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An Empirical Study of the Factors Influencing Users' Intention to Use Automotive AR-HUD

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Abstract: An automotive augmented reality head-up display (AR-HUD) can provide an immersive experience for users and is anticipated to become one of the ultimate terminals for human–machine interaction in future intelligent vehicles within the context of smart cities. However, the majority of the current research on AR-HUD is focused on technological implementation and interaction interface design, and there are relatively few studies that examine the psychological factors that may influence the public's willingness to utilize this technology. Based on the theory of reasoned action (TRA) and the unified theory of acceptance and use of technology (UTAUT), this study constructs a model of users' willingness to use automotive AR-HUD involving both cognitive and social factors. The study recruited 377 participants and collected data on users' effort expectation, performance expectation, social influence, perceived trust, personal innovation, and AR-HUD usage intention through a questionnaire. It was found that users' effort expectation influenced their intention to use AR-HUD through the mediating role of performance expectation. Social influence had an impact on users' AR-HUD usage intention through the mediating role of perceived trust, and personal innovation moderated the strength of the role of social influence on perceived trust as a moderating variable.

Keywords: AR-HUD; usage intention; influencing factors; structural model; theory of reasoned action; UTAUT

Citation: Xia, T.; Lin, X.; Sun, Y.; Liu, T. An Empirical Study of the Factors Influencing Users' Intention to Use Automotive AR-HUD. *Sustainability* **2023**, *15*, 5028. https://doi.org/10.3390/su15065028

Academic Editor: Robert E. Pitts

Received: 8 February 2023
Revised: 27 February 2023
Accepted: 10 March 2023
Published: 12 March 2023

1. Introduction

A long-lasting digital revolution is currently sweeping through the field of automotive technology. Within the context of smart cities, vehicles are becoming more and more intelligent as new technologies continue to be integrated into them. As the level of user demand for intelligent in-vehicle devices is increasing, single devices cannot satisfy all needs due to the restrictions on information access and information processing, making it a necessity to establish mechanisms for information sharing, service access, and interoperability among in-vehicle devices, while interactions within the vehicle are also undergoing a dramatic change [1]. In particular, augmented reality (AR) technology provides a technological innovation for automotive driving by combining engineering and computer technology to add virtual information to the real environment, and to synchronize the real environment with the virtual environment simultaneously in the same spatial relationship [2]. Augmented reality head-up display (AR-HUD) is a new technology that combines AR technology with in-vehicle head-up display to present information to the driver [3].

Automotive AR-HUD is an in-vehicle visual aid that utilizes AR technology to reasonably superimpose and display information of vehicle speed and navigation, the status of the driver assistance system, and the surrounding environmental conditions on the front windshield. Specifically, AR-HUD establishes a network using dynamic data from the environmental sensors of the driver assistance system, global positioning system, and in-vehicle diagnostic system to precisely integrate virtual image information and real traffic conditions into intuitive information, saving the amount of time taken by drivers to switch between the road and the dashboard, enhancing their situational awareness, and thereby improving driving safety [4,5]. When a vehicle incorporates AR-HUD technology, integrated traffic-condition visuals that are reinforced with augmented reality information help drivers be more aware of other vehicles and pedestrians and respond more swiftly when there is an emergency [6]. In addition, compared to static, two-dimensional marker icons, the dynamic, three-dimensional icons of AR-HUD can provide timely information on lane changes, which can better regulate drivers' traffic behavior and ensure their safety [5,7]. Notably, AR-HUD can somewhat reduce driving tension and stress for drivers who experience high levels of interpersonal anxiety [6]. Overall, the driving experience and safety of AR-HUD consumers can be effectively improved.

AR-HUD can provide users with an immersive experience and hopefully become one of the ultimate terminals for future intelligent vehicle human–computer interaction. However, as an emerging technology, its penetration rate still has significant potential for improvement. In addition, most of the previous research on AR-HUD focuses on its technological implementation and interface interaction design, but few studies have examined the psychological factors that determine whether users will accept this emerging technology. Wei et al. explore the direction of the large-scale commercialization of AR-HUD from the perspective of improving technology maturity [8]. Hwang et al. experimentally explore the effect of AR-HUD on drivers' perceived risk and psychological changes, emphasizing the user experience during usage [6]. Charissis et al. describe the virtual simulation requirements of AR-HUD prototype systems and propose a variant of the technology acceptance model (TAM), including perceived usefulness and perceived ease of use, but they do not go into great detail about the factors that influence users' willingness to use AR-HUD technology [9], which provides a research direction for our study. In summary, the current research on AR-HUD either provides theoretical guidance from the perspective of user experience or discusses the commercialization path from the perspective of improving the technological maturity, but it has not yet covered users' willingness to use AR-HUD as an emerging technology from a more comprehensive perspective. The poor utilization of head-up displays (HUDs) has mostly been caused by their design, placing more emphasis on technological implementation than on user demands [10]. Moreover, the conflict between high technology maturity and users' unwillingness to use a new technology may hinder the commercialization and diffusion of the technology [11,12]. In order to profit from the potential environmental, economic, and social benefits [13], there is an urgent need to comprehend the psychological mechanisms behind users' intentions regarding the intention to use automotive AR-HUD.

A large number of researchers have quantitatively studied the acceptance of emerging technologies in the automotive field, such as collaborative vehicle infrastructure systems, self-driving vehicles, and in-vehicle navigation information systems [14–16], and the study of the above emerging technologies can provide reference value for the study of AR-HUD acceptance. In order to promote this technology, this study investigates the factors affecting AR-HUD usage intention and constructs a users' AR-HUD usage intention model based on the theory of reasoned action (TRA) and the unified theory of acceptance and use of technology (UTAUT). This study collects data using a questionnaire method and analyzes the data using SPSS and AMOS to explore the mechanisms of variables such as effort expectancy (EE), performance expectancy (PE), and social influence (SI) on the users' AR-HUD usage intention. Finally, tailored commercialization advice is provided for the automobile sector based on the study results.

2. Theoretical Background and Research Hypotheses

2.1. Theoretical Background and Research Model

This study builds on the TRA and UTAUT to construct a hypothetical model of automotive users' AR-HUD usage intention based on both cognitive and social factors. Although there are many differences in the way researchers study the acceptance of automotive-related products, there are commonalities in the application of theories about human behavior and technology acceptance originally developed outside the automotive field, and these models provide a theoretical framework to define, model, and measure technology acceptance, which includes both the TRA and UTAUT [17].

TRA assumes that behavioral intentions are the determinants of human behavior, while individual behavioral attitudes and subjective norms influence behavioral intentions, with behavioral attitudes being determined by behavioral beliefs and outcome assessments, and subjective norms being the perceptions of significant others in the social environment about an individual's specific behavior [18]. The TRA has been extensively validated on consumer intentions and has been effectively applied to numerous instances of consumer behavior, technology acceptance, and system use [19]. The TRA has been used in certain research to forecast public interest in new technologies such as electric vehicles [20]. In technology acceptance theory, Davis argues that behavioral attitudes in the theory of reasoned behavior are equivalent to perceived usefulness and perceived ease of use [21].

Venkatesh et al. integrated TRA, innovation diffusion theory, and social cognitive theory to propose UTAUT; then, they organized several theoretical frameworks into four aspects: effort expectancy, performance expectancy, social influence, and facilitating condition; the first three of these have a direct impact on usage intention [22]. Since it was proposed, the UTAUT has been widely applied to explain individuals' acceptance of technology; Kaye et al. compared drivers' acceptance of highly autonomous vehicles in different countries based on the UTAUT [23], and Rahman et al. used the UTAUT model to assess users' willingness to use advanced driver assistance systems [17]. In UTAUT, analogous constructs such as perceived usefulness constitute performance expectancy, while effort expectancy incorporates the concept of perceived ease of use [22,24]. Rahman et al. found that perceived ease of use and perceived usefulness significantly predicted behavioral attitudes in TRA, which further influenced the intention to use this system, in a study comparing multiple technology acceptance theoretical models for user acceptance of advanced driver assistance systems. Perceived ease of use and perceived usefulness were found to be significantly similar to the cognitive factors of effort expectancy and performance expectancy in UTAUT. This finding supports the TAM study proposed by Fishbein et al. positing that behavioral attitudes are formed based on beliefs about behavioral outcomes, specifically beliefs of perceived ease of use and perceived usefulness [17,18]. Furthermore, in comparison to other models of technology acceptance, the TRA focuses on measuring the strength of social influence that affects acceptance, and this theoretical foundation has been widely used by previous studies to investigate the adoption of innovative technologies [25]. Larue et al. found that subjective norms are significant predictors of behavioral intention, and a number of scholars have argued that subjective norms that originate from the TRA are the same as the concept of social influence [18,26].

By strictly following the model structure of TRA, our study explores the effect mechanisms that influence users' AR-HUD usage intention in terms of both cognitive factors (behavioral attitudes) and social factors (subjective norms), combining the content of the UTAUT to convert individual attitudes into performance expectancy and effort expectancy, and subjective norms into social influence. The study also refers to TAM, as well as to pertinent references in technology acceptance theories on perceived trust (PT) and personal innovation (PI), so as to identify a set of complex interrelationship factors driving usage intention in the hypothesized model: performance expectancy, effort expectancy, social influence, perceived trust, and personal innovation, through which these variables together construct a model of automotive users' AR-HUD usage intention.

Based on the theories mentioned above, we propose a hypothetical model of automotive users' AR-HUD usage intention, as shown in Figure 1, and we will explain each variable in detail with the corresponding research hypotheses in Section 2.2.

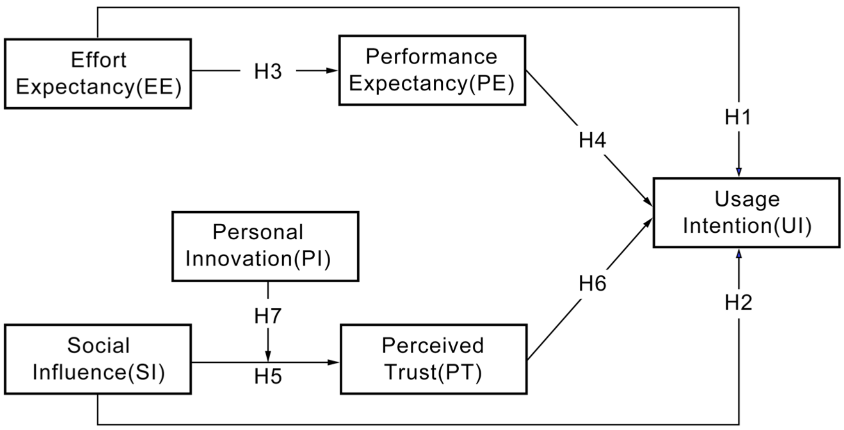

Figure 1. Research model.

2.2. Research Hypotheses

2.2.1. Effort Expectancy

Effort expectancy, which reflects an individual's perceived ease of use of a system, has been suggested by Venkatesh et al. to be an effective predictor of behavioral attitudes in the TRA and it thus affects an individual's willingness to adopt technology, and the definitions of both effort expectancy and perceived ease of use are remarkably similar [22]. Some literature on the acceptance of autonomous vehicles reports controversy on the issue of whether there is a correlation between effort expectancy and behavioral intention [27]; several studies have revealed a positive effect of effort expectancy on behavioral intention [28,29], while other studies have not found a significant effect [30,31]. In our study, effort expectancy represents the user's perceived ease of use of the services provided by AR-HUD technology, which is considered to be one of the better ways to deliver information to the user while keeping the user's cognitive load low [32], and it therefore requires less effort than traditional HUDs. From the above, it can be assumed that users' effort expectancy regarding the AR-HUD affects their usage intention, and the following hypothesis is proposed:

H1. *Effort expectancy positively affects users' intention to use automotive AR-HUD.*

2.2.2. Social Influence

Social influence reflects the extent to which individuals perceive that significant others think they should adopt new technologies and systems. Venkatesh considers social influence to be similar to the factors of subjective norms in the TRA and emphasizes that social influence has a direct influence on behavioral intentions [22]. In our study, social influence refers specifically to the perceptions of people including users' family, friends, and colleagues regarding the usage of AR-HUD technology. Social factors describe individuals' internalization of the subjective culture of their reference group, and Barth argues that social norms and collective efficacy contribute to people's acceptance of technology [33,34]. In terms of the automotive field, various studies have found that social influence significantly affects users' usage intention for autonomous vehicles among emerging technologies [30,35]. While AR-HUD, also as a relatively new technology, is not yet well known to the general public, based on the structure of the TRA and UTAUT, it can be assumed that the information users receive from others will significantly change their own perceptions of AR-HUD and consequently affect their usage intention; thus, the following hypothesis is proposed:

H2. *Social influence positively affects users' intention to use automotive AR-HUD.*

2.2.3. Performance Expectancy

Performance expectancy reflects the extent to which individuals believe that the use of technological systems contributes to performance gains. Performance expectancy, as one of the cognitive factors exploring users' willingness to adopt new technologies, is considered by Venkatesh et al. to be an effective predictor of behavioral attitudes in the TRA, which affects individuals' willingness to use technology; the definitions of both performance expectancy and perceived usefulness are remarkably similar [22]. Studies by Madigan et al. and Leicht et al. confirm that performance expectancy significantly affects users' willingness to adopt and afford autonomous vehicles [30,36], while an extended TAM-based model by Li et al. suggests that perceived usefulness can influence the usage intention of AR-HUD [16]. Furthermore, the study by Rahman et al. demonstrated the mediating role of perceived usefulness in the effect of perceived ease of use on behavioral intention [17]. In our study, performance expectancy represents the extent to which users perceive that using AR-HUD is beneficial during driving. Users can access richer information resources such as vehicle speed, warning signals, and navigation instructions during driving with the support of AR-HUD technology and therefore achieve improved performance [6]. Combined with the above references, it could be assumed that a higher user performance expectancy is associated with a stronger willingness to use the automotive AR-HUD, as well as performance expectancy playing a mediating role in the effect of effort expectancy on usage intention; thus, the following hypotheses are proposed:

H3. *Effort expectancy positively affects users' performance expectancy regarding automotive AR-HUD.*

H4. *Performance expectancy positively affects users' intention to use automotive AR-HUD, and performance expectancy plays a mediating role between effort expectancy and usage intention regarding AR-HUD.*

2.2.4. Perceived Trust

Perceived trust can be defined as the willingness of users to place themselves in a position of vulnerability relative to technology and to assume that outcomes will have positive expectations or that future behavior will be of a positive character [37]. In the automotive driving context studied here, perceived trust represents the level of confidence users perceive towards uncertainties in AR-HUD technology. Users will subconsciously assess the risk of AR-HUD when exposed to it, which includes the security risk, performance risk, and privacy risk dimensions outlined by Featherman et al. [38], the outcomes of which affect the user's trust level. Ghazizadeh et al. advocate considering trust as a factor to explain the individual acceptance of driver assistance systems [39]. Luarn et al. include perceived trust in their research model, arguing that perceived trust is a stronger predictor of behavioral intentions than perceived usefulness and perceived ease of use [40]. Choi et al. empirically discovered that trust has a significant positive relationship with user acceptance of emerging technologies such as autonomous vehicles [41], and a study by Panagiotopoulos and Dimitrakopoulos similarly suggested that users' perceived trust in autonomous vehicles affects their usage intention [42]. Moreover, the study by Chen et al. demonstrated that a key factor and prerequisite for users' acceptance and willingness to adopt AR-HUD is trust [43]. On the other hand, previous studies have shown that social influence affects users' trust in technology [44,45]. Li et al. suggest that social influence is more relevant to the development of trust than cognitive or personal factors [46]. According to research by Zhang et al., trust plays a mediating role in how social influence affects users' intention to utilize emerging technologies such as autonomous vehicles [29]. Based on the above, the following hypotheses are proposed:

H5. *Social influence positively affects users' perceived trust in AR-HUD.*

H6. *Perceived trust positively affects users' intention to use automotive AR-HUD, and perceived trust plays a mediating role between social influence and intention to use AR-HUD.*

2.2.5. Personal Innovation

According to the diffusion of innovation theory put forward by Rogers, personal innovation is defined as the degree to which an individual adopts an innovative or novel idea [47]. Individuals with higher levels of personal innovation tend to have higher expectations of the applicability of emerging technologies as well as tend to be more attentive to the innovative development of technologies, and they often aspire to stay ahead of their peers to be early adopters of emerging products [43,47]. In several theoretical models of technology acceptance, personal innovativeness is assumed to be the moderating variable that regulates the relationship between the predictors of new product adoption and behavioral intentions [22]. It is possible that this view considers innovativeness as secondary in explaining innovative behavior while most of the explanatory power comes from the perceived manner of the product and other variables [48,49]. In the study by Leicht et al., they found that the effect of social influence on the user acceptance of emerging technologies such as autonomous vehicles was moderated by personal innovation, with social influence having a greater effect on acceptance under the conditions of high levels of personal innovation compared to low levels of personal innovation [36]. Referring to the study on personal innovation by Leicht et al., we hypothesize that personal innovation moderates the path from social influence to intention to use AR-HUD, but since the path coefficient of the moderating effect in the original study is weak, it is reasonable to speculate that there is a hidden variable, and we hypothesize that personal innovation specifically plays a moderating role in the effect of social influence on perceived trust, which means that when individuals' innovation acceptance is higher, the evaluation of AR-HUD by significant others in society is more likely to influence the level of trust towards the technology, hence further affecting the usage intention. Based on the above, the following hypothesis is proposed:

H7. *Users' personal innovation positively moderates the strength of the effect of social influence on perceived trust.*

3. Experimental Methods

3.1. Data Collection and Sample Characteristics

The study was conducted using an online questionnaire with the help of the "Questionnaire Star" online survey platform. The questionnaire was verified with a pilot study with 30 participants to assess its validity before it was formally distributed, and this pilot study showed that the questionnaire was suitable for a large-scale study. We made it available to the general public after fine-tuning the wording of the questionnaire based on the comments collected. We used convenience sampling to conduct the survey, and the general public was able to fill out the questionnaire after being informed of the confidentiality of this experiment. A total of 440 questionnaires were collected, and after eliminating invalid questionnaires such as those with too short a completion time, those with obvious inconsistencies, and those with consecutive choices of the same number, 377 valid questionnaires were finally obtained, with a valid recall rate of 85.7%. Among them, male participants accounted for 48.81% and female participants accounted for 51.19%. The largest number of participants was in the age range of 18–39 years old. Additionally, 55.17% of the participants possessed driving experience.

3.2. Instrument Development

Based on the pertinent maturity scales and the real situation of automobile AR-HUD, the related measured items in the questionnaire were suitably adapted. We set six variables for the users' AR-HUD usage intention model and the items were measured on a 5-point Likert scale with "strongly disagree" at 1 and "strongly agree" at 5. Each variable was assessed in the questionnaire using three measured items, which were adapted accordingly with reference to previous studies in the domain of technology acceptance, mainly from Davis and Venkatesh et al. [21,22,30,41,47,50,51], with the questionnaire specifics shown in Table 1.

Table 1. Construct and items.

Construct	Scale Items	Source
EE	EE1: During driving, I think the AR-HUD should present simple and easily understandable interface information. EE2: During driving, I think the interface presented by the AR-HUD technology should make it easy for me to notice the information I need. EE3: I don't think it should take much effort and time for me to learn and use AR-HUD.	[21,22]
PE	PE1: During driving, I think the interface presented by AR-HUD can provide me with the information I want about the vehicle, the road and the surrounding environment. PE2: I think the interface information presented by AR-HUD could improve my driving efficiency during driving, and make my driving more accurate, efficient and safe. PE3: I think the interface information presented by AR-HUD is helpful to my driving process.	[21,22]
SI	SI1: I have friends who are using cars with AR-HUD technology. SI2: I have friends who recommend me to use a car with AR-HUD technology. SI3: I heard about the publicity and promotion of cars with AR-HUD technology from the internet, friends, advertisements, etc.	[30,50]
PT	PT1: I trust the reliability of the interface information presented by AR-HUD technology during driving. PT2: I trust the safety of AR-HUD technology during driving. PT3: Overall, I trust the car with AR-HUD technology to function properly.	[22,41]
PI	EE1: During driving, I think the AR-HUD should present simple and easily understandable interface information. EE2: During driving, I think the interface presented by the AR-HUD technology should make it easy for me to notice the information I need. EE3: I don't think it should take much effort and time for me to learn and use AR-HUD.	[47,51]
UI	UI1: I accept cars with AR-HUD technology. UI2: I will use cars with AR-HUD technology. UI3: I will recommend cars with AR-HUD technology to the people around me.	[21,22]

Note: EE = effort expectancy, SI = social influence, PE = performance expectancy, PT = perceived trust, PI= personal innovation, UI = usage intention.

4. Experimental Data Analyses

4.1. Reliability and Validity Analyses

We first used SPSS 26.0 (IBM, Armonk, NY, USA) to analyze the data for reliability and validity. Cronbach's alpha and combined reliability (CR) were used to measure the reliability. As shown in Table 2, the Cronbach's alpha values of the variables in the automotive users' AR-HUD usage intention model ranged from 0.874 to 0.898, and the CR values ranged from 0.868 to 0.926; all of these are above the standard value of 0.7, indicating that the scale data are real and reliable, and the measured items have high internal consistency as well as good overall reliability.

Table 2. Scales for reliability and convergent validity.

Construct	Item	Loading	α	CR	AVE
EE	EE1	0.915	0.892	0.922	0.798
	EE2	0.891			
	EE3	0.873			
SI	SI1	0.925	0.874	0.913	0.777
	SI2	0.878			
	SI3	0.840			
PE	PE1	0.923	0.898	0.926	0.806
	PE2	0.880			
	PE3	0.889			
PT	PT1	0.914	0.897	0.923	0.801
	PT2	0.896			
	PT3	0.874			
PI	PI1	0.907	0.887	0.917	0.787
	PI2	0.881			
	PI3	0.873			
UI	UI1	0.823	0.889	0.868	0.686
	UI2	0.829			
	UI3	0.833			

Note: α = Cronbach's alpha; CR = composite reliability; AVE = average variance extracted.

We then measured the validity of the questionnaire, which consisted of content validity and construct validity. The items of this questionnaire are referred to the relevant references or adapted from mature scales, so the content validity is good. Structural validity includes convergent validity and discriminant validity, in which convergent validity requires the average variance extracted (AVE) values of the variables higher than 0.5, CR values higher than 0.7, and factor loading values above 0.5. As shown in Table 2, the AVE and CR values of this model meet the criteria, and the factor loading values of each variable are between 0.823 and 0.925, which are above the standard value; thus, the convergent validity is good. In terms of discriminant validity, it is required that the square root of the AVE values of each variable must be in excess of the correlation coefficient between the variables. As shown in Table 3, the square root of the AVE values of all variables is higher than their correlation coefficients, which indicates that the discriminant validity is good.

Table 3. Correlation matrix and discriminant validity.

Construct	EE	SI	PE	PT	PI	UI
EE	**0.893**					
SI	0.010	**0.881**				
PE	0.152	0.041	**0.898**			
PT	0.118	0.153	0.155	**0.895**		
PI	0.183	0.009	0.198	0.178	**0.887**	
UI	0.372	0.370	0.386	0.394	0.380	**0.828**

Note: Scores in bold represent the square root of average variance extracted for a construct.

4.2. Structural Model and Hypotheses Test

We constructed a structural equation model (SEM) using AMOS 24.0 to test the hypothesized model framework and to explore the relationship between each variable and users' AR-HUD usage intention. Firstly, the model fit was tested with CMIN/DF = 2.02, CMIN = 345.76, DF = 171, CFI = 0.977, TFI = 0.971, and RMSEA = 0.05, indicating that the model fit was good. The relationship between the variables is represented by the path coefficients, and the magnitude of the path coefficients can effectively represent the influence degree between different variables, with positive values indicating a positive correlation and negative values indicating a negative correlation. Table 4 presents the parameter estimation and hypothesis results of the users' AR-HUD usage intention model.

The results show that most of the hypotheses are validated, and the collected user data highly sustain our hypothetical model. Specifically, two perspectives—cognitive factors and social factors—are investigated in our proposed users' AR-HUD usage intention model. On the one hand, it confirms that effort expectancy has a direct effect on users' acceptance of AR-HUD (H1, β = 0.153, p = 0.004) and verifies the mediating role of performance expectancy (H3, β = 0.182, p < 0.001; H4, β= 0.147, p = 0.006). On the other hand, social influence indirectly affects users' intention to use AR-HUD through the mediating role of perceived trust (H5, β = 0.698, p < 0.001; H6, β = 0.109, p = 0.041), and personal innovation serves as a moderating variable to regulate the strength of social influence on perceived trust (H7, β = −0.813, p = 0.004). Finally, H2 does not hold, and the path coefficient of H7 is in the opposite direction of the hypothesis. The results are shown in Table 4 and Figure 2.

Table 4. Structural model results.

Dependent Variable	Hypothesis	Path	β	p Value	Hypothesis Supported
UI	H1	EE→UI	0.153	0.004 **	Supported
	H4	PE→UI	0.147	0.006 **	Supported
	H2	SI→UI	0.030	0.547 $^{n/s}$	Not Supported
	H6	PT→UI	0.109	0.041 *	Supported
PE	H3	EE→PE	0.182	<0.001 ***	Supported
PT	H5	SI→PT	0.698	<0.001 ***	Supported

Note: * p < 0.05; ** p < 0.01; *** p < 0.001; n/s = not significant.

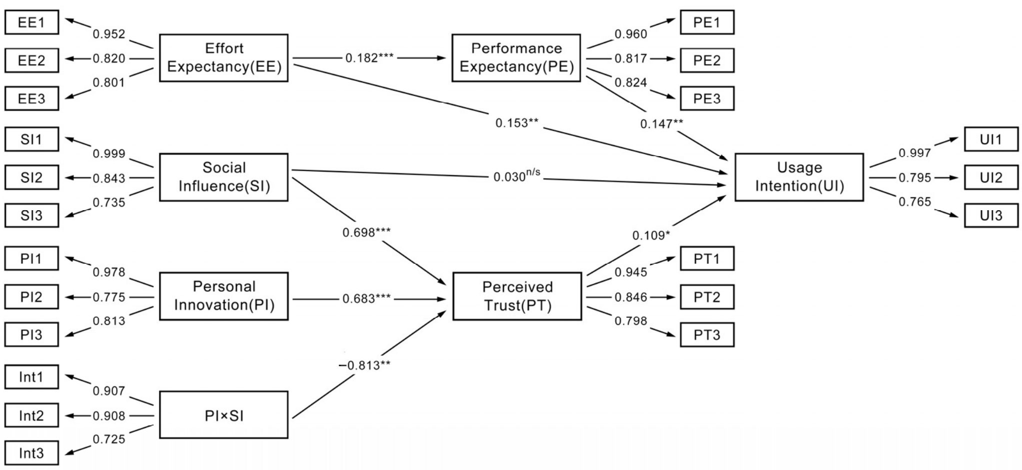

Figure 2. Structural model results. Note: * p < 0.05; ** p < 0.01; *** p < 0.001; n/s = not significant.

5. Discussion and Implications

5.1. Discussion of the Results

This study systematically explores the types of factors that influence users' acceptance of AR-HUD technology and how these factors affect users' usage intention.

The results of this study suggest that, for the dimension of cognitive factors, effort expectancy can directly affect users' intention to use AR-HUD, while indirectly affecting usage intention through the mediating role of performance expectancy. The results support the UTAUT proposed by Venkatesh, which combines several theories including the TRA, that both effort expectancy and performance expectancy can predict users' behavioral willingness to adopt the technology [22]. Several previous studies confirm that both effort expectancy and performance expectancy can significantly affect users' acceptance of emerging technologies in the automotive domain, such as autonomous vehicles [8,28,30,36], and the results of our data analysis similarly suggest that both are applicable to contemporary theoretical studies of automotive AR-HUD. In addition, the data analysis results simultaneously support the hypothesis that there is a mediating effect involved, which is highly analogous to the study on AR-HUD acceptance by Li et al., in which effort expectancy ultimately affects acceptance through the mediating effect of performance expectancy [16]; however, our study extends the direct effect of effort expectancy on AR-HUD usage intention. AR-HUD integrates virtual information with real road conditions precisely by utilizing the advantages of AR technology to the fullest extent and effectively combining with other in-vehicle devices. Users are more likely to be willing to use AR-HUD when they perceive that the interface information is intuitive, the layout and level of the information presentation are clear, and they perceive that using the technology can effectively save time and energy as well as improve driving performance.

From the perspective of social factors, social influence indirectly affects the usage intention of AR-HUD through the mediating role of users' perceived trust. In the UTAUT proposed by Venkatesh, social influence has a direct effect on users' behavioral willingness to accept the technology [22]; however, in the context of automotive AR-HUD technology, our data processing results suggest that the direct effect of social influence on the intention to use AR-HUD is not significant but requires a mediating role of perceived trust. We argue that the evaluation of AR-HUD according to the social environment in which an individual exists and the perception of whether they should adopt AR-HUD does not directly alter the individual's acceptance, because an individual has independent value judgment, which is likely to be based on a sense of trust. In their study, Li et al. found trust to be a direct factor affecting users' intention to use AR-HUD, but did not incorporate social influence as its antecedent variable [16]; instead, Li et al. argued that social influence is more relevant to the development of trust than cognitive or personal factors in technology acceptance [46]. In social information processing theory, Jayaram considered that individuals make trust judgments about uninformed objects by observing the behavior of others in the social environment; they then encode, store, process, and interpret the received social information to adopt appropriate attitudes and behaviors [52]. Since AR-HUD is an emerging technology that has not yet been launched into the public's vision, the public lack sufficient and objective knowledge about it, and are likely to interpret the opinions of others in social networks so as to modify their trust in AR-HUD, thus affecting their usage intentions and behaviors.

What is noteworthy is that, in the AR-HUD context, personal innovation significantly moderates the effect strength of social influence on perceived trust with a substantial influence, and, contrary to our hypothesis, the direction of this moderating effect is negative. The effect of social influence on perceived trust is low when the level of personal innovation is high, while its effect is higher when the level of personal innovation is lower. We consider that, to a large extent, this result is related to the individual's personality traits. Midgley and Dowling define innovativeness as a set of personality traits that individuals possess to a greater or lesser extent [49]. According to the diffusion of innovation theory, Rogers classifies individuals into five categories of innovation adopters based on their level of innovation, including early adopters, who are described as willing to try and pioneer new technologies, and laggards, who are relatively conservative and only passively accept new technologies when they become mainstream [47]. We believe that when an individual's level of personal innovation is relatively high, the individual has their own opinion and value judgment about the innovative technology, and thus their perceived trust in AR-HUD may be less affected by social influence. In contrast, when an individual's level of personal innovation is relatively low, their comparatively conservative personality is usually accompanied by a stronger herd mentality, and thus it is likely that their perceived trust in AR-HUD is more susceptible to the effect of social influence. To some extent, our results confirm previous studies, where Persaud and Schillo propose that consumer innovation moderates the relationship between social influence and perceived value, which in turn affects the willingness to purchase organic products; the direction of the moderation differs from the expected hypothesis, where this moderation is not significantly related to innovation laggards, while the relationship is significant and negative for innovators [53].

5.2. Theoretical and Practical Implications

To start with, this study expands on theories related to automotive AR-HUD technology and explores the influential factors and pathways that affect users' intention to use AR-HUD. Previous research on AR-HUD has mostly focused on practical technological implementation [54–56] or interactive interface design based on improved driving performance and reduced cognitive load [57,58], while theoretical models that establish the mechanisms influencing individuals' willingness to adopt the technology has been absent. Therefore, based on relevant theories and previous studies, we propose a model of automotive users' AR-HUD usage intention. Our study reveals that users' effort expectancy affects their intention to use AR-HUD through the mediating role of performance expectancy, while the model confirms that social influence regarding AR-HUD affects usage intention through the mediating variable of individual perceived trust, and that personal innovation serves as a moderating variable to regulate the strength of the effect of social influence on perceived trust. In conclusion, this study broadens the exploration of factors affecting users' acceptance of AR-HUD and provides a novel, fine-grained perspective on the mode in which cognitive and social factors affect AR-HUD usage intention.

In addition, this study also contributes to the practical value of the development of automotive AR-HUD technology, and the users' usage intention model we constructed for automotive AR-HUD can serve as a reference paradigm for the promotion of this technology in society. On the one hand, based on the perspective that user effort expectancy affects usage intention through the mediation of performance expectancy, the automotive design sector should continuously optimize the user-centered interaction interface design of AR-HUD to constantly improve the ease of use and usability of the system so as to improve the user experience. Research in this area has been advanced in the past, and different scholars have previously explored the relationship between interface design, user cognition, and user experience [57,58]; however, iterative design with close attention to user requirements is still necessary in the future. On the other hand, based on the finding that social influence indirectly affects the intention to use AR-HUD through the mediating role of users' perceived trust, and that personal innovation plays a moderating role between social influence and perceived trust, policymakers in the automotive sector should focus on promotional and marketing activities while developing the technology, and the propaganda department should reinforce the public's objective perception of automotive AR-HUD, focusing on communication and innovation improvements and enhancing consumer psychological simulation through streaming services [59], which can decrease users' perception of risk and thus boost user trust. Additionally, attention should be paid to the early adopters of the innovation, who generally belong to the socially active group with appealing power. Their subjective evaluation can effectively influence the overall evaluation of emerging technologies such as AR-HUD by the general public, so that the innovative technology can be effectively spread and disseminated, and the public usage intention of AR-HUD can be enhanced in the social network on a larger scale.

The World Health Organization and the United Nations have jointly developed the Global Plan for the Decade of Action for Road Safety 2021–2030. The plan moves away from a step-by-step approach and calls on governments and stakeholders to take a new path: prioritizing and adopting an integrated safety systems approach that sees road safety as a key driver of sustainable development. The goal is to reduce the number of road traffic casualties by at least 50 percent during this period [60]. This shows that countries have generally recognized that road traffic casualties have become one of the most serious factors threatening sustainable development, which will certainly drive the transformation of transportation systems. A study by Dingus et al. shows that driver errors of judgment, behavioral errors, and distracted driving account for 87.7% of motor vehicle crashes [61]. In this context, AR-HUD can enhance driver situational awareness and improve driving safety [5], and thus it can be a potential development direction to reduce road traffic casualties and advance the sustainable development goals of the United Nations, and many scholars are working to promote the safety and security capabilities of

AR-HUD for this purpose [62]. In addition, in the future, advanced AR-HUD technology is likely to be combined with the wave of new energy vehicles to create a new form of green mobility in sustainable cities. This study explores the factors that affect users' intentions to use AR-HUD and finds that factors such as users' perceived trust are drivers for the promotion of this emerging technology, which can contribute to the long-term development of sustainable transportation.

5.3. Limitations and Future Research

Our study still has some limitations that provide references for future in-depth research directions. Firstly, since automotive AR-HUD, as an emerging technology, has not yet been commercialized on a large scale, our data are largely based on potential consumer attitudes, and with the subsequent increase in AR-HUD penetration, the factors influencing the usage intention may shift at a rapid pace. Secondly, owing to the low penetration rate of AR-HUD, the influence of demographic variables on its usage intention has not shown any difference in reality, and therefore has not been included in our experimental variables; thus, subsequent studies can explore the influence mechanism of different demographic variables such as gender and age on usage intention. Thirdly, it is also worth noting that our study used convenience sampling for questionnaire data collection; therefore the sample is not sufficiently representative, and future research can use methods such as stratified sampling to improve the sample representativeness. Fourthly, a more diversified research approach can be adopted for AR-HUD exploration in the future, focusing on conducting longitudinal studies. Future research can employ a combination of research methodologies such as field interviews, rooted research, experimental research, and case studies. Finally, future research can take into account the new experience that AR-HUD brings to users in entertainment since the current research on the application of AR-HUD focuses more on its performance in security assurance, whereas the focus of AR-HUD is likely to change in the future due to the combination with autonomous driving technology.

6. Conclusions

Based on the TRA and UTAUT, this study jointly constructs an automotive users' AR-HUD usage intention model involving both cognitive and social factors. We draw conclusions by validating several hypotheses proposed through empirical studies. The findings show that users' effort expectancy affects users' intention to use AR-HUD through the mediating role of performance expectancy, while social influence affects users' intention to use AR-HUD through the mediating role of perceived trust, and personal innovation serves as a moderating variable to regulate the strength of the effect of social influence on perceived trust. Our study contributes to the understanding of the factors influencing the public's usage intention in the context of automotive AR-HUD technology.

Author Contributions: T.X. and T.L. designed the study. T.X. and Y.S. collected and analyzed the data. T.X. and X.L. wrote the first draft and revised version of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by grants from the National Social Science Foundation of China (18BYY089).

Institutional Review Board Statement: This work has been approved by the Departmental Ethics Committee and the Institutional Review Board of the Guangdong University of Technology (No. GDUTXS2022093).

Informed Consent Statement: Written informed consent has been obtained from the participants to publish this paper.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors report no conflict of interest in this work.

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