APPLICATION OF THE MULTIMODAL HUMAN-VEHICLE INTERACTION DEVICE FOR INTELLIGENT CARS IN CHINA

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SULTAN IDRIS EDUCATION UNIVERSITY

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APPLICATION OF THE MULTIMODAL HUMAN-VEHICLE INTERACTION DEVICE FOR INTELLIGENT CARS IN CHINA

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ABSTRACT

Nowadays, various Human-Computer Interaction (HCI) technologies flow into the vehicle, increasing the complexity of HVI. Meanwhile, drivers' recognition load increase significantly, and distraction is caused. There is still a theoretical research gap in accepting and adopting MHVI in China. This study aims to design an MHVI with better effectiveness, efficiency, and less TEORT; exploring an evaluation model for MHVI to obtain more precise evaluation results; and discuss the predictors and determinants that influence the acceptance of MHVI. This study adopts the Design and Development Research (DDR) with a description of the background and objectives, a literature review, and an interview with 30 experts for designing MHV. The interview aims to understand the feasibility of designing the new MHVI, user needs, and traditional HVI's disadvantages. Based on this, a new MHVI is developed, and MHVI's usability is tested by the participation of 30 interviewees in the experimental and control groups. The Structured Equation Modelling (SEM) method was employed to analyze the relationship between the control factors of MHVI's acceptance intention. The study proposes a UTAUT-GOMS mode, and these interviewees complete the interaction task in a simulated driving cab. To verify the UTAUT-GOMS model and test the hypothesis, 401 valid questionnaires were administered. Results showed that the new MHVI has higher efficiency, effectiveness, and less TEORT than the traditional HVI; the UTAUT-GOMS model can be used to better explain the factors that influence the acceptance of MHVI, facilitating conditions/selection rules/operators/behavioral intention and methods influence use behavior positively; behavioral intention can be positively affected by PE, EE, and goals. This research has influenced theoretical models and MHVIS, and this finding can add value to the academic needs in developing MHVI for intelligent cars. This study will benefit users by providing more effective, efficient, and helpful models.

PENGAPLIKASIAN PERANTI INTERAKSI MULTIMODAL MANUSIA-KENDERAAN UNTUK KERETA PINTAR DI CHINA

ABSTRAK

Pada masa kini, pelbagai teknologi Interaksi Manusia-Komputer (HCI) mengalir ke dalam kenderaan, meningkatkan kerumitan HVI. Sementara itu, muatan pengenalan pemandu meningkat secara signifikan, dan mengakibatkan gangguan. Masih ada jurang kajian teori dalam menerima dan menggunakan MHVI di China. Kajian ini menfokuskan kepada mereka bentuk sebuah MHVI yang lebih efektif, cekap, dan kurang TEORT, mengeksplorasi model penilaian MHVI bagi mendapatkan keputusan penilaian yang lebih tepat, dan membincangkan peramal dan penentu yang mempengaruhi penerimaan MHVI. Kajian ini mengguna pakai Penyelidikan Reka Bentuk dan Pembangunan (DDR) dengan penerangan latar belakang dan objektif, tinjauan literatur, dan temu bual dengan 30 pakar untuk mereka bentuk MHV. Temuduga bertujuan untuk memahami kemudahan mereka bentuk MHVI baru, keperluan pengguna, dan kekurangan HVI tradisional. Berdasarkan ini, MHVI baru dibangunkan dan kebolehgunaan MHVI diuji oleh penyertaan 30 responden yang ditemuduga dalam kumpulan ujian dan kawalan. Kaedah Pemodelan Persamaan Berstruktur (SEM) digunakan untuk menganalis hubungan antara faktor-faktor kawalan dengan niat penerimaan MHVI. Kajian ini mencadangkan mod UTAUT-GOMS, dan responden melengkapkan tugasan interaksi dalam teksi pemandu simulasi. Bagi mengesahkan model UTAUT-GOMS dan menguji hipotesis, sebanyak 401 soalan sah dikumpulkan. Hasil kajian menunjukkan bahawa MHVI baru mempunyai kecekapan, keberkesanan, dan kurang TEORT berbanding HVI tradisional; model UTAUT-GOMS boleh digunakan untuk menjelaskan dengan lebih baik faktor-faktor yang mempengaruhi penerimaan MHVI; memudahkan syarat/peraturan pemilihan/operator/niat perilaku dan kaedah mempengaruhi perilaku penggunaan secara positif; niat perilaku boleh dipengaruhi secara positif oleh PE, EE, dan tujuan. Kajian ini telah mempengaruhi model teori dan MHVIS, dan dapatan kajian ini memberi tambah nilai kepada keperluan akademik dalam membangunkan MHVI untuk kereta pintar.. Ujian ini akan memberi manfaat kepada pengguna dengan menyediakan model yang lebih berkesan, cekap dan berguna.

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LIST OF ABBREVIATIONS

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
ADC	Analog-to-digital Converter
AGFI	Adjusted Goodness-of-fit Index
AMOS	Analysis of Moment Structure
AR	Augmented Reality
AR HUD	Augmented Reality Head-up display
AVE	Average Variance Extracted
BI	Behavioral Intention
BLIS	Blind Spot Information System
BT	Bluetooth
C.R.	Composite Reliability
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CAPE	Center for Advanced Photonics and Electronics
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
C-HUD	Combiner Head-Up Display
CMIN	Chi-Square
CSUQ	Computer System Usability Questionnaire
C-TAM-TCP	Integrated TEAM-TCP
DDR	Design and Development Research

DF	Degree of Freedom
EE	Effort Expectancy
FC	Facilitating Conditions
FCW	Forward Collision Warning
FoV	Field of View
GFI	Goodness of Fit Index
GOMS	Goals, Operations, Methods, and Selection Rules Model
GPS	Global Positioning System
GUI	Graphical User Interface
HCI	Human-Computer Interaction
HMI	Human Machine Interaction
HUD	Head-Up Display
HVI	Human-Vehicle Interaction
ICCC	Intraclass Correlation Coefficient
ICS	Intelligent Control System
IDEO	A Global Design and Innovation Company
IDIS	Intelligent Driving Information System
IDT	Innovation Diffusion Theory
IFI	Incremental Fit Index
IOS	iPhone Operator System
ITS	Intelligent Traffic System
IVIS	In-Vehicle Infotainment System
LCD	Liquid Crystal Display
LCoS	Liquid Crystal on Silicon
LDA	Lane Departure Warning Display

LKA	Lane Keeping Assist
LKAS	Lanes Keep Assistant System
LTA	Lane Tracing Assist
MBUX	Mercedes-Benz User Experience
MGA	Multi-Group Analysis
MHVI	Multimodal Human-Vehicle Interaction
MHVI-ICar	Multimodal Human-Vehicle Interaction Device for Intelligent Cars
MM	Motivation Model
MPCU	PC Usage Model
NHTSA	National Highway Traffic Safety Administration
NNFI	Non-Normed Fit Index
OP	Operators
PCW	Pedestrian Collision Warning
PE	Performance Expectancy
PGU	Picture Generation Unit
PLS	Partial Least Squares
PPI	Pixels Per Inch
QUIS	Questionnaire for User Interaction Satisfaction
RMSEA	Root Mean Square Error of Approximation
RO	Research Objectives
RQ	Research Questions
RSA	Road Sign Assist
RTI	Real-Time Integration
S	Second
SAE	Society of Automotive Engineering

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SCT	Social Cognitive Theory
SEM	Structural Equation Modeling
SET	Self-Efficacy Theory
SI	Social Influence
SPSS	Statistical Product Service Solutions
SR	Selection Rules
SRMR	Standardized Root Mean Square
Std	Standardized Estimated
SUI	Speech–User Interface
SUS	System Usability Scale
SWC	Steering Wheel Control
TAM	Technology Acceptance Model
TAM2	Technology Acceptance Expansion Model
TEORT	Total Eyes off-Road Time
TFT	Thin-Film Transistor
TPB	Theory of Planned Behavior
TRA	Theory of Rational Behavior
UB	Use Behavior
UCD	User-Centered Design
UI	User Interface
Unstd	Unstandardized Estimated
UTAUT	Unified Theory of Acceptance and Use of Technology
UX	User Experience
VID	Visual Image Distance
VIF	Variance Inflation Factor

W-HUD	Windscreen HUD
WLAN	Wireless Local Area Network
WoS	Web of Science

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Improving cockpit comfort and driver performance is a primary research direction of automobile research. The human-computer system emphasizes adapting the environment for humans to complete various tasks safely, efficiently, and comfortably (Liu and Yuan, 2005). Researchers have regarded humans as a link of the whole automotive large-scale system, aiming at the driver's ability and characteristics, striving to design the best human-centered manual control system in the driving environment to reduce technical support costs. It has become a key technology to be considered in the overall design (Zhou and Ma, 2000).

The automobile's human-computer interface comprises many displays and control components with a complex structure (Liu and Yuan, 2005; Zhou and Ma, 2000). The excellent layout design of the man-machine interface can provide a comfortable operation posture, good vision, and a pleasant atmosphere for drivers and help give full play to the driver's work efficiency (Yiguan Think Tank, 2015). The complexity of the human-computer interaction interface of automobiles promotes the emergence of new interaction modes. With the development of natural speech, sensor recognition, machine sensory enhancement, and emotional computing, multi-channel fusion interaction has become possible (Baidu and Hunan University, 2018).

This research will first briefly review the historical basis and importance of HCI technology, the shortcomings of HCI technology in the interaction between automobiles and humans, and expound on the necessity and feasibility of new interaction design. There will be a detailed literature review of the HCI, ergonomic assessment, interface design, and laws and regulations related to car driving. At the same time, based on the driver's task flow analysis, this study will study the interaction between the driver and the vehicle based on the theory of limited cognitive resources and analyze the driver's cognitive type. The improved design of human-computer interaction for intelligent cars

(MHVI-ICar)-combines the advantages of various human-computer interaction technologies and human capabilities, limitations, and needs making it a new type of HCI. The study will test and assess the MHVI device. Then the study builds and verifies a model to analyze the factors influencing the adoption and acceptance of MHVI-ICar devices. At last, to explain factors that influenced the acceptance and adoption behavior of MHVI devices.

1.2 Research Background

The vehicle control system has become more intelligent and complex. The rapid development of electronic and intelligent technology and its extensive application in the automotive have made the car more electronic and intelligent and made more and more electronic components, special sensors, and different functions of the executive equipment installed in vehicles. It makes the car a traditional means of transportation and personal space for information acquisition, transmission, communication, and entertainment (Li, 2018). At present, the information model has gradually developed from a single driving and condition information model to a complex information system including automobile information, inter-car information (car to car), information about the vehicle, and other information carriers (auto to x) (Schmidt, Spiessl and Kern, 2009).

In such a complex information system, the drivers' recognition load significantly increases and faces safety risks. Besides completing the main driving task (primary task) of controlling the car, maintaining the lane, and monitoring the road condition, drivers also perform a large number of in-vehicle secondary tasks which have nothing to do with driving or are not directly related to driving. These secondary tasks will occupy the driver's visual, cognitive, and action resources, distract the driver's attention, and produce a higher cognitive load (Wang, Knipling, and Goodman, 1996). Many studies have proved that secondary tasks represented by in-vehicle information interaction seriously affect a driver's driving efficiency and traffic safety (Strayer and Drew, 2004; Kass, Cole, and Stanny, 2007).

Empirical studies have shown that performing visual-manual tasks while driving may reduce driver performance in steering control, headway control, braking behavior, and lane keeping (Tsimhoni, Smith, and Green, 2004; Peng, Boyle, and Hallmark, 2013; Bao et al., 2015; Pavlidis et al., 2016; Harbluk, Noy, and Eizenman, 2002; Lansdown, 2004; Greenberg et al., 2003; Horrey and Wickens, 2004). Studies have also shown a positive relationship between the visual demands of in-vehicle systems and crash risk and accident occurrence (Horrey and Wickens, 2007; Wierwille and Tijerina, 1998). The naturalistic driving study by Klauer et al. (2006) indicated a statistical association between long (2+s) off-road eye glances and increased near-crash/crash risk from baseline driving.

To ensure driving safety, researchers and government departments have proposed standards and guidelines to evaluate a variety of secondary tasks and the designs of in-vehicle systems. The Society of Automotive Engineering (SAE) Standard SAE J2364 (2004) offers that the maximum time for drivers to complete navigation-related tasks involving visual displays and manual controls should be less than 15s (referred to as the 15-Second Rule) (Green, 1999). American National Highway Traffic Safety Administration (NHTSA) published a guideline for in-vehicle electronic devices with recommendations that for the 85th percentile of the driver sample: (1) the mean duration of off-road glances should be less than 2.0s, (2) no more than 15% of the total number of glances should be more significant than 2.0s, and (3) the total eyes-off- road time (TEORT) should be no greater than 12.0s (referred to as the 2/12 Rule) (NHTSA, 2012).

There is a research gap in China's acceptance and adoption of MHVI devices (Lyu, Zalay, and Salleh, 2021). A survey report by Newsijie, a leading consulting company focusing on China's automobile industry, shows that in 2019, the global penetration rate of multimodal human-vehicle interaction equipment was about 9.3%, of which less than 2.6% in China, far below the worldwide average. The researchers must understand the factors that affect users' adoption and use of this multimodal human-vehicle interaction device. Researchers and manufacturers must address the bottlenecks that hinder users' adoption and improve their services.

This study will propose a new multimodal human-vehicle interaction (MHVI) model and test its usability to reduce the user's workload during interaction and improve driving safety, efficiency, and effectiveness. Secondly, this study will use technology acceptance theory to develop a new technology acceptance model and finally use this model to analyze the factors that influence the acceptance of MHVI among car users.

1.2.1 Problem Statement

The automobile human-computer interaction system has entered the intelligent age from the physical era, and the interactive interface and interactive methods have also undergone significant changes. Developing in-vehicle systems has led to a substantial increase in functionality and complexity.

With the introduction of an intelligent traffic system (ITS) and an intelligent control system (ICS), new functions are pouring into automobiles. Interaction mode based on physical buttons is facing significant challenges. A typical case is the increasing number of physical operators such as keys and knobs. The growing number of physical operators leads to difficulties in recognition, reduces cognitive and operational efficiency, and even affects driving safety. (Li et al., 2018).

The touchscreen operation interface has a significant potential safety hazard for drivers requiring great attention (AlAbdulaali et al., 2022). Users often need to open multi-hierarchy menus to adjust, which will inevitably cause the driver's vision to deviate for a long time and adversely affect driving safety (Li et al., 2018). Peng and Lu (2018) argue that driver assistance technologies and real-world driving situations do not meet the conditions for touchscreen interaction and that some vehicle systems blindly follow the idea of mobile touchscreens that increase driving risk.

Driver distraction has been a significant contributing factor in road accidents. According to the World Health Organization (WHO), 2015 driving accidents accounted for 1.25 million fatalities; an estimated 50 million people were injured, and 18.97 million were disabled (World Health Organization, 2015). Distraction accounts for 80% of traffic accidents (The Automobile Times, 2018). A naturalistic driving study suggests that distraction from secondary tasks (i.e., not necessary to drive) accounts for 23% of all crashes and near-crashes (Klauer et al., 2006).

From the above literature review, it is clear that (1) The functions of intelligent systems are increasingly complex, and the driver's information-aware load is significantly increased too (Tan, Zhao, and Wang, 2012). (2) Driver distraction is a significant factor in traffic accidents (Klauer et al., 2006). (3) It is necessary to design An efficient and safe interaction mode based on the driver's cognitive characteristics and workload (Peng et al., 2018). (4) The market penetration of MHVI devices in China is lower than 2.6%, far below the global average of 9.3% (Wu, 2020). There is a research gap in the acceptance and adoption of MHVI devices in China (Lyu, Zalay & Salleh, 2021).

Therefore, it is a need to design and develop a new MHVI device for intelligent cars in China with better effectiveness, efficiency, and less total eye off-road time (TEORT) and to understand the acceptance and adoption factors affecting such a device.

1.2.2 Plans and Strategies for Problems

This research will propose a novel multimodal human-vehicle interaction device that aims to reduce total eyes-off-road time during the necessary human-vehicle interaction and improve operational efficiency and effectiveness. The proposed multimodal human-vehicle interaction device model consists of HUD, steering wheel control, and IVIS systems. When the driver must operate the IVIS, he can observe the content that should be displayed on the IVIS through the HUD system, reducing total eyes-off-road time.

Usability tests will be conducted on both the traditional IVIS and the new MHVI-ICar to verify that the new MHVI-ICar offers better operational efficiency, accuracy, satisfaction, and less TEORT.

This study will propose a conceptual model of technology acceptance and then use the SEM to analyze the factors that influence the behavior of Chinese users in adopting and accepting MHVI devices.

1.3 Aims

This section sets out the research objectives and research questions and creates a link between the research objectives and research questions.

1.3.1 Research Objectives

This research objectives (RO) will relate the problems to the multimodal human-computer interface design for intelligent cars (MHVI) and build a rationale background. Then, it will solve the research problems according to the following objectives:

RO1 To design an MHVI device with higher operational efficiency, effectiveness, and less TEORT during operation than the traditional HVI device.

RO2 To determine the predictive factors (facilitating conditions/ selection rules/ operators/behavioral intention, and methods) that influence use behavior among car users.

RO3 To determine the predictive factors (performance expectancy, effort expectancy, and goals) that influence behavioral intention among car users.

RO4 To identify the influence of goals on performance and effort expectancies.

RO5 To assess the influence of moderator factors such as gender, age, and experience on the relationship between predictive factors, behavioral intention, and use behavior.

RO6 To build a model to explain factors that influenced the use behavior of the multimodal human-vehicle interaction device (MHVI).

1.3.2 Research Questions

As detailed in the purposes and RO, this research formulated six research questions (RQ) to be addressed by the study. The research questions are as follows:

RQ1 How to design an MHVI device with higher operational efficiency, effectiveness, and less TEORT during operation than the traditional HVI device.

RQ2 Is there any relationship between facilitating conditions/selection rules/operators/behavioral intention and methods with use behavior?

RQ3 Do the predictive factors (performance expectancy, effort expectancy, and goals) influence behavioral intention?

RQ4 Are the goals the influence factors of performance and effort expectancies?

RQ5 Are the selected moderator factors such as gender, age, and experience moderate the relationships between predictive factors, behavioral intention, and use behavior?

RQ6 What is the suitable model to explain factors that influenced the acceptance of the multimodal human-vehicle device for intelligent Cars (MHVID) among car users?

1.3.3 The Link between Objectives and Research Questions

The research questions were formulated according to the research objectives, as shown in Table 1.1, A Link Between Objectives and Research Questions.

Table 1.1

A Link Between Objectives and Research Questions

NO.	Research Objectives (RO)	Research Questions (RQ)
1	RO1 To design an MHVI device with higher operational efficiency, effectiveness, and less TEORT during operation than the traditional HVI device.	RQ1 How to design an MHVI device with higher operational efficiency, effectiveness, and less TEORT during operation than the traditional HVI device.
2	RO2 To determine the predictive factors (facilitating conditions/ selection rules/ operators/behavioral intention, and methods) that influence use behavior among car users.	RQ2 Is there any relationship between facilitating conditions/selection rules/operators/behavioral intention and methods with use behavior?
3	RO3 To determine the predictive factors (performance expectancy, effort expectancy, and goals) that influence behavioral intention among car users.	RQ3 Do the predictive factors (performance expectancy, effort expectancy, and goals) influence behavioral intention?
4	RO4 To identify the influence of goals on performance and effort expectancies.	RQ4 Are the goals the influence factors of performance and effort expectancies?
5	RO5 To assess the influence of moderator factors such as gender, age, and experience on the relationship between predictive factors, behavioral intention, and use behavior.	RQ5 Are the selected moderator factors such as gender, age, and experience moderate the relationships between predictive factors, behavioral intention, and use behavior?

NO.	Research Objectives (RO)	Research Questions (RQ)
6	RO6 To build a model to explain factors that influenced the use behavior of the multimodal human-vehicle interaction device (MHVI).	RQ6 What is the suitable model to explain factors influencing the acceptance of the multimodal human-vehicle device for intelligent Cars (MHVID) among car users?

1.4 Research Hypotheses

According to the research questions and objectives, many hypotheses are proposed in this study. The hypothesis for RQ2 is to determine the predictors that influence use behavior. The hypothesis for RQ3 is used to determine the predictors that influence behavioral intention. The hypothesis for RQ4 is to assess the effect of goals on performance expectations and effort expectations. The hypothesis for RQ5 is to examine moderating effects. Descriptive statistics answer RQ1 and RQ6, so it does not require hypotheses. The research hypotheses and relevant research questions are shown in Table 1.2 Research Hypotheses and Relevant Research Questions.

Table 1.2

Research Hypotheses and Relevant Research Questions

Research questions	Research hypotheses
RQ2 Is there any relationship between facilitating conditions/selection rules/operators/behavioral intention and methods with use behavior?	H1 The facilitating conditions of the multimodal human-vehicle interaction device impact the adoption behavior positively. H2 The selection rules of the multimodal human-vehicle interaction device positively impact use behavior. H3 The operators of the multimodal human-vehicle interaction device positively impact Use behavior. H4 The operation methods of the multimodal human-vehicle interaction device positively affect the use behavior. H5 The behavioral intention of the multimodal human-vehicle interaction device positively impacts use behavior.
RQ3 Do the predictive factors (performance expectancy, effort expectancy, and goals) influence behavioral intention?	H6 The goals positively influence the behavioral intention to act on the multimodal human-vehicle interaction device. H7 The users' effort expectancy for the multimodal human-vehicle interaction device positively influences their behavioral intention. H8 The performance expectancy of the multimodal human-vehicle interaction device positively affects behavioral intention.
RQ4 Are the goals the influence factors of performance and effort expectancies?	H9 The goals positively affect the user's performance expectancy of the multimodal human-vehicle interaction device. H10 The goals positively affect the user's effort expectancy for the multimodal human-vehicle interaction device.
RQ5 Are the selected moderator factors such as gender, age, and experience moderate the relationships between predictive factors, behavioral intention, and use behavior?	H11 Gender has a significant influence on the whole model. H12 Age has a significant influence on the whole model. H13 Experience has a significant influence on the whole model.

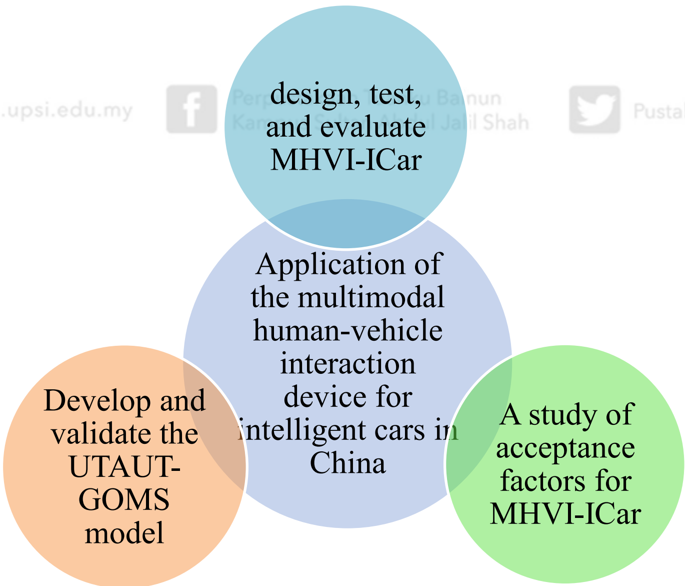
1.5 Scope and Area of Research

1.5.1 Scope of the Research

Figure 1.1 shows that the scope of theoretical research is limited to HCI design, development and verification, technology acceptance theory, and factors influencing the acceptance of MHVI. This area is restricted to existing automotive HCI technologies. The relevant data-were collected in China.

Figure 1.1

Scope of the Research



1.5.2 Theoretical Framework

This research will apply distributed cognitive theory, grounded theory, user-centered design, and the theory of available targets to conduct multimodal human-computer interface research, as shown in Table 1.3 Basic Theory and Application.

Table 1.3

Basic Theory and Application

Research theory	Research content	Research objective
Distributed cognitive theory	1. To analyze driver's activity characteristics; 2. To know the interaction between driver and environment; 3. To analyze the driver workflow; 4. To study the interaction process between humans and vehicles;	RO1 To design an MHVI device with higher operational efficiency, effectiveness, and less TEORT during operation than the traditional HVI device.
User-centered theory DDR theory	To design a human-computer interface;	
Usability goal theory	To evaluate the human-computer interface;	
ATM theory GOMS theory Human interaction theory Behavior theory Cognitive theory	1. To build a model to explain factors that influenced the use behavior of the multimodal human-vehicle interaction device; 2. To examines and analyze the factors that influence acceptance and adoption behavior towards MHVI-ICar; 2. To examine moderator factors such as gender, age, and experience on the relationship between predictive factors, behavioral intention, and use behavior.	RO2 To determine the predictive factors (facilitating conditions/ selection rules/ operators/behavioral intention, and methods) that influence use behavior among car users. RO3 To determine the predictive factors (performance expectancy, effort expectancy, and goals) that influence behavioral intention among car users. RO4 To identify the influence of goals on performance and effort expectancies. RO5 To assess the influence of moderator factors such as gender, age, and experience on the relationship between predictive factors, behavioral intention, and use behavior. RO6 To build a model to explain factors that influenced the use behavior of the

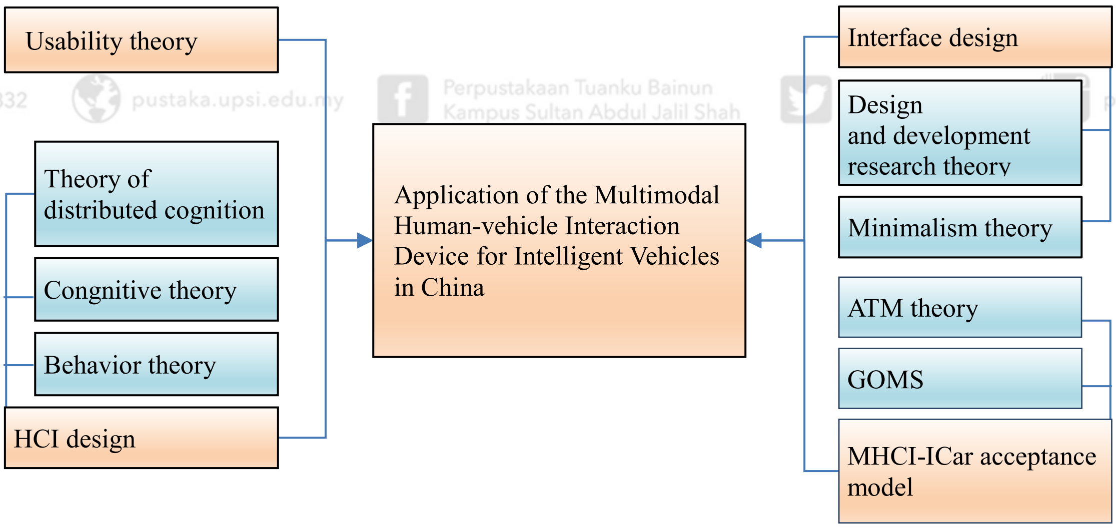
Research theory	Research content	Research objective
		multimodal human-vehicle interaction device (MHVI).

Edwin Hutchins proposed the distributed cognitive theory in the middle and late 1980s. The theory holds that cognition is a system including cognitive subject and environment, and a new analysis unit including all the things involved in cognition. It emphasizes the cognitive processing of media and the interaction between humans and media in a cognitive environment. The theory of distributed cognition regards the interaction between individual and external environment to analyze and study the knowledge representation state of a human, machine, and other media and the interaction between humans and media in task operation. Therefore, Lu (2005) thinks that distributed cognitive theory is particularly suitable for studying the complex human-computer interaction process. This research will establish a theoretical framework of human-computer interaction based on user cognitive resources and distributed cognitive theory. On this basis, this paper proposes a new interaction method for intelligent cars, which aims to reduce the cognitive burden of users in the interaction process, improve the efficiency and effectiveness of the interaction process, and adapt the interaction model to the mental and psychological characteristics of public users.

Saffer (2010) puts forward four main methods of interaction design: (1) user-centered design, (2) activity-centered design, (3) system design, and (4) genius design. In 1985, Gould and Lewis listed three principles they believed could make computer systems useful and easy to use, (1) focus on users and tasks earlier, (2) empirical measurement, and (3) iterative design. The user-centered approach uses these three criteria as the basis. Research by Keil and Carmel (1995) shows that the project's success cannot be separated from the direct participation of users and customers. Kujala (2000) analyzed the cost and benefit of "user research" in the early stage of product development and concluded that the benefit of user research is higher than the cost. Subrayaman et al. (2010) found that developer satisfaction increased for new products with increased user participation. This study will use the user-centered design theory - design a multimodal human-computer interaction device to evaluate the efficiency, effectiveness, and security and further verify the feasibility of the multimodal human-computer interaction theoretical framework.

Figure 1.2

Theoretical Framework for the Study



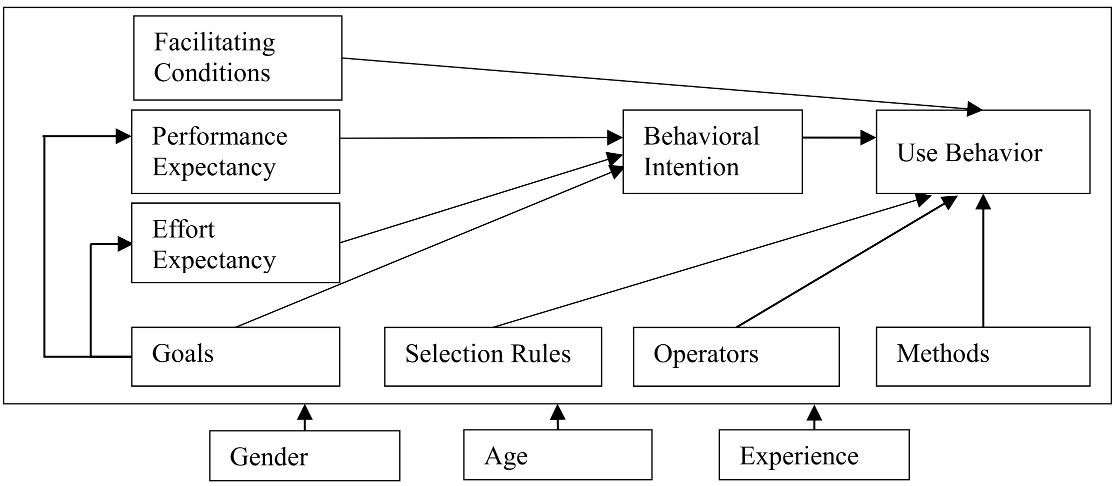
The goal of usability is to provide interaction designers with a specific method to evaluate all aspects of interactive products and user experience. Usability usually includes three factors: effectiveness, efficiency, and satisfaction. Nielsen also pointed out that usability consists of five elements: learnability, efficiency, memorability, error rate, and satisfaction. Although they contain different quantities of elements, their meanings are the same. This study will evaluate and analyze a multimodal human-computer interface's effectiveness, efficiency, and satisfaction. Figure 1.2 shows the theoretical framework for the Study.

1.5.3 Conceptual Framework

According to the summary of scholars' research results and the analysis in the previous section, the UTAUT-GOMS model retains some of the research variables of the original UTAUT model, including facilitating conditions, performance expectancy, effort expectancy, behavioral intention, and use behavior. The UTAUT-GOMS model integrated the GOMS model's factors, goals, selection rules, operators, and methods. Age, gender, and experience are the control variables. This article shows the theoretical model framework used to study the composition of variables as shown in Figure 1.3 conceptual framework for the study.

Figure 1.3

Conceptual Framework for the Study



1.5.4 Definition of Terms

1) Human-Computer Interaction (HCI). The human-computer interaction, also named the human-computer interface, is the medium and dialogue interface for information transmission and exchange between people and computers and the medium for interaction and information exchange between systems and users. It realizes the transformation between the internal form of information and the acceptable form of human beings. The human-computer interface usually refers to the visible part of the user.

2) Multimodal Interaction. Based on intelligent interface technology, multimodal human-computer interaction makes full use of human's multiple perception channels to interact with the computer systems in a parallel and imprecise way, aiming to improve the naturalness and efficiency of human-computer interaction. The most common technical combination of multimodal interaction is voice and visual processing (Meng, Li, Yang, and Wang, 2016).

3) Head-Up Display (HUD). The head-up display is a device that projects the primary driving instrument's attitude guidance, indicator, and main parameters to the front of the driver's helmet or windshield. It lets the pilot see the main driving instrument and its important flight parameters when looking forward at the front view (Zhang and Jiang, 2015).

4) Intelligent Car. The smart car is an integrated system that combines environmental awareness, planning, decision-making, and multi-level assisted driving. It uses

computer technology, modern sensing technology, information fusion technology, communication technology, artificial intelligence, and automatic control, making it a typical high-tech complex. The research on the intelligent car mainly focused on improving safety and comfort and providing an excellent human vehicle interface. The smart car is different from the general self-driving. The intelligent vehicle first has a navigation information database, followed by a GPS positioning system, road condition information system, car collision avoidance system, emergency alarm system, wireless communication system, and automatic driving system (Popular Science China, 2020).

1.6 The Significance of the Research

The increasing functional complexity of intelligent systems and the significant increase in the driver's information perception load (Tan, Zhao, and Wang, 2012) can easily lead to driver distraction. Driver distraction is a significant factor in traffic accidents (Klauer, Dingus, Neale, Sudsweeks, & Ramsey, 2006). There is, therefore, a need to design a new, efficient, and less TEORT-based human-vehicle interaction model (Peng, Yu-Yuan, et al., 2018).

The market penetration of MHVI devices in China is below 2.6%, much lower than the global average of 9.3% (Wu, 2020). There is a research gap in the acceptance and adoption of MHVI devices in China (Lyu, Zalay, and Salleh, 2021), and there is a need to understand the factors that influence user acceptance in China.

The significance of the research is: to establish the multimodal human-computer interface interaction modal and theory for the user's cognitive characteristics; the automobile-oriented interface interaction methods can help the interface designer overcome the limitations of the traditional interface design and development strategies, and the design and development are in line with the use the user's cognitive characteristics, the interface easy to understand and use by the driver; from the perspective of cognitive load, to study the automobile interface and explore a more accurate and effective method of automobile interface evaluation, can help the interface evaluators to break through the limitations of traditional usability evaluation methods and get more precise evaluation results.

1.6.1 Expect Contribution

The expected contributions of this study are as follows,

1) This study will investigate to identify a suitable methodology for developing MHVI-ICar that is rigorous, reliable, and can be applied to human-computer interaction design.
2) A new human-vehicle interaction model will be designed for this study. This human-vehicle interaction model is expected to have higher operational efficiency, effectiveness, and less TEORT than the traditional IVIS.
3) This study integrates the UTAUT and GOMS models to propose a new UTAUT-GOMS conceptual model to investigate the factors influencing MHVI-ICar acceptance, as shown in Figure 1. 4 The conceptual framework of the study. This model is expected to have reliable explanatory power and can

better explain the factors affecting the acceptance of HVI devices.

4) The predictive factors influencing car users' behavioral intention and use behavior.

5) A model and evaluation method for assessing HCI device use behavior and behavioral intentions provides good explanatory factors that influence user acceptance of MHVI-ICar devices.

1.7 Thesis Outline

This thesis organized the chapters as follows.

Chapter 1 mainly presents the research background, purpose, questions, hypotheses, theoretical framework, conceptual framework, and research significance.

Chapter 2 provides a detailed literature review of HCI, HVI, human interaction theory and Behavior, and technology acceptance theory.

Chapter 3 describes the research methodology, which includes two parts. The first part involves the population, sampling, survey, instruments, data collection procedures, and data analysis of the design, testing, and evaluation of the new MHVI-Icar. The second section deals with applying SEM to test research hypotheses, including the population, sampling, experiments, instruments, data collection procedures, measurement models, structural equation modeling, and data analysis methods.

Chapter 4 is a detailed description of how to achieve RO1. Chapter 4 is about the design, testing, and evaluation of the MHVI-Icar, which will use quantitative research to analyze the operational efficiency, effectiveness, TEORT, satisfaction, and usability of the MHVI-Icar.

Chapter 5 describes how to achieve RO2 to RO5. Chapter 5 examines the research hypotheses using structural equation modeling to test the factors influencing acceptance and adoption behavior towards MHVI-ICar. A multi-group analysis examines moderator factors such as gender, age, and experience on the relationship between predictive factors, behavioral intention, and use behavior.

Chapter 6 details the conclusions, contributions and significance, scope and limitations, the novelty of the research, and recommendations.

1.8 Chapter Summary

This chapter identifies the problems with the current intelligent car human-machine interface, which has many functions and is not easily recognized, the strict traffic regulations proposed by the government, and the low market penetration of MHVI-ICar. This study suggested six research objectives and questions to address these issues, as shown in Table 1.2.

This study will propose a novel multimodal human-vehicle interaction device to reduce total eyes-off-road time during the necessary human-vehicle interaction and improve operational efficiency and effectiveness. Also, this study will develop a UTAUT-GOMS model and proposes 13 research hypotheses to understand the factors that influence acceptance by Chinese drivers. Table 1.2 shows the research hypotheses.

This chapter also presents the study's theoretical and conceptual frameworks in Figure 1.1 and Figure 1.2, respectively. The thesis is organized as shown in section 1.7, Thesis Outline.