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Assessing Drivers' Trust in Automated Driving Systems: An Integrated Study

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ABSTRACT

At present, the automatic driving system is accelerating the evolution from L2 assistant driving system to L5 with the advanced automatic driving function in full scenarios. The drivers' trust in automated driving systems has been proved to be one of the most important factors that affect drivers' acceptance of automated driving technology. It is also a primary determinant of understanding how to promote productive interaction between drivers and automated driving systems. This paper presents two mixed-method studies that combine demographic and experimental methodologies to assess trust in AVs. 1131 drivers with different driving experiences were investigated on their initial trust in AVs through an online questionnaire. Twenty-six participants evaluated dynamic trust in six sessions of varying road complexity in an L3 automated driving simulator. Data collected included subjective measures of trust, behavior, and physiological measures through ECG and GSR. The results show that drivers' initial trust related to individuals' disposition includes age, driving years, gender, driving experience, perceived risks, acceptance of new technology, and the perception of risk. As well as drivers' initial learned trust depends on the understanding of AVs technology, driving capacity, and the experience of AVs. The dynamic trust changes with the understanding of AVs performance and the external environment. The audible reminder can effectively enhance drivers' situational awareness and trust as a strong reminder to supplement the visual channel in automated driving systems. These findings provide an effective basis for further research and design related to improving the trust in AVs.

Keywords: Trust assessment, Automated vehicles, Human-machine interaction, Situational awareness

INTRODUCTION

At present, the automatic driving system is accelerating the evolution from L2 assistant driving system to L5 with the advanced automatic driving function in full scenarios through gradually decreasing the takeover rate from automated driving to manual driving. It means that automated systems free drivers from the cognitive workload of having to focus on monitoring traffic and performing driving tasks. Meanwhile, drivers will face the gradual transfer of the control right to automated systems and how to coordinate with them to be safe.

Numerous studies showed trust plays an important role in influencing an individual's inclination to use the autonomous system. Parasuraman and Riley (1997) propose that a user's trust level of the automation can cause misuse, disuse, or abuse. Many studies have utilized a variety of different automated systems in diverse experimental paradigms to identify factors that impact users' trust. Hoff and Bashir (2015) proposed a human-automation trust model that revealed three layers: dispositional trust, situational trust, and learned trust based on a systematic review of empirical research. That can be applied to design procedures that encourage appropriate trust. Trust is seen as essential to the success of new intelligent technology design and implementation, especially in automated driving in recent ten years (Ekman, Johansson and Sochor, 2018; Wintersberger et al., 2020)

Most of the current research associated with AVs recognizes trust as the essential factor influencing drivers' acceptance of automation technology. The American Automobile Association (AAA) reported that only one-in-ten (12%) U.S. drivers would trust to ride in a fully self-driving vehicle and 28% are unsure in March 2020. Körber, etc. (2018) examined and found that trust in an automated driving system is positively correlated with reliance on the automated driving system. An online survey with 443 U.S. drivers showed significant differences in AV expectations based on age, gender, education, driving experience, personality traits, and so on (Zhang, Yang and Robert, 2021). The initial level of trust seems to be crucial in further trust calibration and modulating the effect of automation performance (Manchon, Bueno and Navarro, 2021). That is, trust formation is a dynamic process. Changes in trust over time are influenced by factors related to user interaction with the system (Ekman, Johansson and Sochor, 2018). In previous research, the highlighted factors that affect dynamic trust in human-machine interactions include: 1) Automated system-related factors, such as automated system performance (Hancock et al., 2011), HMI design such as more anthropomorphic features (Waytz, Heafner and Epley, 2014) and providing both "how and why" messages to explain AV actions(Koo et al., 2015), automated driving styles(Manchon, Bueno and Navarro, 2021), and so on; 2) Drivers learned factors, such as technical competence (Choi and Ji, 2015), perceived ease of use and perceived usefulness (Zhang et al., 2019); 3) situational factors: the specific events, uncertain situations and road complexity (Holthausen et al., 2020). Trust is a primary determinant of understanding how to promote productive interaction between drivers and automated driving systems.

Making automated vehicles commercially available is therefore reliant upon understanding how to trust in AVs is built, maintained, and fluctuated over time. The goal of our research is to build a framework of factors that affect drivers' initial trust in AVs and to study how drivers' trust dynamic changes and adjusts in the process of interacting with AVs. However, much trust assessment is based on questionnaires or experiments in laboratories alone, and not on a combination of behavioral, physiological, and subjective measures of trust. Therefore, we presented an integrated study that combines demographic and experimental methodologies to assess trust in AVs. Data collected included subjective measures of trust, behavior, and physiological measures through ECG and GSR.

METHODOLOGY

A Trust Assessment Framework

Hoff and Bashir (2015) proposed a three-layered trust model, which includes dispositional, situational, and learned trust based on a systematic review of empirical research. Dispositional trust represents an individual's enduring tendency to trust automation that is influenced by culture, age, gender, and personality. Situational trust includes the external environment and the operator. The external variability depends on the type of system, system complexity, task difficulty, workload, perceived risks, perceived benefits, organizational setting, and the framing of the task. In the context of driving, this may involve weather conditions, traffic, and road complexity. Internal variability includes self-confidence, subject matter expertise, mood, and attentional capacity. Learned trust represents users' evaluations of a system drawn from experience or the current interaction. It can be divided into two categories: initial learned trust that is based on preexisting knowledge included attitudes, reputation of system or brand, experience with system or similar technology, and understanding of system; dynamically learned trust depends on system performance during the interaction, which including reliability, validity, predictability, dependability, timing of error, difficulty of error, type of error and usefulness.

The framework above is a general summary of trust in automation, and measures vary. Based on this framework, we propose an approach to measure the trust in AVs according to the characteristics of autonomous driving and drivers (see Table 1).

Initial Trust Assessment

Questionnaire Design. Firstly, the framework of the trust model is verified and the main factors affecting the initial trust are summarized by a demographic questionnaire survey for drivers in China. There were two parts to this questionnaire. The first part collected the demographic information of users, including age, gender, driving experience, and autonomous driving experience; The second part investigated the dispositional and the learned factors in the trust framework with a 7-point Likert scale.

Participants. A total of 1131 valid questionnaires were obtained; the ratio of users with AVs experience to users non-AVs experience was 654:479 (see Table 2).

Dynamic Trust Assessment

Experiment Design. The experiment was conducted on the simulated driving system. A VR helmet (HTC Vive Pro Eye) was used for displaying experimental scenes and recording the participants' gaze data. Click data Program developed based on Logitech g29 driver was used to collect the real-time acceleration and braking data. iMotions was used to record ECG and GSR data synchronously. Subjects had a questionnaire to assess their trust in AVs after each task on the simulator. GSR is divided into SCR (phase skin conductivity)

Table 1. Integrated approach to assess the trust in AVs.

	Dispositional factors		Learned factors		Situational factors	
			Initial	Dynamic	Internal	External
Factors Framework	Age Gender Driving years Driving experience	Perceived risks Acceptance of new technology Perceived safety risks	Reputation of AVs Understanding of AVs technology Driving capacity Experience of AVs	Perceived usefulness Perceived ease of use	Road complexity Traffic System performance	Self-confidence Mood Attentional capacity

	Initial trust	Dynamic trust
Measuring Methods	Subjective scales	Self-report • Self-reported trust after each session Behavioral • Accelerating and braking times Physiological • ECG • GSR

			
Questionnaire	AD simulator	HTC Vivi Pro Eye	ECG and GSR

Table 2. Demographic characteristics of the initial trust in AVs questionnaires.

Gender	Age		Driving years		Experience of AVs	
	group	Percentage	Item	Percentage	Item	Percentage
Male (85.15%)	18-25	1.50%	<1 year	2.74%	Yes	52.43%
	26-30	19.10%	1-2year	5.84%	No	32.71%
	31-35	31.21%	3-6 year	12.91%		
	36-40	19.45%	>6 year	63.66%		
	>40	13.88%				
Female (14.85%)	18-25 age	0.00%	<1 year	1.86%	Yes	5.22%
	26-30 age	3.36%	1-3 year	1.41%	No	9.64%
	31-35 age	5.48%	3-6 year	2.12%		
	36-40 age	2.65%	>6 year	9.46%		
	>40 age	3.36%				

Table 3. Experiment scenarios.

Session number	Complexity	Included events
1	Medium	Cut in, Pedestrian, Crossing
2	High	Large curvature curve, Crossing
3	High	Cut in, Tunnel
4	Low	Cut in, Highway, Crossing
5	Medium	Cut in, Pedestrian, Large curvature curve, Crossing
6	Low	Cut in, Obstacles, Pedestrian ahead, Crossing

and SCL (basic skin conductivity). The peak value of SCR represents that the person is stimulated by emergencies and the conductivity increases.

Experiment Tasks. This experiment has designed six sessions according to daily traffic scenarios (see Table 3) with different road complexity, including six types of events: cut-in, obstacles, pedestrian, large curvature curve, highway, and so on. Auditory reminders of different events were provided as a supplement to visual reminders according to the subjects' choices before the experiment.

Participants. Twenty-six participants aged 18-50 years old participated in the experiment. The participants carried out 5-minute training to operate the simulated driving system and completed six sessions in random order.

RESULTS AND DISCUSSION

Factors Analysis that Affect Initial Trust in AVs

One-way analysis of variance (ANOVA) was used to examine potential differences in initial trust in AVs based on individual differences. The alpha level of all statistical tests was set to 0.05. The responses are summarized is shown in Table 4. Initial trust in AVs were significantly different among age ($F = 2.462$, $p = 0.044 < 0.05$), driving years ($F = 3.333$, $p = 0.019 < 0.05$), gender ($F = 5.698$, $p = 0.017 < 0.05$), Driving experience ($F = 34.816$, $p < 0.001$), experience of AVs ($F = 97.393$, $p < 0.001$), driving capacity ($F = 12.138$, $p < 0.001$), acceptance of new technology ($F = 52.601$, $p < 0.001$), understanding of AV technology ($F = 33.716$, $p < 0.001$), privacy risks ($F = 71.979$, $p < 0.001$), and perceived safety risks ($F = 57.826$, $p < 0.001$). There was no significant difference among reputation of AVs ($F = 2.146$, $p = 0.117$).

There were significant differences in driving capacity ($T = 6.136$, $p < 0.001$), acceptance of new technology ($T = 3.836$, $p < 0.001$), driving experience (($T = 7.141$, $p < 0.001$), understanding of AV technology ($T = 6.968$, $p < 0.001$), reputation of AVs ($T = -3.604$, $p < 0.001$), perceived privacy risk ($T = -2.688$, $p < 0.001$) between male and female groups. Male have higher evaluation on their driving ability (mean = 5.78 > 4.99), higher acceptance of new technology (mean = 6.35 > 6.04), relatively more mature driving experience (mean = 5.45 > 4.39), higher understanding of AV technology (mean = 5.31 > 4.36), less trust in AVs (mean = 4.4 < 4.87) and less concern about perceived privacy risk (mean = 4.47 < 4.88) (see Table 5).

Table 4. Analysis results of assessment of initial trust in AVs.

Item		Trust				
		Number	Mean	St. dev.	F	P
Experience of AVs**	No	479	4.32	1.538	97.393	**<0.001**
	Yes	652	5.25	1.589		
Driving years *	<1 year	52	4.37	1.547	3.333	**0.019**
	1-3 years	82	4.52	1.565		
	3-6 years	170	4.82	1.619		
	>6 years	827	4.93	1.641		
Gender*	Male	963	4.91	1.643	5.698	**0.017**
	Female	168	4.58	1.553		
Age*	18-25 Age	17	5.35	1.902	2.462	**0.044**
	26-30 Age	254	4.84	1.546		
	31-35 Age	415	4.86	1.645		
	36-40 Age	250	5.05	1.621		
	>41 Age	195	4.61	1.685		
Driving capacity**	-1	40	4.20	1.884	12.138	**<0.001**
	0	364	4.60	1.450		
	1	727	5.03	1.680		
Acceptance of new technology**	-1	9	2.89	2.205	52.601	**<0.001**
	0	183	3.87	1.369		
	1	939	5.07	1.592		
Driving experience**	-1	115	4.16	1.819	34.816	**<0.001**
	0	361	4.49	1.416		
	1	655	5.19	1.631		
Understanding of AV technology**	-1	89	4.06	1.540	33.716	**<0.001**
	0	503	4.60	1.498		
	1	539	5.24	1.674		
Reputation of AVs	-1	174	4.66	1.880	2.146	0.117
	0	619	4.86	1.511		
	1	338	4.97	1.705		
Privacy risks**	-1	427	4.29	1.405	71.979	**<0.001**
	0	474	4.92	1.453		
	1	230	5.79	1.693		
Perceived safety risks**	-1	154	3.87	1.774	57.826	**<0.001**
	0	677	4.80	1.442		
	1	300	5.51	1.683		

Factors Analysis that Affect Dynamic Trust in AVs

By comparing the trust scores of all participants before and after the experiment, we found that the final trust of most participants was improved compared with the initial trust. There was a significant difference between final trust and initial trust (by a non-parametric test, $P = 0.028 < 0.05$). Analysis of the statistical data found that participants with AVs experience had higher initial trust than those without. After the experiment was completed, the increase in trust was more pronounced among participants with no experience of AVs (see Figure 1).

Table 5. Analysis results of gender.

Gender		Driving capacity	Acceptance of new technologies	Driving experience	Understanding of AV technology	Reputation of AVs	Perceived privacy risk
Male	Mean	5.78	6.35	5.45	5.31	4.40	4.47
	St. dev.	1.258	0.978	1.776	1.505	1.679	2.011
Female	Mean	4.99	6.04	4.39	4.36	4.87	4.88
	St. dev.	1.597	1.014	1.824	1.664	1.523	1.789
	T	6.136	3.836	7.141	6.968	-3.604	-2.688
	p	0.000	0.000	0.000	0.000	0.000	0.008

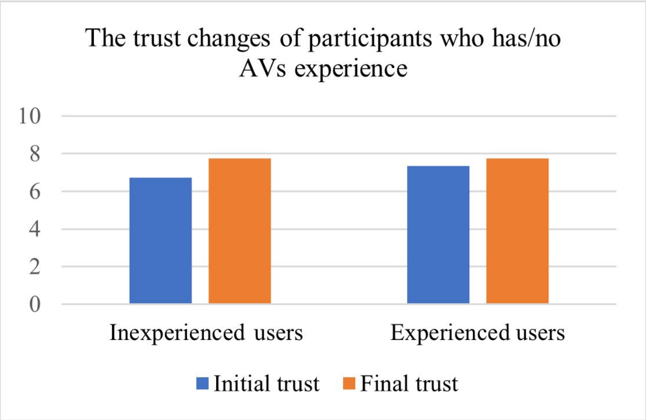

Figure 1: The trust changes of participants who has/no AVs experience.

In this experiment, the effects of audible reminders on situational awareness and trust in AVs were comparatively analyzed. The level of situation awareness was scored with a score of 1 to 5. In the situation of pedestrians and obstacles with audible reminders, the participants' perception, understanding of the current situation, and prediction of the future situation and trust had higher scores than those without audible reminders, as shown in Table 6. For the situation of pedestrians and obstacles, the score with audible reminders was significantly higher than that without audible reminders in the perception ($p<0.01$) and understanding ($p<0.01$) of the current situation. The results indicated that for higher-risk events such as pedestrians and obstacles, the audible reminder can effectively enhance drivers' situational awareness and trust as a strong reminder to supplement visual channel in automated driving systems.

According to the average score of the participants, the complexity of the experimental session was 2, 3, 1, 5, 6, and 4 from large to small, as shown in Figure 2. Paired Wilcoxon signed rank test was performed on the scores. It was found that there was no significant difference between the scores of sessions 1, 5, and 6, and there were significant differences among the others. It shows that sessions 1, 5 and 6 can be used at the same complexity level. The complexity of six sessions was divided into four levels: session 4 was

Table 6. Analysis results of audible reminders for pedestrians and obstacles.

Dimension		Perception	Understanding	Prediction	Trust
With audible reminders	Mean	4.5	4.8	4.5	8
	St. dev.	0.707	0.422	0.85	1.054
Without audible reminders	Mean	2.5	3.5	4	6.5
	St. dev	0.707	0.707	0	0.707
	T	3.651	3.662	1.861	1.89
	p	**0.004**	**0.004**	0.096	0.088

Figure 2: The analysis of road complexity, trust and physiological measures.

level 1, sessions 1, 5, and 6 were level 2, session 3 was level 3, and session 2 was level 4. Relabel each session with the value of grade division to find the correlation between road complexity and various indicators.

The renewed road complexity classification was negatively correlated with the average peak times of SCR (r = -0.602) and trust (r = -0.687); and it was positively correlated with heart rate (r = 0.639). To some extent, the results can explain that the more complex the road conditions, the higher the heart rate, the more nervous the participants were during the experiment, and the lower the trust, which is related to situational trust factors such as drivers worried about the performance of the automated driving system to deal with the complex situation.

CONCLUSION

This study assessed drivers' initial and dynamic trust in AVs from the perspective of individual dispositional, learned, and scenarios factors. Findings in this study emphasize the importance of individual differences in understanding how to trust in AVs is built, maintained, and fluctuated over time in the process of interaction between humans and AVs. More specifically, higher initial trust in AVs is more often generated by drivers who are younger, male, have more driving years, more experience of AVs, higher driving capacity, higher acceptance of new technology, more understanding of AV technology, and less privacy risk and safety awareness. The dynamic trust changes with the understanding of the performance of the AVs and the external environment. Trust in AVs increased after experiencing how the system responded to different events in traffic, especially among those who had not experienced AVs. The audible reminder is an effective way to enhance situational awareness in high-risk scenarios, which helps to perceive and understand sudden changes in the environment. The results of this study provide an effective basis for further research and design related to improving the trust in AVs.

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