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Continuous Usage Intention of In-Vehicle Infotainment Systems: An Integrated ECM-TAM Approach

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Article

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Abstract

In-vehicle infotainment systems (IVIS) differ from static information systems due to complexity, safety-critical nature, and over-the-air (OTA) evolution. While initial adoption is well known, the driving forces of continuous intention to use (CITU) are still poorly studied. Integrating the Expectation-Confirmation Model (ECM) and Technology Acceptance Model (TAM), this study explored how intrinsic motivations—perceived security (PS), perceived usefulness (PU), perceived ease of use (PEU), and perceived enjoyment (PE)—interact with external factors, including system & service quality (SSQ), confirmation (CON), and satisfaction (SAT), to influence CITU. 516 Chinese users were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). Results showed that the framework was powerfully explanatory. PS emerged as the main driving force of CITU, surpassing PU and PE, underscoring the criticality of risk aversion in smart mobility. SSQ and PU are identified as primary antecedents of SAT. Mediation showed that CON affects CITU via multiple paths, and the functional route (CON → PEU → SAT → CITU) is the strongest influenced. These results suggest that while OTA updates change user expectations, long-term engagement depends on security and utility against hedonic experiences.

1. Introduction

1.1. Research background

Driven by rapid digitalization, the automotive industry is changing rapidly[1], and the IVIS has emerged as a critical embedded operating platform Vehicle diagnostics[2], navigation[3], entertainment and communication[4]. The IVIS position automobiles as the third-largest mobile media terminal and intelligent interconnection platform, after television and smartphones[5,6].

The widespread adoption of IVIS[7] makes it a standard feature of new cars[5]. Other than encouraging technological acceptance, automakers have also put IVIS as a tool to enhance user experience and brand loyalty[8]. Driver Monitoring System (DMS)[9] monitors driver fatigue and distraction level in real time and issues safety alerts to reduce accident risk. Intelligent seat system (ventilation, massage, adjustment, and vital sign monitoring)[10] reduces driving and riding fatigue, maintains driver alertness, and provides comfort and stability during long drives. More functions of safety and comfort are developed and deployed in order to improve driving safety and user experience.

The purpose of this paper is to study unique use cases, strict safety standards, OTA capability, improved user experience, and new business strategies of smart vehicles. We aim to understand why users continue to use IVIS and the gap between initial adoption and ongoing usage intentions.

1.2. Literature review

IVIS not only fulfills driving and entertainment needs through physical features but also through emotional design. Physically Multimodal interaction[11] (see, hear, touch, taste, smell) improves device control efficiency (e.g.,) while driving, reduces distraction and improves safety, and a private

headrest[12]improves independence and privacy in the cabin. From the emotional side, customized music recommendations [7]and ambient light adjustments[13] enhance entertainment and relaxation, and reduce stress and fatigue in long journeys. The onboard sensor detects accidents and hazards, enabling accurate positioning and automatic alerts to emergency services[14].

The ECM proposed by Bhattacherjee[15] is a theoretical framework for considering continuance intention in information systems (IS). In the automotive sector, the ECM and extended versions have been used to identify factors influencing continued use of autonomous driving services[16] and electric vehicles[17], and to assess acceptance and perceived effectiveness of functional constraints[18]. The TAM introduced by Davis[19,20] has been used widely to assess and predict user adoption of vehicle-related technologies. It provides a theoretical framework for the study of GPS navigation systems[21] and future in-vehicle interfaces[14]. Beyond conventional applications, TAM is often used to deconstruct acceptance of autonomous driving technology. To enhance the explanatory power in this domain, researchers often extend the core model by contextual variables such as social attitudes[7], perceived risk (PR), sensation seeking[22], and safety[23].

Using these theories, we show how external factors play an important role in driving IVIS acceptance. Experiments show that PU and PEU are the main drivers for IVIS acceptance[24]. For vehicle pre-warning systems, PEU is the main factor driving acceptance and use[25]. In the same way, internal factors influence user behavior[26], quality of electric vehicles[17], PS bias[27], and PE[16] are strong predictors of their intention to adopt and use new technologies.

1.3. Identification of Research Gaps

Most IVIS research is still in its early stages of application. Most of the empirical work is focused on TAM and extensions with emphasis on PU and PEU as key factors for user acceptance of navigation systems[3] and vehicle monitoring systems[25]. In the area of advanced driver assistance systems (ADAS), research focused on the PS role in user acceptance decisions[28]. While we identified key factors for initial acceptance, we did not address fundamental differences between users' initial acceptance and willingness to continue using the system[29]. This gap has directly prevented enterprises from developing effective user retention strategies. From a commercial perspective, sustained user engagement can lower customer acquisition costs and enhance user lifetime value through models such as service subscription[30] and data value-added services[31].

ECM has proved to be highly explanatory. It has been validated in specific IVIS contexts such as in-car gaming[32] and interface aesthetics[8]. These results suggest that ECM is a theoretical complement to TAM for dealing with the cognitive complexity of user continuance. In addition, the literature on IS suggests that a coherent ECM-TAM model provides a more general approach. Based on motivation theory, it distinguishes user motivations into intrinsic and extrinsic types[33–35]. By anchoring users' intrinsic expectations, it reveals the complexity of satisfaction and service quality from multiple dimensions, and

thus the driving forces for sustained engagement. This model has been widely supported in fields such as smart wearable devices[36] and mobile instant messaging[37].

At present, IVIS research exhibits theoretical limitations: it has not fully deconstructed the internal mechanisms linking technical satisfaction to users' psychological changes[38], nor has it effectively integrated a dynamic coupling framework for extrinsic motivation; consequently, it struggles to comprehensively reveal the multidimensional drivers of users' continued-use intention.

Second, current studies on IVIS lack a dynamic perspective. This is manifested mostly by studies that treat IVIS as a static system in real environments (say, laboratory conditions)[39,40] which reflect not only real driving conditions[1,6,27,41], but also how user expectations are changed by IVIS OTA updates[42]. These environmental factors combined with continuous updates have a persistent impact on user cognition and pose ongoing safety issues. Design practices are starting to explore ways to help users adapt to changes in the environment and updates, such as reducing information interference in HMI design to reduce cognitive load[43] or using hierarchical display and smart filtering to ensure important information is prioritized[44], which allows us to account for dynamic changes in IVIS. Therefore, current IVIS research overlooks real-world driving and the constant effects of OTA updates and how user behavior evolves over time.

In response to the limitations identified above, this research aims to mitigate these deficiencies from the following two dimensions:

First, this study conducts a quantitative analysis to compare the varying intensities of internal and external motivation that influence the willingness to continue using IVIS, thereby elucidating the distinct mechanisms by which these factors affect users' ongoing usage behavior.

Second, it investigates the specific mechanisms that influence users' willingness to continue using IVIS, focusing on OTA updates and examining the mediating roles of expectation confirmation and satisfaction.

1.4. Research purpose

This study uses ECM-TAM integration to investigate how system and SSQ influence the intention to continue using IVIS, mediating variables like CON and SAT. We investigate how SSQ influences CON, mediating perceptual factors such as PEU, PU, PE and PS, resulting in CITU through SAT. We combine a questionnaire survey with partial least squares structural equation modeling (PLS-SEM). The expected results show different degrees of influence of internal and external factors and emphasize the role of functional pathways (e.g., CON→PU→CITU) over emotional ones (e.g., CON→PE→CITU). This study addresses the following questions:

1. What is the relative influence of internal and external factors (such as PS, PE, PU, PEU) on the likelihood of using IVIS? How do these factors differently influence user behavior through distinct

mechanisms?
2. How does SSQ specifically influence the intention to continue using IVIS through the mediating paths of CON and SAT? What role does OTA dynamism play in this process?
3. What are the differing roles of functional pathways (e.g., CON→PU→CITU) and affective pathways (e.g., CON→PE→CITU) in conveying the expected confirmation effect on the intention to continue using IVIS?

This study extends the ECM-TAM model by adding intrinsic motivation and the dynamic external factor of SSQ together. By merging intrinsic motivation and the dynamic external factor of SSQ together, the static model of acceptance of technology is able to overcome cognitive limitations and provides new perspectives on complex and evolving behavior choices in human–machine collaboration scenarios. In practice, the results help automakers optimize IVIS design and OTA updates.

1.5. Research purpose

The organization of this paper is as follows: it commences with a review of the theoretical foundations of IVIS research, followed by a detailed description of the methodology employed. Next, the structural validity and reliability of the experimental results are evaluated. The paper culminates in a comprehensive discussion of the results and the formulation of concluding remarks.

2. Research model and hypotheses

2.1. Current State of Research on IVIS

To provide a comprehensive contextual foundation, this section delineates the technological evolution and the current scholarly landscape of IVIS.

IVIS has evolved from text-based interfaces to graphics-based interfaces to touch screens, multimodal interfaces, and wireless communication[45] through the integration of software and hardware, to provide complex and varied interaction[46] functions such as user instruction execution, information acquisition help, task collaboration[47], SSQ theories and users' needs.

IVIS can be classified into functional and service categories, which include software and hardware implementations, information presentation, and information sharing. It ensures system stability through high-performance software and hardware[11,48]; adapts to various scenarios and stakeholders in the smart car market[1,6,41]; improves comfort[49] and safety features[23]; and improves cabin experience and user perception of software and hardware quality. Information presentation focuses on efficient transmission and security by improving information quality[2] and balancing hardware implementation and services. Improves interaction experience, security, and visual support for personal experiences, system updates, and data security in the service functionality category.

The service functionality category contains several important aspects. Firstly, OTA updates use wireless technology to improve system performance, security, and fix vulnerabilities[50], supporting system development. Finally, user support and personal service provide tailored experiences and real-time responses based on user behavior[51], boosting responsiveness and perceived empathy. Finally, data security safeguards user privacy through encrypted communications and vulnerability correction[52], increasing trust among users and service reliability. Table 1 presents the system architecture, technical paradigm, functions, and features of IVIS.

Table 1
System Architecture, Technical Paradigm, Functions, and Characteristics of IVIS

system architecture	Technological Paradigm	Functional Description	Features
Software and hardware	Center Console[53]	High-performance hardware and software support system stability.	Adaptability、Availability、Reliability、Response time、Usability[47]
	Head-Up Display (HUD)[6]	By integrating multimodal interaction technology and through the collaborative complementarity among different sensors, the user experience and driving safety are significantly enhanced.	
	Voice Recognition[5]		
	Gesture Recognition[54]		
	Face Identification[55]		
	Haptic Recognition[56]		
	Multi-screen Collaboration[57]	Suitable for a variety of scenarios	
	Intelligent Seat[10]	Enhance cabin comfort, entertainment, adaptability, and privacy	
	Intelligent Steering Wheel[58]		
	AR/VR[59]		
	In-Vehicle Robot[60]		
	Interactive Ambient Lighting[13]		
	Audio System[7]		
	Privacy Headrest[12]		
	In-Vehicle Monitoring System[61]		
	Driver Posture Recognition[9]		
	Attention Monitoring[62]		

system architecture	Technological Paradigm	Functional Description	Features
	Communication Services[4]		
Information Presentation	Navigation & Real-time Traffic Information[63]	Dynamic path optimization and real-time traffic updates ensure completeness, understandability and relevance	Completeness Ease of understanding Personalization]Relevance Security[47]
	Screen Transition Animations[64]	Optimized interface design, reasonable transition methods, and appropriate transition types and intervals can significantly enhance satisfaction and perceived quality	
	Information Layout on Screen[65]		
	Safety Information Entertainment Information Social Information[2]	Through technologies such as smart cameras and HUDs, driver fatigue detection, line-of-sight deviation warning and vehicle posture monitoring are achieved, effectively reducing the risk of driver distraction.	
Software Services	OTA[66]	Regularly optimize system performance, fix vulnerabilities or add new features	Assurance]Empathy Respoånsiveness[47]
	Personalized Customization[51]	Music recommendations, driving mode adjustments, and travel route recommendations enhance entertainment	
	Real-time Response[45]	Remote customer service in emergency situations and AI assistants	
	Data Security Services[52]	Adopt encrypted communication and vulnerability repair mechanisms to protect privacy and enhance the sense of trust in service quality.	

The technology is changing rapidly, and IVIS not only improves its function as a driving-assistance tool but also improves user self-actualization and pleasure through non-instrumental qualities and emotional design[67]. Reconstruction of the business ecosystem and cross-industry entry of Internet companies are

driving a paradigm shift in the automotive sector[68]. IVIS is a new point of access to mobility, and the business model of “hardware micro-profit + service value-added” is evolving. The system integrates safety, comfort, entertainment, and connectivity to give the user a new and enjoyable experience[69].

Traditional information systems quality comprises information quality and system quality[70]. Digital information systems integrate service quality into the information systems success model to better assess system performance and user perception[47]. Ahn extended the TAM model to analyze users’ intention to use online retail websites and found that website quality, system quality, information quality, and service quality strongly favor active shopping behavior[71]. Yi-Shun Wang[72] identified system quality, information quality, and service quality as the main drivers of e-commerce system success. Eunil Park[36], in a study on the acceptance of smart wearable devices, showed that system quality and service quality influence users’ willingness to adopt these technologies. IVIS system has three main modules: software and hardware implementation, information presentation, and services (see Table 1). As a complex hybrid information system, it combines hardware product characteristics and software service orientation[6,41], blurring the boundary between driving assistance and entertainment[73]. These characteristics are closely aligned with existing dimensions of information system quality and service quality, yielding multidimensional quality characteristics. Therefore, quality of integrated information systems and service quality are considered as upstream variables.

PS researchers have investigated the extended TAM. Klara Ljubi showed that perceived safety is a key factor in user acceptance of automated driving aid[74]. Zhang extended this finding by showing that initial trust is the key to user acceptance, and the first requirement to develop it depends on the user's cognitive evaluation of its reputation, quality, and security. He also identified PU and PS as key elements in initial trust[75]. Jihye Lee reported that PU, self-efficacy, PS, relative advantage, and psychological ownership have been shown to influence acceptance of assisted driving[76]. In digital security research, scholars studied PR for IVIS on intelligent connected vehicles.

Some technological improvements enhance PS along two lines. Guy H. reduced drivers’ task load by automated task research to improve driving safety[77]; Li Shuang developed an IVIS evaluation framework to improve functional safety[78]. However, they do not take into account the role of emotional experience in meeting users’ needs. Intelligent cockpit technology evolves rapidly, and improving safety is the main goal[79]. Although improving system performance can optimize user emotions and trust model, there are two new research challenges. First, the dynamic coupling between technological innovation, user preferences, and security needs is not understood. Second, higher system performance may lead to overtrust risk[80]. Experimental studies indicate that PS, system availability, and user pleasure are strongly in tension. We treat PS as an extended variable and investigate dynamic effects on users.

PE is the main motivation for technology use, while user emotions are the actual result of interaction[81]. The system of IVIS is complex and distinct (Table 1), and its emotional attributes, which complement functional attributes, strengthen positive emotional connection between users and vehicles[82].

This IVIS research focuses on tool attributes, such as a locking system to decrease driver distraction and improve safety and enjoyment[18], and information transmission and driver assistance functions to improve efficiency, safety, and enjoyment[7]. In addition, IVIS PE is aesthetically pleasing[8], multimodal interaction[11], and personalized content for pleasure, which is tied to human well-being and satisfaction[83]. However, most user models emphasize PU and PE as separate factors in technology acceptance while neglecting long-term dynamic interactions between product performance and emotions[81]. As the IVIS system is updated by OTA technology, dynamic changes in users' emotions are increasingly impacting their willingness to continue using it[84]. Existing research shows a significant gap in explaining how PE shapes user behavior and exploring dynamic emotions. We consider PE as a broad research variable.

2.2. Theoretical Basis

2.2.1 Expectation-Confirmation Model (ECM)

Bhattacherjee's ECM theory has a fairly well-developed model, where CON, SAT, and expectations following use[85] are key drivers of users' use, and how users change expectations depending on feedback on their own and other users[15].

This model has been widely applied to study user acceptance of smart wearable devices[36]. Researchers have applied ECM frameworks across diverse contexts, including mobile instant messaging[86], e-learning[87], and Internet television[88].

In the present IVIS work, single functions have been studied more broadly, such as the reasons why in-vehicle games continue[32] and locking in infotainment systems[39]. As a complex human–computer interaction system, IVIS has multifunction synergy effects which differ significantly from influence mechanisms of isolated functions[3]. Hence, ECM can only explain IVIS systems.

2.2.2 Technology Acceptance Model(TAM)

TAM[19] s an important theory to evaluate the use of new technologies and services. PU and PEU are perceived variables that determine user acceptance of information technology[20].PU indicates the user's opinion of whether a technology improves work efficiency or quality of life, and PEU indicates the user's opinion of difficulty using it.

This model has demonstrated broad applicability across multiple domains. It has been shown to explain willingness to use traditional shopping and mobile payments in e-commerce[89], acceptance of traffic information[90], and adoption of shared bicycle systems[91].

2.2.3 The Theoretical Basis and Research Model

To capture the multi-dimensional drivers of continued IVIS use, this study employs an integrated ECM–TAM framework. The integration compensates for the theoretical limits of any single model in complex IVIS contexts.

First, this integrated framework addresses users' journey from initial adoption to continued use. ECM emphasizes cognitive feedback during continuous use, but it is not enough to integrate external perceptual factors driving initial acceptance[3]. Many studies extend the ECM. For example, studies on continuous use of autonomous driving integrate UTAUT2, Coolness Theory, PS, brand value, and loyalty to establish user SAT as the central factor driving continued use[16]. For new energy vehicles, PS, environmental concern, Task-Technology Fit, perceived value, and government support are used to explain how electric vehicle quality impacts drivers' continued use behavior[17].

Although TAM has few variables and a static structure[92], the long-term dynamical interactions between drivers and complex in-vehicle technologies are difficult to model. Its basic structure easily accommodates EA[93], PE, trust[21], and hence provides more systematicity and explanatory power.

The two models complement each other: TAM provides external perception, and ECM fills the internal dynamic pathway. Together, they capture IVIS user behavior from initial trial to long-term adaptation. SSQ acts as the main variable that, via CON mediation, influences the TAM core perceptual factors (PU, PEU, PE, PS), and CITU through SAT.

Second, we can better adapt to the IVIS operating environment. TAM emphasizes initial acceptance but ignores users' adjustment after implementation[92]. The main variables of the framework (PU, PEU, CON, SAT) are closely related to extended ECM-IT (EECM-IT). The extended ECM-IT captures more detail on the dynamic evolution of user beliefs after technology adoption and allows detailed empirical analysis of key relationships across different stages of technology development. Compared with ECM-IT, EECM-IT increases R2 for continuing intention to use IT by more than 15%[94]. This supports the explanatory power of this framework. For sustained willingness to use mobile instant messaging, Oghuma[37]integrated the ECM–TAM framework to study how SSQ, CON, PU, PE, UI, and SAT affect continuance intention. High service quality, well-integrated enjoyment features, and appealing interface design increase user willingness to continue. In this empirical case, we prove that the integration framework can extend beyond general information systems to IVIS contexts with higher technical requirements and more complex interactions.

2.3. Research hypotheses

2.3.1 Satisfaction

Satisfaction is the overall post-experience evaluation of users after first interaction with the product or service[95] based on psychological responses to purchase or use[96]. A system that meets expectations increases satisfaction[97] and thus encourages technology adoption[98]. If real experience meets or

exceeds expectations, satisfaction increases, thereby strengthening loyalty and continuing use[99]. In this paper, satisfaction is defined as the overall post-experience evaluation formed after the first interaction with the IVIS system. It measures psychological and emotional responses during interaction and determines whether system performance meets or exceeds expectations, influencing continued use intentions. Based on this theory, we propose the following hypothesis:

H1: SAT positively influences the CITU of IVIS.

2.3.2 Confirmation

Confirmation refers to the user's psychological judgment on whether the actual performance of an information technology system meets or exceeds expectations after first use[87,100]. Based on cognitive dissonance theory, if the actual experience meets or exceeds expectations, confirmation increases, the expected benefits of the system are realized, and satisfaction increases[37]. This mechanism also describes the relation between CON and PEU, PU, PE, and PS. Improved system performance will raise CON, reduce dissonance between expectations and experience, and thus increase SAT and continue use intention. CON is operationalized as the comparison between users' actual IVIS experience and their initial expectations: If expectations are confirmed, users tend to feel satisfied with the IVIS and recalibrate their PEU, PU, PE, and PS according to real usage. Based on this theory, we propose the following hypotheses:

H2: CON positively influences the SAT of IVIS.

H3: CON positively influences the PEU of IVIS.

H4: CON positively influences the PU of IVIS.

H5: CON positively influences the PE of IVIS.

H6: CON positively influences the PS of IVIS.

2.3.3 System & Service Quality

System quality is usually defined as system performance perceived by users when using an information system[70]. Service quality is perceived by users as quality of service[101]. In previous work, system quality and service quality are considered to be important antecedents of SAT in IS[102]. User SAT depends not only on actual performance of the system but also on the dynamic alignment between user expectations and actual experience. CON behavior captures changes in user perception by comparing expectations and actual performance[37]. In this paper, SSQ is defined as the perceived alignment between user expectations and real performance of an IVIS system; when performance meets expectations, SSQ significantly increases system SAT. Based on this theory, we propose the following hypotheses:

H7: SSQ positively influences the CON of IVIS.

H8: SSQ positively influences the SAT of IVIS.

2.3.4 Perceived Ease of Use

PEU is widely recognized as the major cognitive factor in user acceptance in the initial stages of technology adoption[19]. As a response[103], PEU can increase user SAT in domains[104,105], but with continuous use, PEU's influence on SAT decreases[19] and thus reduces its role in CITU[29]. PEU refers to the user's initial acceptance of an IVIS: a simpler, easier-to-use system reduces learning costs and increases initial SAT. As users advance in use, the effect gradually weakens. Based on this theory, we propose the following hypothesis:

H9: PEU positively influences the SAT of IVIS.

2.3.5 Perceived Usefulness

PU is the extent to which users think using a particular system will improve their job performance[19]. It is the sum of how an information system performs tasks[96]. Users prefer behaviors with tangible benefits over ones driven by the experience. IVIS users make rapid decisions, usually using simple decision rules: Will this system help me to complete tasks more efficiently? These decisions are usually automatic, without a conscious evaluation of pleasure or reward[15].

As a cognitive belief, PU strongly influences users' intentions at every stage of interaction with the system[29] and is strongly associated with adoption, SAT and CITU.PU is the benefit the user perceives of the functionality value of the system at the first IVIS experience, leading to increased SAT; after use, this value becomes product dependent, and the user automatically decides to use. Based on this theory, we propose the following hypothesis:

H10: PU positively influences the SAT of IVIS.

H11: PU positively influences the CITU of IVIS.

2.3.6 Perceived Enjoyment

PE is the pleasure of using a technology[106]. Previous studies show that PE improves users' SAT and acceptance[107], psychology[108], and marketing[109]. PE positively affects WITU[36,110]. PE is pleasure experienced by users of IVIS. With constant OTA system upgrades, users can have a pleasant experience that stays stable over time. Based on this theory, we propose the following hypotheses:

H12: PE positively influences the SAT of IVIS.

H13: PE positively influences the CITU of IVIS.

2.3.7 Perceived Security

PS refers to users' subjective beliefs about a system's safety, which directly influence user SAT[111]. Previous work showed that inadequate security reduces user WITU and loyalty, while effective security solutions increase SAT and continued use[112]. In this paper, PS refers to users' beliefs and SAT about physical and digital security of an IVIS and the system's ability to maintain user safety over time. Based on this theory, we propose the following hypotheses:

H14: PS positively influences the SAT of IVIS.

H15: PS positively influences the CITU of IVIS.

The research model is shown in Fig. 1.

3. Research Methods

3.1. Questionnaire

This study was reviewed and approved by the Biomedical Ethics Committee of Hefei University of Technology. All procedures involving human participants were conducted in strict accordance with relevant ethical guidelines and regulations as well as the principles of the Declaration of Helsinki. Prior to data collection, all participants were fully informed of the research objectives, survey procedures, expected completion time, and the voluntary and anonymous nature of participation via the homepage of the questionnaire. Written informed consent was obtained from all adult participants before formal survey completion. No minor or adolescent subjects were involved in this study, and all collected data were used solely for academic research purposes.

The official questionnaire comprised two parts. The first part collected respondents' demographic characteristics, including gender, age, education, occupation, and frequency and duration of use. The second part contained 31 items measuring eight constructs: CON, SSQ, SAT, CITU, PEU, PU, PE, and PS. All items used a 5-point Likert scale (1: strongly disagree; 5: strongly agree). Measures were drawn from the literature and adapted in accordance with standard psychometric scale development procedures[113]. The items measuring CITU, CON, and SAT were adapted from Bhattacherjee[15], Davis[19], Oghuma[37], and Tan & Kim[114]. PEU items were drawn from Briz-Ponce[115], Flavián[116], Hyo-Jeong[104], and Moon[117].PU is adapted from Davis[19], Thong[73], and Moon[117].SSQ is adapted from Roca[118]and Yi-Shun Wang[72]. PS is adapted from Osswald[119], Susanto[112], and Se Hun Lim[120]. To ensure rigor and professional language, four experts in intelligent vehicles reviewed and revised the manuscript prior to formal submission, aligning it with the research topic and academic norms. Appendix A presents the questionnaire content.

3.2. Procedure

This study collected research data via online questionnaires distributed to users of JAC intelligent vehicles in China with the support of JAC Motor Company. Before respondents formally completed the questionnaire, the homepage informed participants of the core research purpose. The questionnaire

instructions clearly stated the principles of voluntary participation, anonymity, and truthful response. All respondents were assured that the collected data were solely for academic research purposes and that their personal privacy would be strictly protected. The data were analyzed with SPSS 29.0 and SmartPLS 4.0. Given the relatively small sample size, we employed partial least squares structural equation modeling (PLS-SEM), which does not require normally distributed data and accommodates complex models with many constructs, indicators, and structural paths[121]. Accordingly, SmartPLS 4.0 was used to test the model and hypotheses. Because all data originated from a single source, we assessed common method bias using SPSS 29.0. The survey was conducted from January to April 2026.

3.3. Samples

A total of 540 questionnaires were distributed in this study. After excluding invalid responses, 516 valid questionnaires were collected, yielding an effective response rate of 95.6%. Among the respondents, 298 were male (57.5%), and 218 were female (42.25%). The data further indicated that most participants had purchased smart cars within the past two years, with prices predominantly ranging from 150,000 to 350,000 RMB. Additionally, the majority reported frequent use of the IVIS. Table 2 presents the demographic characteristics of the respondents.

Table 2
Demographic sample of participants

Item	Category	Frequency (n = 516)	Percent %
Gender	Male	298	57.75%
	Female	218	42.25%
Age (years)	18 ~ 24	71	13.76%
	25–34	247	47.87%
	35–44	131	25.39%
	45–54	49	9.50%
	≥ 55	18	3.49%
Education	Less than college	59	11.43%
	College	112	21.71%
	Undergraduat	271	52.52%
	Post-graduate	66	12.79%
	Doctor	8	1.55%
Smart car purchase period	After 2022	133	25.78%
	2022	236	45.74%
	2021	72	13.95%
	2020	47	9.11%
	Before 2020	28	5.43%
Smart car purchase price (□10,000 yuan)	< 15	87	16.86%
	15–25(including 15)	122	23.64%
	25–35(including 25)	139	26.94%
	≥ 35	168	32.56%
Frequency of use of IVIS	Every time I drive	44	8.53%
	Often	167	32.36%
	Sometimes	136	26.36%
	Seldom	121	23.45%
	Never	48	9.30%

4. Results

4.1 Common Method Bias

The data were collected using questionnaires. To reduce common method variance[122], though necessary controls were implemented during surveys, additional measures were taken to improve the study. Before data analysis, we used the Harman single-factor test for statistical control by performing unrotated principal component analysis on all variables. Results obtained in SPSS 29.0 showed that the first factor was responsible for 38.7% of the variance, less than the critical 50%. These results indicate that the data are not common method biased.

4.2 Reliability and Validity Test

We used partial least squares structural equation modeling (PLS-SEM) to evaluate the reliability and validity of 516 valid survey responses (Table 3). Composite reliability (CR) and Cronbach's coefficients for all constructs were 0.70[123] and are adequate. Average variance extracted values were 0.50[123] and are consistent and convergent.

Table 3. Loadings, reliability, and convergent validity.

Variables	Items	Factor Loading	CA	CR (α)	AVE
CITU Continuance Intention to Use	CITU1	0.872	0.856	0.912	0.777
	CITU2	0.887			
	CITU3	0.884			
CON Confirmation	CON1	0.879	0.818	0.892	0.733
	CON2	0.852			
	CON3	0.838			
PE Perceived Enjoyment	PE1	0.857	0.828	0.897	0.744
	PE2	0.866			
	PE3	0.864			
PEU Perceived Ease of Use	PEU1	0.872	0.886	0.913	0.638
	PEU2	0.784			
	PEU3	0.822			
	PEU4	0.795			
	PEU5	0.759			
	PEU6	0.755			
PS Perceived Security	PS1	0.83	0.792	0.878	0.705
	PS2	0.851			
	PS3	0.837			
PU Perceived Usefulnes	PU1	0.835	0.826	0.884	0.656
	PU2	0.805			
	PU3	0.806			
	PU4	0.795			
SAT Satisfaction	SAT1	0.921	0.9	0.938	0.834
	SAT2	0.91			
	SAT3	0.908			
SSQ Service & System Quality	SSQ1	0.842	0.874	0.905	0.615
	SSQ2	0.755			
	SSQ3	0.752			

SSQ4	0.785
SSQ5	0.769
SSQ6	0.797

In order to verify the measurement, we also checked discriminant validity. First, all loadings of items were less than 0.7 and statistically significant ($p < 0.001$); hence, we converge well. Second, Table 4 shows that, according to the Fornell-Larcker criterion[124], the square root of the average variance extracted (AVE) of each construct was more than its highest correlation with any construct.

Table 4. Discriminant validity (Fornell-Larcker criterion).

	CITU	CON	PE	PEU	PS	PU	SAT	SSQ
CITU	**0.881**							
CON	0.514	**0.856**						
PE	0.515	0.468	**0.862**					
PEU	0.573	0.462	0.446	**0.799**				
PS	0.524	0.432	0.424	0.453	**0.84**			
PU	0.506	0.371	0.427	0.435	0.391	**0.81**		
SAT	0.581	0.556	0.582	0.549	0.532	0.555	**0.913**	
SSQ	0.519	0.474	0.506	0.492	0.432	0.41	0.597	**0.784**

Notes: AVE's square root is shown in bold.

Finally, all heterotrait-monotrait (HTMT) ratios of correlations between variable pairs were below the discriminant validity threshold of 0.85 (Table 5). These results collectively demonstrate that the measurement model exhibits satisfactory discriminant validity[124], thereby allowing for subsequent hypothesis testing of the structural model.

Table 5. Discriminant validity (HTMT values).

	CITU	CON	PE	PEU	PS	PU	SAT	SSQ
CITU	—							
CON	0.611	—						
PE	0.609	0.564	—					
PEU	0.653	0.539	0.516	—				
PS	0.631	0.533	0.511	0.533	—			
PU	0.595	0.446	0.512	0.502	0.472	—		
SAT	0.659	0.646	0.668	0.611	0.623	0.637	—	
SSQ	0.596	0.556	0.59	0.554	0.513	0.478	0.67	—

4.3 Structural Model

This study used SmartPLS 4.0 to analyze the hypotheses using partial least squares structural equation modeling (PLS-SEM). PLS-SEM is very useful for modeling complex structural equation models as it investigates relations between variables and shows strong explanatory and predictive power. We bootstrapped with 5,000 subsamples and implemented the PLS predict method.

The coefficient of determination (R2) represents the proportion of variance in endogenous variables explained by exogenous variables. According to Falk & Miller's[125], R2 values should not exceed 0.10 for significance. As shown in Table 6, all R2 values in our model satisfied this requirement. As per the standard[126,127], R2 values of 0.19, 0.33, and 0.67 represent weak, moderate, and strong effects, respectively. In our model, SSQ, CON, PE, PEU, PS, and PU explained 59.4% variance in SAT, and SAT, PE, PEU, PS, and PU contributed 46.1% variance in CITU, which is a very strong explanatory power.

Furthermore, we assessed predictive relevance using Stone-Geisser's Q^2 statistic[128,129]. All Q^2 values in our study exceeded zero (Table 6), confirming the model's appropriate predictive quality[130]. This finding suggests that the model possesses adequate predictive relevance for the endogenous constructs.

Table 6. Values of R2 and Q

Construct	R2	R2 adjusted	Q2
CITU	0.461	0.457	0.182
CON	0.225	0.223	0.22
PE	0.219	0.218	0.174
PEU	0.213	0.212	0.166
PS	0.187	0.185	0.134
PU	0.138	0.136	0.113
SAT	0.594	0.589	0.325

Additionally, we employed goodness-of-fit measures to evaluate model residuals and covariate bias for comprehensive model assessment. The standardized root mean square residual (SRMR) was utilized to examine the structural model fit. Following Hu & Bentler's[131] criteria, SRMR values below 0.1 are considered acceptable, with a more stringent threshold of SRMR < 0.08 indicating excellent fit[131]. In the current study, the model demonstrated a strong fit, with an SRMR of 0.052, substantially below the rigorous 0.08 benchmark.

To complement R^2 analysis, we calculated f^2 effect sizes to evaluate the unique contribution of each exogenous variable to the explanation of the endogenous variable, independent of other predictors[132]. Consistent with Cohen's[126] guidelines, we interpreted f^2 values of 0.02, 0.15, and 0.35 as representing small, medium, and large effect sizes, respectively[126]. These metrics provide critical insights for model refinement and understanding variable importance within the structural framework.

Figure 2 presents the hypothesized structural model, displaying the estimated path coefficients (β) between constructs along with their corresponding significance levels, as well as the external loadings of indicator items and their statistical significance.

4.4 Hypotheses Test

The structural model was analyzed using Smart-PLS 4.0 software with bootstrapping resampling (5,000 subsamples at 95% confidence intervals). The path analysis revealed significant relationships supporting our hypothesized model (see Table 7). For CITU, significant positive predictors included SAT($\beta = 0.227, p < 0.001$), PU($\beta = 0.203, p < 0.001$), PE($\beta = 0.194, p < 0.001$), and PS($\beta = 0.242, p < 0.001$), thereby supporting H1, H11, H13, and H15. Effect size analysis showed PS had the strongest influence ($f^2 = 0.075$), followed by PU ($f^2 = 0.051$), SAT ($f^2 = 0.047$), and PE ($f^2 = 0.044$).

Regarding SAT, significant antecedents were CON($\beta = 0.167, p < 0.001$), SSQ($\beta = 0.210, p < 0.001$), PEU($\beta = 0.125, p < 0.001$), PU($\beta = 0.215, p < 0.001$), PE($\beta = 0.187, p < 0.001$), and PS ($\beta = 0.149, p < 0.001$),

supporting H2, H8, H9, H10, H12, and H14. Among these predictors, PU demonstrated the largest effect size ($f^2 = 0.08$), indicating its predominant explanatory power for SAT.

Furthermore, the analysis confirmed that SSQ significantly predicted CON (β = 0.474, p < 0.001; H7 supported), which in turn significantly influenced PEU (β = 0.462, p < 0.001; H3), PU (β = 0.371, p < 0.001; H4), PE (β = 0.468, p < 0.001; H5), and PS (β = 0.432, p < 0.001; H6). The effect sizes for CON's impacts were consistently medium-to-large across these endogenous variables: PEU ($f^2 = 0.271$), PE ($f^2 = 0.281$), PS ($f^2 = 0.230$), and PU ($f^2 = 0.160$), suggesting CON's robust yet varying explanatory contributions to these constructs.

Table 7. Summary of hypothesis tests.

H	Path	β	T statistics	P values	Supported	$f2$	Effect size
H1	SAT → CITU	0.227	4.567	0	Yes	0.047	Small
H2	CON → SAT	0.167	4.501	0	Yes	0.044	Small
H3	CON → PEU	0.462	13.248	0	Yes	0.271	Medium
H4	CON → PU	0.371	9.514	0	Yes	0.16	Medium
H5	CON → PE	0.468	13.944	0	Yes	0.281	Medium
H6	CON → PS	0.432	12.677	0	Yes	0.23	Medium
H7	SSQ→CON	0.474	14.197	0	Yes	0.29	Medium
H8	SSQ→ SAT	0.21	5.357	0	Yes	0.065	Small
H9	PEU→ SAT	0.125	3.063	0.002	Yes	0.024	Small
H10	PU → SAT	0.215	5.977	0	Yes	0.08	Small
H11	PU → CITU	0.203	5.273	0	Yes	0.051	Small
H12	PE → SAT	0.187	4.68	0	Yes	0.053	Small
H13	PE → CITU	0.194	4.554	0	Yes	0.044	Small
H14	PS→ SAT	0.149	4.249	0	Yes	0.037	Small
H15	PS→ CITU	0.242	5.753	0	Yes	0.075	Small

4.5 Mediation Analysis

This study examined the mediation effects of SSQ, CON, SAT, and CITU using ECM and TAM. We used the Variance Accounted For (VAF) method[133] to quantify the effect of indirect to total effect (indirect +

direct). The default assumption[134] is a partial mediation effect when 20% ≤ VAF < 80%, V AF ≥ 80% means a full mediation effect; VAF < 20% means a weak mediation effect.

The analysis revealed three key findings(see Table 8): First, SSQ demonstrated differential mediation pathways: (1) a weak indirect effect on SAT through CON (β = 0.038, p < 0.001; VAF = 10%), (2) partial mediation on CITU via SAT (VAF = 59%), and (3) a weak chained mediation through CON→SAT (VAF = 8%). Second, CON showed significant partial mediation effects on CITU through multiple pathways: SAT (VAF = 13%), PU (VAF = 11%), PE (VAF = 20%), and PS (VAF = 5%). Similarly, CON's influence on SAT was partially mediated by PEU (VAF = 11%), PU (VAF = 11%), PE (VAF = 4%), and PS (VAF = 3%). Finally, the chained mediation analysis revealed substantial variance explained by CON→PEU→SAT→CITU (VAF = 59%), CON→PU→SAT→CITU (VAF = 28%), and CON→PS→SAT→CITU (VAF = 21%), while the CON→PE→SAT→CITU pathway showed minimal mediation (VAF = 2%).

Table 8. Direct and indirect impact analysis.

	Relationship	β	SE	t-Value	p	Supported	VAF
Total effect	SSQ→CITU	0.225	0.022	10.153	0	Yes	
	SSQ→SAT	0.426	0.035	12.202	0	Yes	
	CON→CITU	0.374	0.023	16.242	0	Yes	
	CON→SAT	0.456	0.034	13.538	0	Yes	
Indirect effects	SSQ→CON →SAT	0.038	0.012	3.122	0.002	Yes	10%
	SSQ→SAT→CITU	0.222	0.025	8.769	0	Yes	59%
	SSQ→CON→SAT→CITU	0.031	0.008	3.767	0	Yes	8%
	CON→ SAT→CITU	0.049	0.013	3.75	0	Yes	13%
	CON→PU→CITU	0.041	0.01	4.232	0	Yes	11%
	CON→ PE→CITU	0.075	0.017	4.377	0	Yes	20%
	CON→PS→CITU	0.018	0.005	3.566	0	Yes	5%
	CON→PEU→SAT→CITU	0.219	0.025	8.712	0	Yes	59%
	CON →PU→SAT →CITU	0.104	0.021	4.991	0	Yes	28%
	CON →PE→SAT→CITU	0.007	0.002	3.12	0.002	Yes	2%
	CON →PS→SAT→CITU	0.079	0.018	4.452	0	Yes	21%
	CON →PEU→SAT	0.048	0.014	3.363	0.001	Yes	11%
	CON→PU→SAT	0.05	0.011	4.645	0	Yes	11%
	CON →PS→SAT	0.02	0.006	3.37	0.001	Yes	4%
	CON →PE→SAT	0.013	0.006	2.226	0.026	Yes	3%

5. Discussion

This study contributes both theoretically and practically by integrating and extending the ECM–TAM framework to examine drivers of IVIS continuance intentions. PLS-SEM analysis provided comprehensive support for the 15 research hypotheses and revealed dynamic interactions among PS ($\beta = 0.242$, $p < 0.001$), PU ($\beta = 0.203$, $p < 0.001$), PEU ($\beta = 0.125$, $p < 0.001$), and PE ($\beta = 0.194$, $p < 0.001$) within the CITU dynamic interaction mechanisms[33–35].

First, PS affects more than PU, PEU, and PE adoption, and user risk avoidance behavior is greater in high-risk intelligent travels[73,76]. This study validated the PS effect on initial adoption[27,28], and showed that PS also strengthens user engagement through dynamic processes. These studies validated the driving effect of PS on SAT (H14) and CITU (H15), and show that users perceive that safety and protection

during smart car use are fundamental; safety outweighs functionality and shapes a positive user experience. Positioning safety perception as the key basis of post-adoption satisfaction, we offer a new theoretical perspective and lead to future research to explore how safety perception fosters user engagement and trust in autonomous driving services.

Second, SSQ($\beta = 0.210$, $p < 0.001$) and PU($\beta = 0.215$, $p < 0.001$) are the main antecedents of SAT, supporting H8.SAT partially mediates the relationship between SSQ and CITU (VAF = 59%), whereas the chain mediates the relationship through confirmation (VAF = 8%). This model illustrates the role of OTA technology in shaping user expectations and the confirmation process[135]. OTA can shape expectations and improve satisfaction by optimizing interfaces, expanding functionality, and providing security updates[136].

Third, mediation analysis shows that CON influences CITU by many pathways. The CON→PEU→SAT→CITU path has the strongest mediation effect (VAF = 59%), followed by CON→PU→SAT→CITU (VAF = 28%) and CON→PS→SAT→CITU (VAF = 21%), CON→PE→SAT→CITU weakest (VAF = 2%). These results show that functional factors (PEU, PU) play a more mediating role than PE in linking user expectations to satisfaction.

Fourth, using ECM's post-adoption CON and SAT combined with TAM's PU and PE, we explain 59.4% variance in SAT and 46.1% variance in WITU. This captures both initial adoption dynamics and subsequent user behavior, which provides a framework for understanding IVIS use in driving scenarios.

5.1. Theoretical Implications

In this study, we integrated ECM with TAM and introduced SSQ, PS, and PE to construct a dynamic framework for CITU in IVIS.

Conceptualize SSQ as an external driver that affects PU, PEU, PE, and PS through CON, and influences CITU via SAT, creating a chain of transmission from external factors to internal states and, finally, to continued use. The framework extends service-led logic[137] and information system success models[47] to dynamic environments, positions SSQ as a central expectation in the IVIS context, and demonstrates that OTA-driven, continuous value enhancement promotes user stickiness. It also underscores the theoretical value of the "hardware micro-profit + service value-added" model. Empirically, the explanatory power of functional paths such as CON→PU→SAT→CITU and CON→PEU→SAT→CITU is substantially greater than that of emotional paths such as CON→PE→SAT→CITU, indicating that continued use is driven more by practicality and ease of use. In addition, the dynamic nature of OTA updates significantly enhances CITU by improving SAT, indicating that a perceptible, ongoing increase in value is central to maintaining user stickiness. Moreover, within the comprehensive framework, PE addresses prior neglect of hedonic factors. The mediating role of the degree of confirmation clarifies how aligning system performance with user expectations works. By integrating OTA data analysis with user feedback, we

propose a path for dynamically optimizing expectations, thereby bridging the theoretical gap between traditional ECM in consumer behavior and the application of intelligent vehicle technology[96].

Overall, this integrated framework broadens the theory of success and continuous use of information systems, clarifies how user behavior evolves in dynamic, multi-source human–machine collaboration scenarios, and offers a generalizable theoretical tool for IVIS design, OTA strategies, and related research on continuous information-system use.

5.2. Practical Implications

First, strengthen IVIS design and implementation abilities. In a sustainable use model, firms should design products along the “external quality – internal belief – continuous use” chain, highlighting how SSQ, PS, and PEU support long-term retention and business value, encouraging long-term use and service improvement of IVIS. For original equipment manufacturers, product development should balance system, information and service quality improvement and precise OTA rhythm management to align external perception with internal satisfaction.

Second, treat OTA as the main channel of experience redesign and perform iterative updates of SSQ on interface usability, functional value, security, and personalized content. To improve user trust, satisfaction and retention, create a multi-dimensional transparent and traceability system with clear, verifiable reports on system performance and updates. Since OTA dynamically influences user expectations, satisfaction, and use, enterprises should trade off update frequency, functional updates, and emotional updates. This will coordinate improvements to features and experiences, close the expectations gap, and adapt the system to user needs.

Third, security perception affects not only initial acceptance but also keeps on increasing via SAT→CITU pathway. Firms should invest in data protection, privacy governance, real-time risk alerts, and vulnerability remediation to improve both experience quality and trust. PS and PE should be integrated to ensure perceived security, trust, and enjoyment drive retention, in addition to functional factors like PEU and PU; this strengthens the role of CON and SAT on CITU. We recommend the combination of a pleasant interface, multimodal interaction, and personalized content to balance utilitarian and entertaining.

Fourth, from the business model perspective, firms can focus on low-margin hardware with value-added services. OTA-driven continuous updates can provide data services, personalized content, and security services to extend product life-cycle value. At the same time, firms should link user willingness to continue using the service with subscription plans and value-added data services to sustain the revenue model and user retention.

Fifth, enterprises should establish an IVIS quality and OTA security governance framework. SSQ, CON, and SAT will standardize evaluations of system, information, and service quality, as well as OTA security, across the industry. Based on this measurement system and governance framework, organizations

should promote data sharing and collaborative innovation among suppliers, platform providers, and service providers.

Sixth, based on the research findings, enterprises and regulatory authorities should develop security standards, verification procedures, and traceability capabilities for OTA updates. In addition, they should implement data governance and privacy-protection mechanisms for IVIS applications.

5.3. Limitations and Future Directions

This study has three main limitations. First, the sample is based in one country, and we lack cross-cultural validation, which may limit generalization of results to the global smart car market. Second, age-related differences in technology adoption were not addressed fully; generational differences in PEU, PE, and PS might weaken the model's explanatory power. Third, the cross-sectional design does not capture the effects of AI-driven changes in IVIS over time, which may limit understanding of users' long-term behavior.

To address these limitations, future work should conduct cross-cultural comparisons to test cultural influence on IVIS adoption. Future work should also consider technology acceptance across age groups and develop age-specific products and services. Finally, building a dynamic evaluation framework based on longitudinal tracking and real-time data would enable monitoring how AI and other technological advancements affect user experience, satisfaction, and persistence intentions.

By integrating and extending the ECM-TAM model, this study offers theoretical insights into the mechanisms underlying continuous IVIS use and practical guidance for automotive practitioners operating in the evolving intelligent mobility landscape. Future work should deepen understanding along the directions outlined above.

6. Summary

This study systematically examined the drivers of continued IVIS use by extending the ECM-TAM framework, offering both theoretical insight and practical guidance for research on intelligent-vehicle user behavior. We found that PS, PU, PEU, and PE together drive continuance intention, with PS assuming a leading role in complex driving conditions, thereby underscoring users’ core demand for safety. SSQ exerts a significant effect on CON and SAT via OTA updates and, through this mediated path, on continuance intention. This result further confirms that as technology advances and system and information quality improve, service quality becomes increasingly salient in the long term[1,6]. When strong SSQ leads users to satisfaction or to exceeded expectations, users develop confirmation and trust in the technology; this confirmation raises perceived service value and sustains satisfaction by verifying that the service meets or surpasses their standards. These findings align with the work of Bhattacherjee[15] and Tam[86] et al. Compared with PE, PEU, and PU, PE exerts a stronger influence on satisfaction and continued-use intention, aligning with results in technology-driven contexts but differing from studies of entertainment-oriented systems. The study, therefore, reveals a multidimensional

mechanism driving continuous IVIS use and, while assuming safety is maintained, suggests that improving service quality and optimizing user experience can guide user-retention strategies and technological innovation in the intelligent automotive industry.

Declarations

Data Availability

Research data were deposited into the Mendeley Data (DOI: 10.17632/nhbt8kjpvf.1) and are available at the following URL: https://data.mendeley.com/preview/nhbt8kjpvf?a=07b3d496-9e2e-4b3a-a81c-959cb0856b74

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Figures

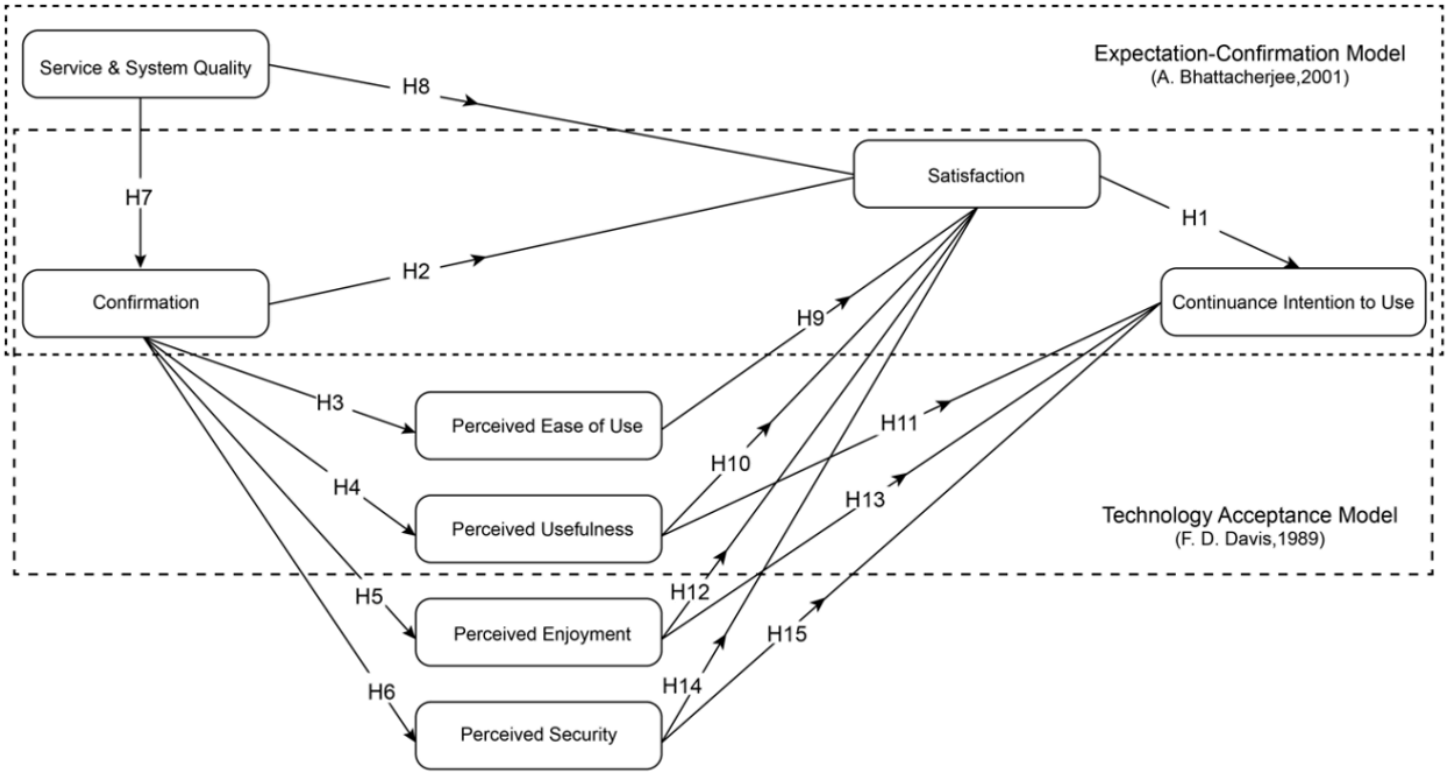


Figure 1

Research model

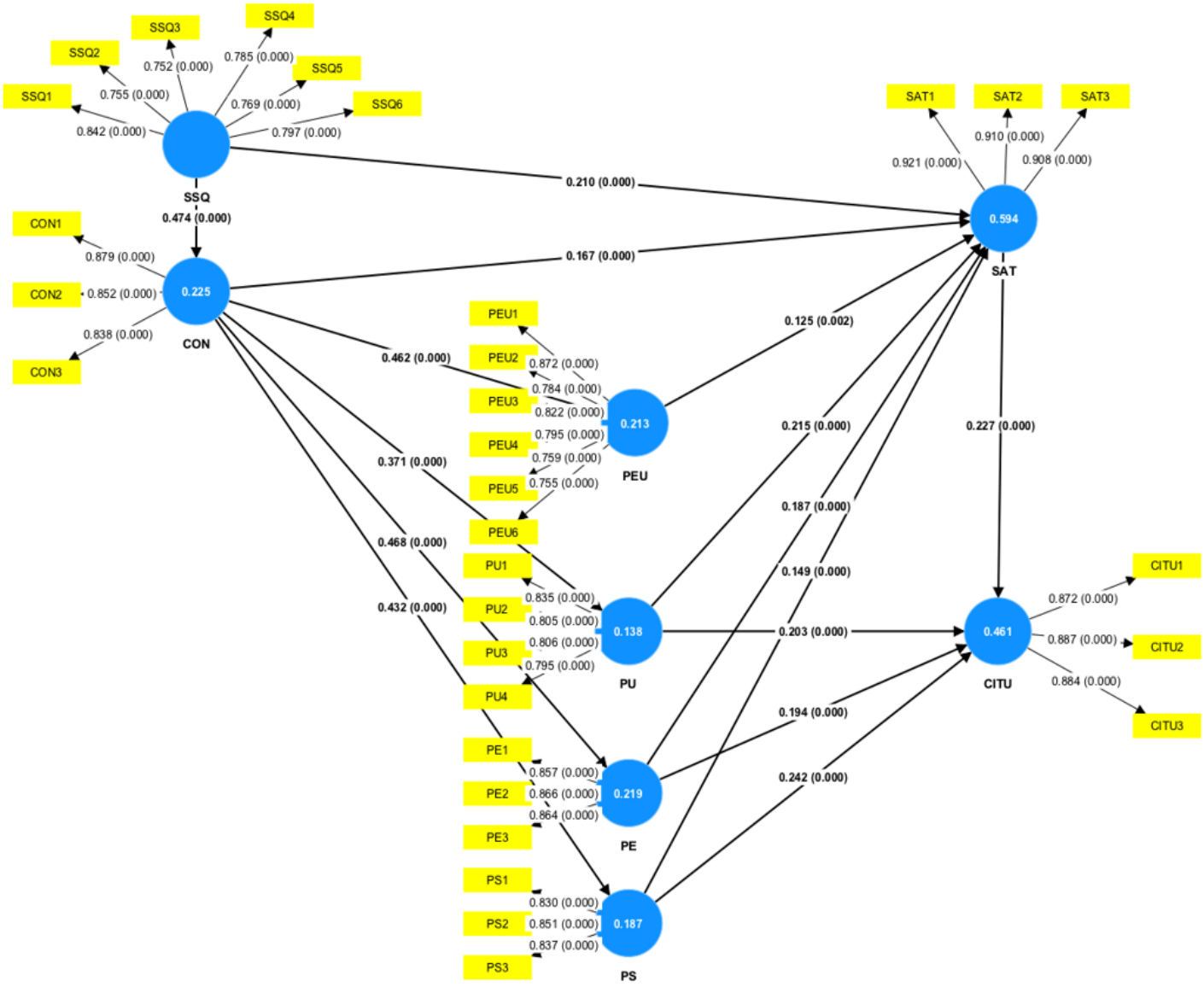


Figure 2

Results of the structural model test

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Data.xlsx
- Appendix.docx