Expectations and Trust in Automated Vehicles

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Abstract

A lack of trust is a major barrier to the adoptions of Automated Vehicles (AVs). Given the ties between expectation and trust, this study employs the expectation-confirmation theory to investigate in trust in AVs. An online survey was used to collect data including expectation, perceived performance, and trust in AVs from 443 participants which represent U.S. driver population. Using the polynomial regression and response surface methodology, we found that higher trust is engendered when perceived performance is higher than expectation, and perceived risk can moderate the relationship between expectation confirmation and trust in AVs. Results have important theoretical and practical implications.

Author Keywords

Automated Vehicles(AVs); Trust; Expectation Confirmation Theory; Performance; Risk.

CCS Concepts

•**Human-centered computing → Human computer interaction (HCI);** *Haptic devices;* User studies;

Introduction

A lack of trust may ultimately hinder the adoption of Automated Vehicles (AVs). Trust in AVs refers to the willingness of people to be vulnerable to the AVs' actions based on

their expectations that the AVs is fully capable of driving even in conditions characterized by uncertainty and vulnerability [26, 31]. Trust is one of the primary drivers of AVs' adoption; therefore, understanding how to promote trust in AVs remains a vital challenge [7, 15, 29].

Expectations are likely to be important for understanding trust in AVs, yet this topic is vastly unexplored. Defined as beliefs about future actions involving the use of the technology associated with its capabilities, expectations are typically tied to consequences of current actions [3, 8]. People are more willing to use technology when it meets users' expectations [3]. Given the causal expectation-trust-adoption linkage, it becomes vital to examining this causal linkage in the specific case of AVs for both practice and research.

The Expectation-Confirmation Model (ECM) is developed to understand the impact of expectations on desirable outcomes. However, there is a gap in understanding trust using ECM in the AVs domain. Also, previous research highlight the importance of driving situations, which help define the potential risks associated with trust in AVs [11]. Nevertheless, it is not clear if and how driving situations can influence the relationship between expectation-confirmation and trust in AVs.

The goal of this study is to understand if and how expectation-confirmation can influence AV trust and how risk might alter this influence. An online survey study was conducted with 443 U.S. drivers. This study involved two types of weather conditions as the external environment factor: sunny and snowy; two kinds of AVs driving behaviors as the internal factor: normal drive and aggressive drive. The results found that highest trust was produced when perceived performance was higher than expected, and both internal and external factors had moderation effects on the relationship between expectation-confirmation and trust in AVs. The re-

sults of this study have crucial implications for AVs research and design.

Background

Trust in Automated Vehicles
Trust is important in the domain of automated vehicles (AVs). AVs, as the vehicles capable of driving autonomously without human supervision or intervention, have the potential to save lives, reduce crashes, congestion, fuel consumption, and pollution [1]. Despite many benefits provided by AVs, people still have trouble of accepting it. A lack of trust is a major barrier to their widespread adoption [2, 9, 14, 21]. Models and theories are used to understand how trust can influence people's behavioral intention of AVs [7, 15, 29]. The technology acceptance model (TAM) is used to show that trust strongly affects perceived usefulness, and both factors determine behavioral intention to adopt AVs [5]. In other words, trust is a major construct for predicting the AVs adoption.

Insights into factors that affect trust have drawn attention from researchers. A stream of literature investigates the factors influencing trust in AVs [7, 15, 29]. Improving driver's perception of the accuracy of the AVs, providing system information to help drivers predict and understand the operation of the AVs, and satisfying the driver's desire to know the driving situations are important for forming trustful relationship between drivers and AVs [5, 23].

In sum, AV trust is an important part of the research in the acceptance of AVs. There are many models and theories discussing factors affecting people's trust in automation and AVs. To enhance drivers' trust in and further acceptance of AVs, more studies are needed to explore the factors that impact AV trust [9].

Expectation–Confirmation Theory (ECT) and Trust
The importance of expectations has significantly been emphasized with respects to attitudes toward and the adoption of technology. By definition, expectation can specifically be described as real-time representations of future situations, which involve the use of technology associated with its capabilities [3]. The initial expectation about a technology is formed based on existing knowledge and the interactions with communication channels or information source [40]. People's expectations may vary for the same technological product/service, depending on the quality and reliability of received information involving advertising, package information, media reports, media interviews and interpersonal communication [36]. In the AVs domain, prior research has found that expectations directly contribute to the acceptance and adoption of the AVs. With higher expectations, people would be more likely to accept and drive with AVs [17, 37]. Expectation also has an indirect impact on the AVs adoptions. Positive expectations increase the generation of positive attitudes which are correlated with reliance on the AVs [20, 30].

Expectation-Confirmation Theory (ECT) and its counterpart Expectation-Disconfirmation Theory (EDT), both have been used to explain how technology adoption is influenced by whether someone's initial expectation of a technology is actually confirmed or dis-confirmed by their actual experience with that technology [6, 28, 38]. Described using the term "performance" in the EDT, experience illustrates an individual's post-usage belief about how the technology performed on the expectation attributes during the use period [4, 22]. A confirmation occurs when performance meet expectation perfectly [12]. Disconfirmation includes positive disconfirmation when performance of the technology exceeds expectations, and negative disconfirmation when the

technology performance fails to meet expectations [28, 34, 12].

Some previous literature states that trust can be linked to ECT because of the way the trust literature uses the terms "expect" and "expectation" in definition. For example, trust can be defined as expectations that an actor can be relied on, will be predictable, and will act fairly [39]. Trust is also described as "a set of expectations shared by all those involved in an exchange" [41]. Also, Trust theory has mentioned that trust grows when trust is positively confirmed but declines or is destroyed when trust is negatively disconfirmed [27]. These definitions and theories indicate that the progression of trust is related to the disconfirmation of trust-related expectations and further relate trust to ECT [19, 24, 32, 33]. ECT is used to understand trust in technology. The results show that as disconfirmation becomes increasing positive, trust will increase. Negative disconfirmation impacts trust negatively. The results also show that negative disconfirmation will have a stronger negative effect on trust compared to the positive effect that positive disconfirmation will have [22]. Based on ECT, we argue that people generate a higher trust if their perceived AVs performance exceed the initial expectation.

H1: Positive disconfirmation lead to the highest trust in AVs.

The development of trust is related to the perception of risk because both attributes are related to uncertainty [11]. According to risk perception theory, risk-taking behavior is mediated by the level of perceived risk in the outcome of the behavior [25].In the context of driving, adverse weather is one of the critical causes of an elevated risk of traffic accidents and compromised traffic flow in the U.S. [18]. Also, internal characteristics which are the factors that occur inside the vehicle can also impact people's perceived risk of driving. Thus, one hypothesis is developed to bet-

ter understand if and how the perceived risk introduced by weather and AVs driving behavior can influence the impact of expectation-confirmation on trust in AVs.

H2: Weather and AVs driving behavior will moderate the impact of expectation-confirmation on driver's trust in AVs.

METHOD

We conducted an online survey with 443 participants using a web-survey tool (Qualtric). This research complied with the American Psychological Association code of ethics and was approved by the University's Institutional Review Board. All participants provided informed consent.

Participants and data collection
A total of 443 U.S. drivers participated in this study. To create a representative sample, participants were screened for selected demographic characteristics that mark the driver population in the United States. A sampling profile was developed according to the demographic statistic from the U.S. Department of Transportation and AAA Foundation, which includes age, gender, race ethnicity, education, income, marital status, census region, frequency of driving, and driving experience [35]. Of the 443 participants, about 49% were male, and the average age was 47 years with a range from 18 to 84 years. Eighty-four percent of them drive almost every day, and others drive sometimes or rarely. Participants were compensated $5 for completing the study.

Qualtrics Online Research Service was used to select a representative sample, U.S. drivers, and to conduct a web-based survey to test the hypotheses proposed above. We provided to Qualtrics the number of each subsample according to its demographic profile and sample size. The service selected and included the subjects in our participant poll if their demographic information were qualified for this study. Then, the central part of the online survey was distributed to collect data, in which each participant was required to watch four different videos and rated their perceptions after each of the videos.

Independent variables
This study is a 2 x 2 factorial design manipulated two independent variables related to factors that impact AVs externally (i.e. weather) and internally (i.e. AVs driving behavior). Figure 1-4 show the video screenshots for different conditions.

Weather conditions: As the influential external factor, weather conditions were manipulated by altering the weather in which the AV drives. Sunny weather conditions were coded as "1", snowy weather conditions were coded as "2". When a participant watched the videos showing the sunny weather conditions, the road visibility and video brightness were much higher than the videos showing the snowy weather condition.

AVs driving behaviors: The driving behavior of AVs as the influential internal factor was measured as "1" if the car drove normally, and "2" if the car performed an aggressive driving behavior. Normal and aggressive driving behavior is differentiated by the number shown on the car speedometer and frequency of car shake. The videos showing aggressive driving behavior shaken more times, and the average speed was higher than the videos presenting normal driving behaviors.

AVs expectation: A three-item scale was appropriately worded to measure participants' AVs expectation before they watch the study videos. The questions based on a 7-point Likert scale (1 = low, 7 = high).

Perceived performance: Participants' perceived performance of AVs was measured with three items reflecting

Figure 1: Normal AV driving in sunny weather

Figure 2: Aggressive AV driving in sunny weather

Figure 3: Normal AV driving in snowy weather

Figure 4: Aggressive AV driving in snowy weather

peoples' perception about what can realistically achieve or delivery by an AV. All the items were rated on seven-point Likert-type scales (1 = low, 7 = high).

Dependent variable
Trust is the dependent variable in this study, which was measured using a questionnaire consisting of twelves seven-point Likert scales [16]. This scale is a highly validated instrument for gathering date about human and automated system trust. Questions in the trust questionnaire were appropriately revised to suit the AV context.

Manipulation check of Risk Conditions
We checked to confirm that the two different weather conditions and driving behaviors manipulated internal and external influential factors differently. The questions based on a 7-point Likert scale (1 = low, 7 = high) [10].

RESULTS

Preliminary Analysis
Construct internal consistency was supported by Cronbach's alpha with all construct reliability is at the acceptable threshold of .80 or above. To determine whether the measurement constructs were valid, we assessed convergent and discriminant validity through principal components analysis with varimax rotation that yielded a five-factor solution. All items loaded at .7 or above.

Hypotheses Testing
Polynomial regression analysis coupled with response surface methodology is used to test the hypotheses. H1 suggested that drivers have the highest trust in AVs if their perceived AV performance exceed their initial expectations. We propose:

$$Z = b_0 + b_1 E + b_2 PP + b_3 E^2 + b_4 EPP + b_5 PP^2 + e \quad (1)$$

Table 1: Polynomial Regression Analysis Results

	Regression coefficients
Intercept/constant	4.060**
Expectation(E)	-0.069*
Perceived Performance (PP)	0.451**
E^2	-0.032*
$E * PP$	0.026*
PP^2	0.018
**Significant at the 0.001 level(2-tailed).	
*Significant at the 0.05 level(2-tailed).	

Where, E=Initial expectation, PP= Perceived Performance. Table 1 reports the polynomial regression results.

We compare the position of the ridge (First principle axis) to the line in the XY plane which contains all congruent predictor combinations: X=Y (Congruence line) [13]. Based on the First principle equation: Y= p_{10}+p_{11}X=10.422+4.091X. The first principle axis shifted away from X=Y as its intercept p_{10}=10.422 is significantly different from 0 (p<.001). Also, the slope of first principle axis p_{11}=4.091 is significantly different from 1 (the slope of X=Y) meaning the first principal axis is both shifted and rotated away from the X=Y. Thus, H1 was supported.

H2 suggests that AVs internal factor (AV driving behavior) and external factor (weather) will moderate the impact of (in)congruence between initial expectations and perceived performance on driver's trust in AVs. As shown in equation 5, moderation effect can be tested by assessing the increment in R^2 yielded by the terms XV, YV, X^2V, XYV, and Y^2V. As putting AV driving behavior as the "V" into the model, the increment in R^2 is 4.127 (p<.05), the moderation effect of AVs driving behavior thus supported. When treating weather as the "V" in the model, the increment in

R^2 is 5.058 (p<.05) which indicates that weather has significant moderation effect as well. In sum, H2 was strongly supported.

DISCUSSION

This study sought to make contribution to the previous literature in the following ways. Firstly, this study contributes to AVs trust research by demonstrating the role of expectation on trust are related to perceived performance.This study is among the first to demonstrate that the role of expectations is relative to perceived performance. People's trust in AVs fluctuates with the relationship between expectations and performance. The impact of expectation on trust cannot be understood without considering perceived performance. Going forward, this means that future studies of AVs should consider examining the role of perceived performance along with expectations.

Secondly, this study provides evidences that not only are expectations important but confirming and disconfirming them are also important and have different impacts relative to perceived performance on AVs trust. The results of this study support the hypothesis of saying positively disconfirming expectations lead to the highest trust in AVs, This conclusion may seem intuitive but previous literature does not provide evidence about how much more benefit comes with exceeding compared to meeting expectations. This study shows that trust in AVs continuously increases as perceived performance increased to meet and exceed expectations, and the highest trust produced when the ratio between perceived performance and expectation becomes 4.091/1.

Finally, this study contributes to the literature by demonstrating that internal and external risk can moderate the effect of confirmation and disconfirmation on AVs trust as indicated in above contribution. This may because of the impact of risk perceptions on perceived performance. Uncertainty and potential loss introduced by a higher level of risk increase the possibility of individual's cognitive recognition about the product malfunctioning and usefulness which in turn impede the favorable evaluation.

CONCLUSION

This study extends our understandings in AVs trust by examining the role of expectation on trust in AVs as it related to perceived performance. Findings also indicate that the impact of expectation confirmation depends on internal and external risk factors including weather and driving behaviors respectively. With the polynomial regression model being supported, results of this study provide key insights into the role of expectation and perceived performance in trust in AV. This study opens up new topics and theoretical ground for future research to build and expand on the findings of this paper.

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