performance, Driver acceptance, Gender, Age, Driver aggression, Field operational test

1. INTRODUCTION

Rear-end, angle and sideswipe crashes accounted for 32.2%, 22.7% and 9.8% of all road crashes in the US in 2010, respectively (NHTSA, 2012). The numbers were 40.4%, 6.6% and 4.1% for highway crashes in China in the same year (Ministry of Public Security Traffic Management Bureau, 2011). To improve road safety, various Advanced Driver Assistance Systems (ADASs) were developed to provide drivers specific features, e.g., Forward Collision Warning (FCW) system, Lane Departure Warning (LDW) system, and Side Blind Zone Alert (SBZA) system. The potential functionality of ADAS on reducing road crashes has been recognized by both automotive industry and academia. In the NHTSA research priority plan for 2011 ~ 2013 (NHTSA, 2011), FCW is in the list of Priority Projects, and the other two systems (LDW and SBZA) are included in the list of Other Significant Projects.

From an operational point of view, the development of such systems clearly departs from traditional driving tasks at all times (Piao and McDonald, 2008). Instead, ADASs could help or replace drivers on some decisions and actions. This makes it possible to eliminate many pre-accident human errors and achieve more benefits on driving safety and fuel economy than before.

FCW is developed to alert a driver to avoid or mitigate the imminent collision with an obstacle ahead of the subject vehicle. Based on laser or radar technologies, FCW can measure inter-vehicle distance, angular position, and relative speed with the target vehicle ahead, and alert drivers in various visual/audio/haptic ways (Jeong and Green, 2012). Some enhanced systems, to further assist drivers, have additional functions to support and substitute drivers to control the brake (Floudas *et al*., 2004; Shaout *et al*., 2011; Oikawa *et al*., 2014). Wandering out of the current lane may result in severe collisions with vehicles in adjacent lanes. To reduce this type of crashes, LDW is developed to help avoid departure dangers. Embedded with a camera to recognize lane markers, LDW is activated to present warnings when an unintended lane departure is recognized. Steering wheel vibration and/or slight automatic correction may also be provided when needed in some systems (Suzuki and Jansson, 2003). SBZA provides another kind of lateral movement assistance to help drivers avoid lane change crashes. Typically using ultrasonic radar technology to detect vehicles in side blind zones, SBZA alerts drivers to prevent crashes primarily caused by “did not see other vehicles” when planning a lane change maneuver. Besides the most common visual and audio alerts, assistance in steering has also been available in some

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products (Shaout *et al.*, 2011).

It has been found that crashes can be effectively avoided or mitigated if the interference strategies of ADASs are provided correctly and properly. For example, according to an investigation conducted by National Transportation Safety Board, 60% of rear-end crashes could be avoided if an FCW alarm was given 0.5 second ahead, and around 90% of rear-end accidents could be avoided if the alarm could be given 1.5 seconds ahead (National Transportation Safety Board, 2001). Lee and Jeong (2014) proposed a method to generate warnings at different times according to the driving peopensity determinded by three metrics, including predicted time headway, required deceleration, and resultant acceleration. Properly activated warnings to avoid crashes were verified on both test groud and public roads. It is estimated by some case studies that ADASs can prevent up to 40% of traffic accidents, varying across system types and accident scenarios (Zador *et al.*, 2000; Jagtman *et al.*, 2001; Golias *et al.*, 2002). Although the original purpose of ADASs is to affect traffic safety positively, negative effects have been found as well (Lindgren and Chen, 2006; Dragutinovic *et al.*, 2005; Saad, 2004; Brookhuis *et al.*, 2001). Driver's reaction delay and false alert nuisance are reported most (Brookhuis *et al.*, 2001). Accordingly, driver trust and acceptance of ADASs vary across drivers depending on both their performance and driver characteristics (Lindgren and Chen, 2006).

Many Field Operational Tests (FOTs) have been conducted to evaluate ADASs performances and to examine their driver acceptance. Alkim *et al.* (2007) carried out an FOT to perform an objective assessment on ACC (Adaptive Cruise Control) and LDW, and found a promising result that driving with ACC and LDW could improve traffic safety with approximately 8% reduction on time headway and 3% improvement on fuel economy. Adell *et al.* (2011) examined the effects of the driver assistance system on keeping safe distance and speed. The findings showed both positive and negative effects in terms of safety concerns. Considering driver gender and age, Najm *et al.* (2006) conducted a test to characterize the performance and to determine driver acceptance of an FCW. Results showed that older driver group were more willing to rent or purchase an FCW-equipped vehicle than younger groups. Ervin *et al.* (2005) conducted a test to examine the suitability of an FCW from the perspectives of both driving safety and driver acceptance. Results indicated that the acceptance of FCW was mixed due to false alarms and was not found to be significantly related to FCW alert rate. Similar tests were carried out on other types of FCW, SBZA, and LDW (LeBlanc *et al.*, 2006; Sayer *et al.*, 2011). Besides FOTs, Lee and Peng (2005) developed an alternative method to identify 'threatening' and 'safe' data sets and used it to evaluate the performance of five published collision warning systems by simulations.

Driver characteristics can significantly affect the ADAS performance and driver acceptance. It has been found that driver gender and age made independent significant contributions to traffic accident involvement (Reason *et al.*, 1990), thus leading to diversities on ADASs performance and subjective acceptance across gender and age groups (Najm *et al.*, 2006; LeBlanc *et al.*, 2006; Sayer *et al.*, 2011). Besides gender and age, driver aggression is another important factor needs to be considered (Xie and Parker, 2002). Self-report questionnaire is a most popular way to investigate drivers' aggression. Buss and Perry (1992) proposed an aggression questionnaire to measure people's physical aggression, verbal aggression, anger, and hostility. Correlation analysis results showed that anger is the bridge between each two of the other three scales. Specifically for driving anger scale, Deffenbacher *et al.* (1994) measured how much a driver would be irritated by driving-related situations. Since China has a booming automotive industry, and Chinese drivers behave differently with drivers abroad (Zhang *et al.*, 2006; Li *et al.*, 2010), it is important to know how ADASs work in typical Chinese road conditions. To date, although many studies have been reported in China, few FOT attempts in naturalistic traffic flow have been made.

The purpose of this paper is to conduct an FOT in typical Chinese road conditions to examine how do driver gender, age, and aggression affect the performances and driver acceptances of three commonly used ADASs, including FCW, LDW, and SBZA. The remainder of this paper is structured as follows: Section 2 describes details of the experiments, including data collection system, test route design, and participants' information; Section 3 presents the affection of driver gender, age, and aggression on ADASs performances and driver acceptances; Section 4 discusses the test results and summarizes the flaws needed to be improved for future ADAS development; Section 5 concludes this paper.

2. METHODOLOGY

2.1. ADASs Equipped in the Test Vehicle

The test vehicle used in this study is a passenger car with a 4.6L internal combustion engine and a 5-speed automatic transmission. Equipped ADASs include FCW, SBZA, and LDW. Both visual and auditory warnings are provided in all three systems. The FCW is automatically functional to use radars to detect target vehicles when the subject vehicle speed exceeds 32 km/h (20 mph). When a vehicle is detected, a green-car-icon will be displayed on a screen mounted on the upright side out of the dashboard. Cautionary alerts, indicated by a yellow-car-icon, will be visually presented to the driver when the following distance is closer. Consisted of a red-collision-icon and a buzzing sound, crash imminent alerts will be presented when the following distance is too close. The LDW is activated when the speed is higher than 56 km/h (35 mph) and at least one side of lane markers is detected. The camera used to detect lane markers is mounted near the rearview mirror.

When lane marker is detected, a green icon will be displayed on the dashboard. The color will change to red and flash with low buzzing sound when the driver departs the lane without using turning signal. The SBZA uses radars to detect vehicles 5 m behind rearview mirrors in adjacent lanes. An icon will be displayed in the rearview mirror when a vehicle in the side blind zone is detected. Meanwhile, if a driver intends to move to the next lane without using turning signal, the icon will flash with a displayed arrow.

Table 1. Participants information.

	Participant number	Age		Driving experience	
		Mean	*SD*	*Mean*	*SD*
All	33	43.9	10.8	14.2	7.7
Male	22	45.0	11.1	16.0	8.2
Female	11	41.7	10.2	10.4	5.0

2.2. Test Route

Considering the affection of traffic situations on different road types, the test route in and around Beijing (between Tsinghua University in Beijing and Xianghe in Hebei province) was selected for experiments. As shown in Figure 1, city roads (*a*), city expressways (*b*), and inter-city highways (*c*) were included, totally about 225 km. Total distance of section *a* was about 23 km and the speed limits varied from 30 to 60 km/h. The fourth ring-road, marked as *b* in Figure 1, was selected as city expressways. The total distance was about 56 km and the speed limit was 80 km/h. A section of Beijing-Harbin highway, marked as *c* in the figure, was selected as inter-city highways. The total distance was about146 km and the speed limit was 120 km/h.

Participants were given route guidance instructions verbally by an experiment assistant present in the vehicle all the time in the experiment. This was provided to ensure all drivers received the same instructions according to a predetermined script. All participants drove the same instrumented vehicle throughout the study.

2.3. Data Collection System

Six cameras were installed in the test vehicle to record the road situations (channel *A*: front road image, channel *E*: left blind zone, and channel *F*: right blind zone), driver status and operations (channel *C*: face image, channel *D*: foot image), and warning system status (channel *B*: FCW warning status). This image collection system saved images into a hard-disk recorder at 25 Hz. Another camera (camera *G*) was equipped to record the front road images for data synchronization. See Figure 2 for the architecture of the data collection system and Figure 3 for an example of the collected images. Recorded CAN bus data include variables about vehicle state, driver operation and warning system alert timing. Figure 4 shows a sample of the collected CAN bus data. This data acquisition system saves both CAN bus data and channel *G* images at 10 Hz into a laptop. To synchronize data, channel *A* images were used to match the front road images captured by channel *G*.

2.4. Participants

The following criteria were required for participants:
(1) Driver age must be between 20 and 65.

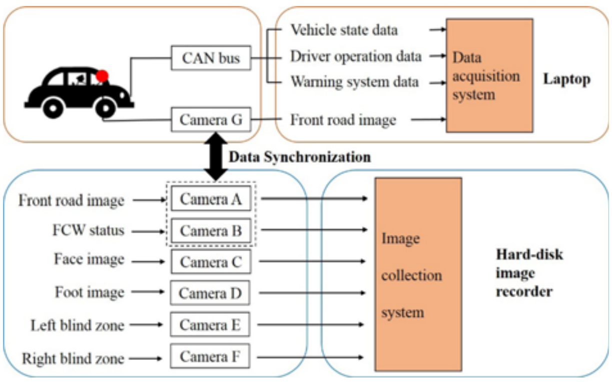

Figure 2. Data collection system architecture.

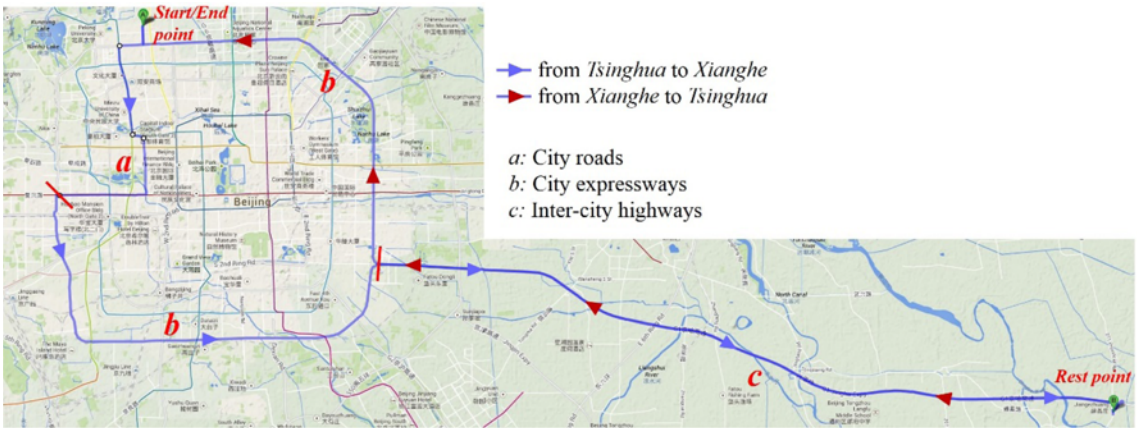

Figure 1. Selected test route in and around Beijing.

Figure 3. Example of the images and warning system data.

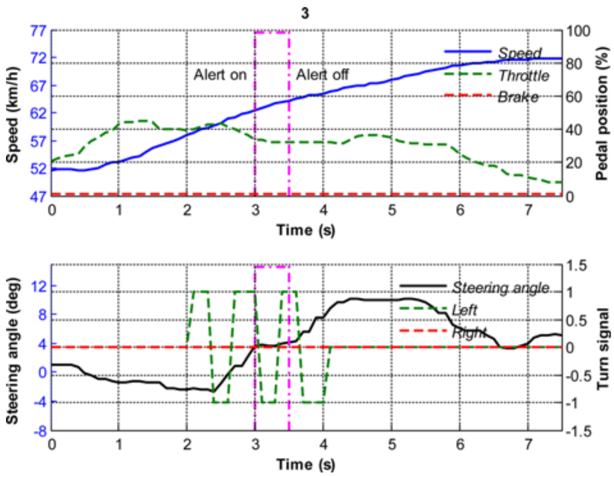

Figure 4. Example of the CAN bus data.

(2) Driving experience should be no less than 2 years.
(3) The driver must have his/her own car.
(4) The driver should not have previous driving experience with ADASs.

Note that the last criterion was required to avoid interference on driver behaviors and subjective ratings from his/her previous driving experience.

Finally, thirty-three participants (22 male and 11 female) were recruited to take part in this study, with an accumulation of 7,500 km of driving. Their age ranged from 28 to 65 years old (*Mean* = 43.9, *SD* = 10.8). On average, they had 14.2 years driving experience, ranging from 3 to 33 years (*SD* = 7.7). Detailed information about the male and female participants can be found in Table 1.

2.5. Procedure

A set of training was provided prior to starting the FOT. They were given a verbal explanation on what they need to do and what would happen during the experiment. To get used to the systems, a video on how the ADASs work was exposed to the participants as well to help them better understand their capabilities and limitations. The assistant would check the working status of the vehicle, data acquisition system and image collection system before starting the experiment. It would roughly take about 80 minutes to drive from the start point to the rest point. Drivers could take a break at the rest point, and then it would take another 80 minutes to drive back to the end point.

After the experiment, subjective data were collected through a simple questionnaire as well as an interactive debriefing that was done to collect drivers' advice on systems improvement. All the three statements listed in the questionnaire were *I am satisfied with the FCW/SBZA/LDW*, specifically. Using Likert Scale (Joy, 2007), subjects were asked to rate a value from *1* to *5* indicating how much they agree with each of the statements, with *1* representing *Strongly disagree* and *5* representing *Strongly agree*.

Another questionnaire was also presented to drivers to investigate their driving aggression level. This questionnaire was mainly developed from two previous studies (Buss and Perry, 1992; Deffenbacher *et al.*, 1994), and was split into three sections: driver characteristics, driving environments, and driver preferences. Subjects were required to rate each item shown in Table 2 in terms of how characteristic they were of the subject himself/herself (for driver characteristics and driver preferences questions) or how likely would a specific traffic situation irritate the driver to be angry (for driving environment questions). Seven-level Likert Scales were adopted. The sum of all the rating scores came up to a driver's aggression score. The higher the number was, the more aggressive the driver would probably be. Cronbach's alpha was adopted to evaluate the internal consistency of the scale scores (Cronbach, 1951). The alpha values for driver characteristics, driving environments, and driving preferences scales were 0.76, 0.88, and 0.83, respectively. See Table 3.

Table 2. Driver aggression questionnaire.

		Questions
Driver characteristics	1	My friends say that I'm somewhat argumentative.
	2	I tell my friends openly when I disagree with them.
	3	I can't help getting into arguments when people disagree with me.
	4	I get into fights a little more than the average person.
	5	I have trouble controlling my temper.
	6	I have become so mad that I have broken things.
Driving environments	7	Someone starts moving late, when the traffic light signalizes green.
	8	Cyclist is cycling in the middle of the lane and slowing the traffic.
	9	Someone drives very slowly in the fast left lane and you want to overtake.
	10	Someone is pushing on the back of your car (e.g., wants to force the release of the lane).
	11	Someone cuts in front of you for the parking place you are waiting for.
	12	Someone drives between lanes and blocks your way.
	13	Someone is reversing in front of you without looking back.
	14	Someone in the opposite direction does not dim his/her lights.
	15	Someone increasing the vehicle speed when you are trying to overtake hem/her.
	16	Someone made inappropriate gestures to you because of your style of driving.
Driver preferences	17	I like driving faster than others.
	18	I start earlier than others when the traffic light turns to green.
	19	I brake harder than others.
	20	I change lanes in a shorter time than others.
	21	I follow a lead vehicle closer than others.
	22	I like to drive as I want for sensation seeking (e.g., drag racing).
	23	I think my driving skill is better than the average level.
	24	I think I am an aggressive driver.

3. RESULTS AND ANALYSIS

Thirty-three participants drove a total of about 7,500 km during the FOTs. The data collection system did not work well in two of the tests. Besides, another driver did not take the aggression questionnaire seriously, filling 67% of the questions with the most negative answer which did not match his driving image record at all, so that his data was eliminated in the analysis concerning driver aggression. The analysis of variance (*F*-test) is used when the normality and homoscadicity requirements are satisfied. Otherwise, a nonparametric test (Kruskal-Wallis one-way analysis of variance) is used to test whether the results originate from the same distribution.

Table 3. Means, standard deviations, and alpha reliability coefficients for three driver aggression scales.

	Number of items	*Mean*	*SD*	*α*
Driver characteristics	6	1.68	0.50	0.76
Driving environments	10	3.05	0.97	0.88
Driver preferences	8	2.39	0.93	0.83

Table 4. Significance test results of ATPK.

	City roads	City expressways	Inter-city highways	*p*
FCW ATPK	0.0	2.7	5.3	< 0.001
SBZA ATPK	44.9	29.0	5.6	< 0.001
LDW ATPK	14.5	29.6	39.1	< 0.001

3.1. Overall ADASs Performance and Driver Acceptance

Concerning the overall performance of ADASs, three drivers did not receive any FCW alert during the driving back and forth. The mean alert times per driver for FCW, SBZA, and LDW were 9.8 (*SD*=10.8), 37.1 (*SD*=21.0), and 92.2 (*SD*=62.5), respectively.

To further analyze ADASs alert frequency in various traffic situations, alert times per 100 km for each driver (referred to as ATPK) was used as an evaluation index. As shown in Figure 5, almost no FCW alerts occurred on city roads. That is because the FCW would only be triggered to be functioned when vehicle speed was higher than 32 km/h. However, heavy traffics on selected city roads forced vehicle speed to be under 32 km/h most of the time. For city expressways and inter-city highways, analysis on speed distributions indicated that driving speed ranged from 50 to 75 km/h and from 105 to 120 km/h individually, aligning with the posted speed limits. Thus, indicated by Figure 5, higher speed would contribute to more FCWs and LDWs,

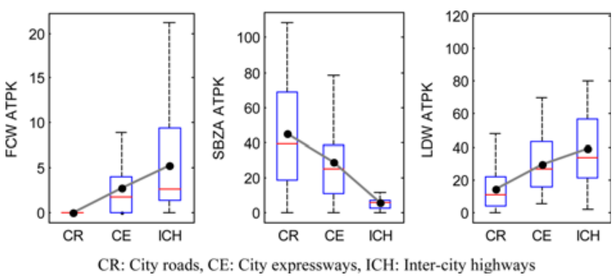

Figure 5. Overall ATPK in different traffic situations.

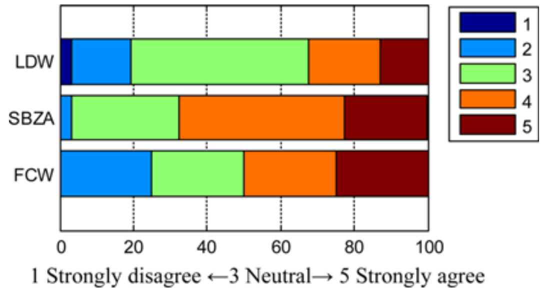

Figure 6. General driver acceptance of each system.

but less SBZAs. Statistical significances were found for all systems. See Table 4. The mean differences between each two traffic situations were also proved to be significant ($p < 0.05$) in pairwise comparisons tests.

The mean subjective ratings on the SBZA were 3.9 (*SD*=0.6), compared to 3.2 (*SD*=2.3) on the FCW and 3.2 (*SD*=1.0) on the LDW. Define driver acceptance rate here as the percentage that a driver rates a system as *4* or *5*. As shown in Figure 6, drivers never scored FCW or SBZA as *1*. Although LDWs were received far more frequently than any of the other two kinds of warnings, it got the lowest acceptance rate (32.3%). The FCW and SBZA got an acceptance rate of 50.0% and 67.7%, respectively.

3.2. Gender

The alert times per driver of each warning system were shown in Figure 7. On average, male drivers triggered 162% more FCWs than female drivers, but 25% fewer LDWs. The more FCW alert times for male drivers (*p*= 0.065) is probably because male drivers tend to drive more aggressively than female drivers in hazardous situations (e.g., driving through heavy traffic) and in dangerous ways (e.g., rapidly approaching and closely following). SBZAs did not vary much between genders (Male: 31.8, Female: 33.8).

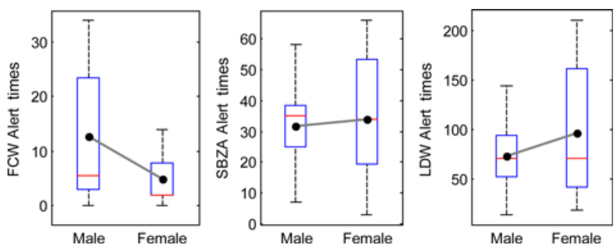

Figure 7. Alert times per driver as a function of driver gender.

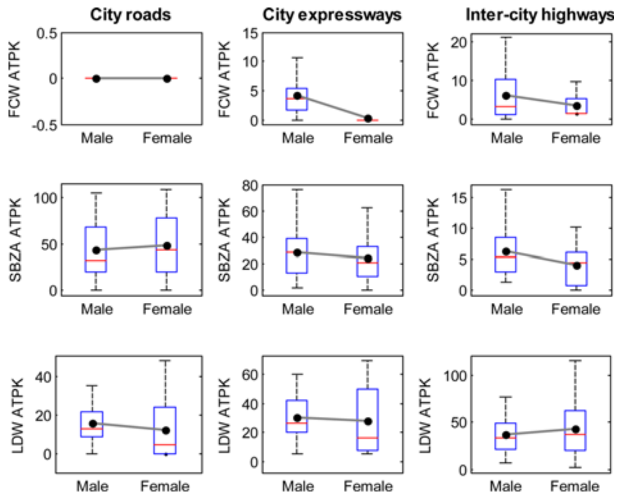

Figure 8. ATPK in different traffic situations as a function of driver gender.

As illustrated in Figure 8, ADAS ATPK as a function of driver gender varies across traffic situations. When comparing FCW ATPK between males and females on city expressways, the former showed a higher probability to trigger FCWs. Statistical significance was found (*p*= 0.005). The observed mean FCW ATPK for females on city expressways was 0.4 (*SD*=0.8) compared to 4.2 (*SD*=4.0) for males. Similar trend was shown for FCW ATPK on inter-city highways. No significant differences were found for SBZA ATPK and LDW ATPK.

Female drivers viewed each system more positively than male drivers in general. The acceptance levels male drivers ascribed to FCW, SBZA, and LDW were at an average of 3.4 (*SD*=1.1), 3.7 (*SD*=0.7), and 3.1 (*SD*=0.9), respectively, while female drivers rated them at an average of 3.7 (*SD* =1.2), 4.3 (*SD*=0.8), and 3.5 (*SD*=1.1). Significance was found for SBZA (*p*=0.042). The observed acceptance rate

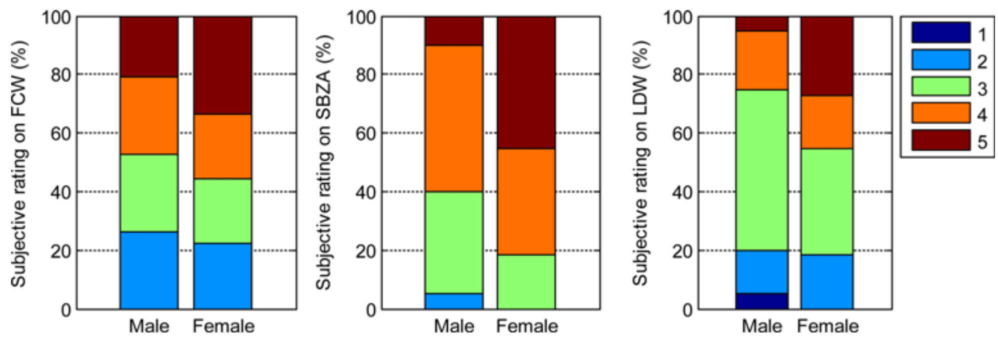

Figure 9. Driver acceptance as a function of driver gender.

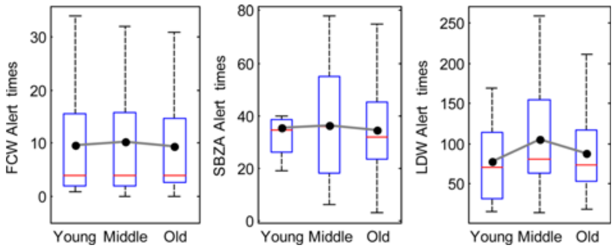

Figure 10. Alert times per driver as a function of driver age.

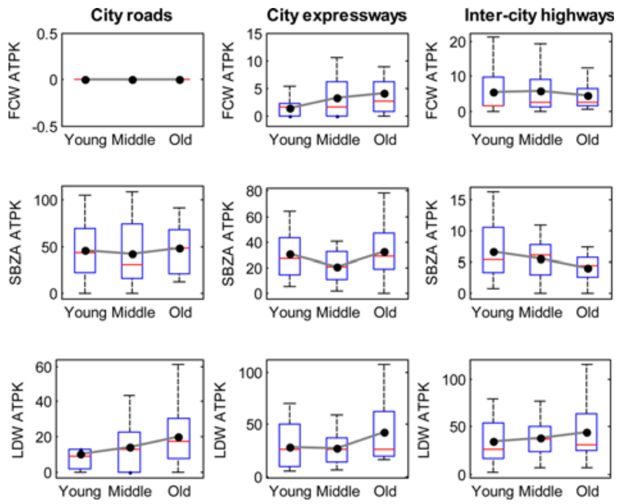

Figure 11. ATPK in different traffic situations as a function of driver age.

of SBZA for females was 82%, 22% higher than that for males. Similarly, females rated FCW and LDW 9% and 20% higher than males, respectively. See Figure 9.

3.3. Age

According to their age, subjects were divided into three groups: young (21 to 35 years old), middle (36 to 50 years old), and old (51 to 65 years old). The mean age for each group was 30.3 (*SD*=2.9), 41.9 (*SD*=3.7), and 57.9 (*SD*= 2.8), respectively. As indicated in Figure 10, the total alert times per driver did not vary much across age groups. LSD test was adopted to examine statistical significances between each two of the groups and no significance was found.

No consistent trend of ATPK as a function of driver age was found for the systems. Considering ADASs performances in specific traffic situations, older drivers had lower SBZA ATPK than younger drivers on inter-city highways. See Figure 11. Besides, it seems that older drivers received more FCWs on city expressways and more LDWs on city roads and inter-city highways, which needs further verifications.

As indicated in Figure 12, FCW acceptance differed among drivers due greatly to driver age (p=0.027). Younger drivers favored FCW more than older drivers. Significant difference were found to strengthen this finding (young and old: p=0.038). In the evaluations of all the three systems, young drivers' acceptance rate ranked the highest among the age groups. In general, SBZA got the highest evaluation score among the three systems in any age group.

3.4. Driver Aggression

According to their aggression scores, subjects were divided into three groups: prudent (0 to 55), moderate (56 to 70), and aggressive (71 to 90). No one got a score higher than 90. The mean aggression score for each group was 33.9 (*SD*=16.1), 61.5 (*SD*=3.3), and 79.1 (*SD*=6.5), respectively.

As expected, male drivers (*Mean*=65.9, *SD*=18.5) were more aggressive than female drivers (*Mean*=48.9, *SD*= 21.4). Statistical significance was found between genders (F(1,28)=5.231, p=0.030). This finding was consistent with the results found by Reason *et al.* (1990). Considering driver age, people tended to be more prudent as their age increased (F(2,27)=1.269, p=0.297), consistent with the results found by Lajunen and Parker (2001). The mean aggression scores for young, middle, and old groups were 64.1 (*SD*=16.2), 63.2 (*SD*=19.2), and 50.4 (*SD*=26.2), respectively.

The relationships between ADASs performance and driver aggression index varied across systems. The overall performance of FCW showed that alert times increased with driver aggression level (p=0.120). Unlike FCW, both SBZA and LDW alert times had poorer correlation with driver aggression levels. See Figure 13.

When comparing FCW ATPK across aggression groups,

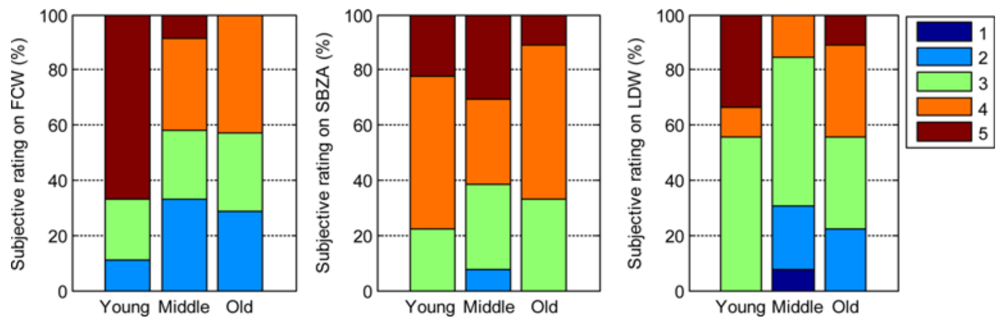

Figure 12. Driver acceptance as a function of driver age.

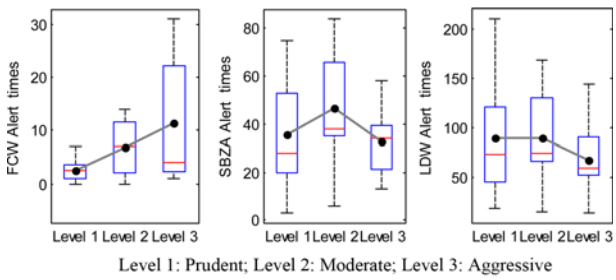

Figure 13. ADASs performance as a function of driver aggression.

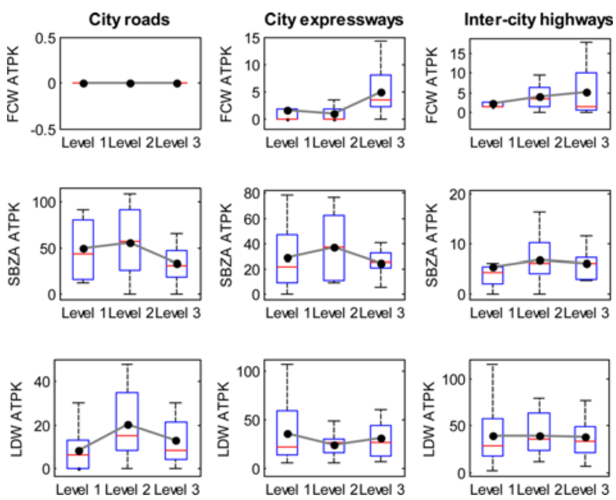

Figure 14. ATPK in different traffic situations as a function of driver aggression.

aggressive drivers triggered FCW more frequently than the other two groups. See Figure 14. The mean FCW ATPK on city expressways were 1.6 (*SD*=3.1), 1.0 (*SD*=1.3), and 4.3(*SD*=1.3) for prudent, moderate, and aggressive drivers respectively. The values were 2.2 (*SD*=1.4), 4.0 (*SD*=3.4), and 5.3 (*SD*=5.9) on inter-city highways. Statistical significance was found on city expressways (p=0.003). Multiple comparison results presented more details (prudent and moderate: p=1.000; prudent and aggressive: p=0.021; moderate and aggressive: p=0.007). No significance was found for either SBZA or LDW.

As indicated in Figure 15, prudent drivers' acceptance rate was the highest among the aggression groups in the evaluation of any ADAS. Differences between moderate and aggressive groups did not consist across the subjective rating on ADASs. No statistical significance was found.

4. DISCUSSIONS

4.1. Driver Acceptance and Driver Age

Consistent with the result found in this study, Ervin *et al.* found that FCW acceptance differed among drivers due largely to age, but contrarily, what Ervin *et al.* (2005) found was older drivers viewed the FCW more favorably than either middle or young drivers. As noted in this study, drivers can change sensitive setting of the FCW and it was found that older drivers preferred the most-sensitive setting significantly more frequently than the other two groups did. However, the evaluated FCW in this study shared the same algorithm across all subjects. When the FCW could not meet older drivers' expectations, they may fully get back to rely on their accumulated driving experience and take the additional alerts as nuisances. This may be the reason leading to the contrary results in these two studies.

4.2. Driver Acceptance and Driver Aggression

As indicated in Figure 15, prudent drivers' acceptance rate was always the highest among the aggression groups, while the ranking of moderate and aggressive group did not keep consistent. That's probably because of the aggression group categorization. Driver aggression score could range from 0 to 144, but gathered from 61 to 89. The mean aggression scores for prudent, moderate, and aggressive groups was 33.9 (*SD*=16.1), 61.5 (*SD*=3.3), and 79.1 (*SD*=6.5), respectively. As indicated by the data distribution, moderate drivers may have similar subjective feedback as Aggressive drivers do. This probably may lead to the non-significant results found between the aggression groups in this study. Drawn from observations on typical aggressive drivers in this study, they do like to change lanes frequently to overtake other vehicles, drive over speed limits, and follow a lead vehicle closely. All these behaviors are likely to trigger an ADAS alert. For further analysis, more aggressive drivers

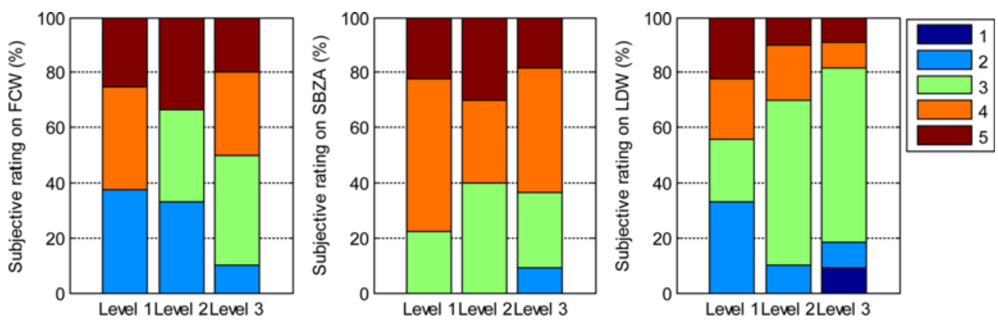

Figure 15. Driver acceptance as a function of driver aggression.

are needed to clarify the results.

4.3. ATPK

As indicated in Figure 5 and Table 4, higher speed traffic situations would lead to significantly more FCWs and LDWs, but fewer SBZAs. Statistical significances found in driver gender, age, and aggression groups strengthened this finding. See Tables 5, Table 6, and Table 7. Similar situations happened in driver acceptance results. Consistently, SBZA ranks the first and LDW ranks the last in any group of driver gender, age, or aggression. See Figures 9, Figure 12, and Figure 15. This complies with the results shown in Figure 6.

4.4. False Alerts

As can be deduced from the results, a driver would receive at least 3.3 false alerts per 100 km regardless of LDW. However, in a study conducted by Sayer *et al.* (2011), the average rate of false alerts for all warning types across subjects was just about 0.5 per 100 km, 15% of the number in this study. The relatively higher alarm rate of ADASs in this study may be caused by the complex traffic situations and typical road infrastructures in China. The rapidly expanded Chinese automotive market and the lack of roads and road infrastructures tremendously lead to serious traffic situations in China. This greatly challenges the effectiveness and acceptance of ADASs which may never happen in US or Europe. Concerning road infrastructures, metal guardrails exist almost everywhere by the sides of a road in China, far more than that abroad. The guardrails would easily trigger a SBZA when a driver is driving in the left or right most lane. This aspect of system performance would, in a way, negatively influence driver acceptance of SBZA.

4.5. Driver Feedback

Although the assessment of driver acceptance comes from questionnaire responses overwhelmingly, extra communications on the advantages and disadvantages of ADASs have added a degree of clarity in seeking to explain the results lying behind the performance and driver acceptance. From the perspective of ADASs advantages, they help drivers to avoid crashes. Drivers can never detect everywhere in the blind zone. If they want to know more about the traffic situations in the blind zone, they have to look over their shoulders every time they want to make a lane change. This would take them more attention and make them easily get tired. In China, as there is no legal requirements to look over shoulders when changing lanes, most

Table 5. Significance test results and multiple comparisons results for gender groups.

		Mean			Significance test result	Pairwise comparisions results (p value)		
		CR	CE	ICH	p	CR & CE	CR & ICH	CE & ICH
FCW ATPK	Male	0.0	4.2	6.2	<0.001	<0.001	<0.001	0.685
	Female	0.0	0.4	3.6	<0.001	0.378	<0.001	0.001
SBZA ATPK	Male	42.8	29.1	6.4	<0.001	0.428	<0.001	<0.001
	Female	48.6	24.2	4.1	0.001	0.194	<0.001	0.011
LDW ATPK	Male	15.8	30.3	36.8	0.001	0.009	<0.001	0.230
	Female	12.2	28.4	43.0	0.019	0.060	0.006	0.377

Table 6. Significance test results and multiple comparisons results for age groups.

		Mean			Significance test result	Pairwise comparisions results (p value)		
		CR	CE	ICH	p	CR & CE	CR & ICH	CE & ICH
FCW ATPK	Young	0.0	1.6	5.6	0.004	0.032	0.001	0.248
	Middle	0.0	3.4	5.7	<0.001	0.010	<0.001	0.162
	Old	0.0	4.3	4.4	0.003	0.006	0.001	0.687
SBZA ATPK	Young	45.9	31.0	6.8	0.005	0.476	0.002	0.016
	Middle	42.1	20.7	5.6	0.002	0.348	<0.001	0.012
	Old	47.8	32.7	4.2	0.001	0.332	<0.001	0.009
LDW ATPK	Young	10.3	29.0	34.5	0.078	0.090	0.031	0.594
	Middle	14.0	27.0	38.1	0.004	0.057	0.001	0.111
	Old	20.3	42.5	45.0	0.148	0.110	0.077	0.852

Table 7. Significance test results and multiple comparisons results for aggression groups.

		Mean			Significance test result	Pairwise comparisions results (p value)		
		CR	CE	ICH	p	CR & CE	CR & ICH	CE & ICH
FCW ATPK	Prudent	0.0	1.6	2.2	0.002	0.104	<0.001	0.063
	Moderate	0.0	1.0	4.0	0.001	0.096	<0.001	0.050
	Aggressive	0.0	5.0	5.2	0.001	0.001	0.001	0.990
SBZA ATPK	Prudent	49.3	28.8	5.5	0.003	0.223	0.001	0.028
	Moderate	56.1	37.0	6.9	0.004	0.712	0.002	0.007
	Aggressive	33.2	24.3	6.1	0.001	0.537	<0.001	0.003
LDW ATPK	Prudent	8.7	36.1	39.5	0.036	0.036	0.018	0.781
	Moderate	20.4	24.4	39.7	0.065	0.642	0.027	0.082
	Aggressive	13.4	31.3	38.2	0.009	0.027	0.003	0.382

Chinese drivers just look at the side mirrors to decide if it is safe to do that. But the ‘did not see’ errors may lead to a crash. The SBZA assist them in such situations and decrease their workload. This leads to drivers’ preference for SBZA assistance. According to traffic regulations in China, the driver in the following vehicle would have to take all the penalties and loss when a rear-end crash happened. FCW can remind a driver when he/she follows a lead vehicle too closely. This may prevent drivers from being involved in a rear-end crash. Driver drowsiness can lead to a lane departure while driving. When a vehicle departs from a lane, the LDW can help alert the driver to avoid a potential crash. Even if the driver is quite awake, a proper LDW would help to keep in the center of the lane to avoid conflicts with vehicles in adjacent lanes.

Feedback on ADASs disadvantages could help find problems. Among the complaints on FCW, alert nuisances caused by trucks or buses in adjacent lanes on inter-city highways rank the first. For SBZA, false alters caused by guardrails should be solved properly. Besides, passing-by vehicles caused alerts may also be viewed as nuisance when a driver was going straight without lane change intention. Concerning the highest ranking complaints on LDW, alerts were not expected to be triggered when a driver was driving straight, far from riding the lane markers. When ADASs alert drivers to more actual threats, their opinions of ADASs will be more positive. However, if drivers do not experience many actual treats, negative opinions will accumulate, resulting from false alerts that are deemed excessive or recurring (Najm *et al.*, 2006). To improve ADASs performance and driver acceptance in China, the nuisances caused by trucks/buses, road infrastructures, and other environment factors have to be solved. Additionally, driver lane change maneuver needs to be recognized more precisely and timely, and driver reaction time in various traffic situations has to been take into account (Li *et al.*, 2014).

5. CONCLUSION

From the perspective of overall ADASs performance and driver acceptance, LDW was triggered far more frequently than either FCW or SBZA in Chinese typical road conditions, while getting the lowest acceptance rate among the systems. Alert frequencies of FCW and LDW increased in higher speed traffic situations, whereas that of SBZA declined. Subjective rating results showed that Chinese drivers’ most favorable system was SBZA, with FCW ranking the second and SBZA being the last. Similar trends were found in each of the gender, age, or aggression groups. Considering gender effect, male drivers received more FCW alerts but fewer LDW alerts than female drivers, and female drivers rated each ADAS more positively than male drivers. In terms of driver age, older drivers received fewer SBZA alerts than younger drivers did. Among the age groups, young drivers’ subjective ratings ranked the highest. Besides gender and age, driver aggression also showed capability to affect ADASs performances and driver acceptances. The more aggressive a driver was, the more FCW alerts he/she would receive. The observed acceptance rate of prudent drivers ranked the highest in the evaluation of each ADAS. These findings should be helpful for the development of future ADASs for automotive industry. However, this study is limited to short-term exposure with the ADASs. This may not yield enough comprehensive information for drivers to get adapted with the systems. For future studies, longer exposure will be conducted.

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