Research on Automotive Intelligent Cockpit

Jun Ma
Zaiyan Gong

Automotive Human-Machine Interaction (HMI) Evaluation Method

机械工业出版社
CHINA MACHINE PRESS

Springer

Research on Automotive Intelligent Cockpit

Series Editors

Jun Ma, HVR Lab, Tongji University, Shanghai, China

Zhenhai Gao, College of Automotive Engineering, Jilin University, Changchun, China

Zaiyan Gong, HVR Lab, Tongji University, Shanghai, China

Hongyu Hu, ASCL, Jilin University, Changchun, China

The book series presents the latest developments and advances in the multidisciplinary field of intelligent automotive cockpits. The aim is to cover methods (evaluation systems, cognitive models, usability testing, development process, etc.), technologies (system architectures, algorithms, AI and cloud computing, interactive modalities, etc.) and applications (cockpit definition trends, UX/UI design, ecosystems) of the automotive intelligent cockpit as embedded in the fields of engineering, human factors, psychology, design and socioalogy. The series includes monographs, papers and edited volumes in the field of research and development of automotive intelligent cockpit. The book series aims to introduce multidisciplinary knowledge and applications to researchers and engineers. The individual volumes in the series are thematically organised. The aim of each volume is to provide the reader with a comprehensive overview of the design, development or evaluation of the intelligent cockpit in a particular area. As a collection, the series provides valuable resources for a wide audience in academia, engineering research, industry, and anyone else wishing to expand their knowledge of the automotive intelligent cockpit.

Jun Ma · Zaiyan Gong

Automotive Human-Machine Interaction (HMI) Evaluation Method

机械工业出版社
CHINA MACHINE PRESS

Springer

Jun Ma
HVR Lab
Tongji University
Shanghai, China

Zaiyan Gong
HVR Lab
Tongji University
Shanghai, China

ISSN 2948-250X ISSN 2948-2518 (electronic)
Research on Automotive Intelligent Cockpit
ISBN 978-981-99-9950-7 ISBN 978-981-99-9951-4 (eBook)
https://doi.org/10.1007/978-981-99-9951-4

Jointly published with China Machine Press Co.,Ltd.
The print edition is not for sale in China (Mainland). Customers from China (Mainland) please order the print book from: China Machine Press Co.,Ltd.
ISBN of the Co-Publisher's edition: 978-7-111-71594-8

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

The automotive industry has undergone unprecedented transformations over the 130 years since the inception of the automobile. Electrification has fundamentally changed how automobiles work, with batteries and electric motors featuring at its technological core, while internal combustion engines and transmissions have begun to fade from prominence. Furthermore, intelligence has transformed the logic behind the assessment of a vehicle's value. Nowadays, software and user experience are the foundation values of new generation vehicles, whereas the number of functions and configurations merely serve as added bonuses. Electrification and intelligence are intertwined trends that are jointly driving the transformation of the automotive industry. As an integral part of automotive intelligence, automotive human-machine interaction (HMI) is at the forefront of this transformation. With the advancement in the Internet of Things (IoT), valuable experience in the development of intelligent vehicles has been gained. The popularization of smart products, such as mobile phones, has refined user habits to intelligent vehicle experiences; and the rapid growth of emerging automotive brands has fostered agile and efficient HMI development and interactive methods. Consequently, traditional brands are drastically adjusting their organizational structure to respond more proactively to this transformation.

Just as ships at sea rely on lighthouses for guidance, so does the development of automotive HMI require a guiding light. However, there is no ready-made solution within the automotive industry. Although various brands are vying for innovation and excellence in the field of HMI, the competition is too close to call, and there is no general consensus on an optimal approach as yet. Smartphones are no longer a sufficient influencing model. Although we have learned from their interaction methods and application ecosystems, intelligent vehicles face unique challenges such as reducing driving distractions, adapting to usage scenarios, and creating immersive spaces, which smartphones do not have to address. Therefore, the only guiding light that can lead the development of automotive HMI lies within the methodology itself. In the face of constantly emerging technologies, scenarios, and demands, automotive companies must discover their own research and development (R&D) methods for HMI. We need product definition methods to understand the requirement of next-generation products, scenario research methods to identify pain points in the user experience, interaction design methods to cater to users' aesthetics and value orientations, software development methods to achieve efficient over-the-air (OTA) updates and iterations as well as HMI evaluation methods to identify product issues and propose suggestions for improvement.

Our focus in this book is on automotive HMI evaluation methods, which aim to reduce driving distractions, lower operational loads, optimize user experience design, and enhance user value.

The content of this book is divided into three parts. Part I, consisting of Chaps. 1–3, introduces the development of automotive HMI and the current status and challenges of its evaluation. We emphasize the industry's need for a comprehensive, systematic, and quantifiable automotive HMI evaluation method. In addition, we propose a three-dimensional orthogonal evaluation system that incorporates all evaluation items into a space matrix composed of three dimensions: interaction tasks, interaction modalities, and evaluation indexes. This enables the proposed evaluation system to achieve completeness and extensibility without overlap when evaluating the complex automotive HMI system.

Part II, comprising Chaps. 4–11, presents a comprehensive elaboration and in-depth discussion on all HMI evaluation indexes. Chapter 4 introduces the origins of seven first-level evaluation indexes and analyzes the differences in user demands between the Chinese and European markets. In Chaps. 5–7, we introduce three rational evaluation indexes: utility, safety, and efficiency, respectively. Each chapter focuses on one first-level evaluation index; it introduces the development of relevant theories, clarifying the associated second-level evaluation indexes, and discussing common issues in HMI design based on actual vehicle testing experience. At the end of Chap. 7, we provide detailed suggestions concerning the selection of suitable interaction modalities for various interaction tasks. In Chaps. 8–11, we introduce four emotional evaluation indexes: cognition, intelligence, value, and aesthetics, respectively. Among them, value and aesthetics are two highly subjective indexes, which previous studies have found challenging to incorporate into a standardized evaluation process. Based on Hofstede's cross-cultural research theory, this book summarizes common differences in value between Chinese and European users. In addition, based on the research on symbolic techniques in interface design, we collate the typical aesthetic orientation of automotive HMI, to standardize the evaluation of these two subjective indexes to some extent.

Part III, consisting of Chap. 12, describes the application of our proposed HMI evaluation system in the automotive R&D process. It elaborates on the methods for using this evaluation system in practice, and the integration of testing and evaluation with the actual product development process to achieve efficient design iterations.

The comprehensiveness and universality of this HMI evaluation system have been verified through a large number of real-time vehicle tests and discussions within automotive companies. The evaluation results can significantly distinguish between automotive HMI systems of different levels, and accurately assess their strengths and weaknesses. It can also fully reflect the differences in demands of users from different countries for automotive HMI systems. By adjusting the weights within the system, it can adapt to users in different markets.

The Human-Vehicle Relationship Lab (HVR Lab) team has long been devoted to research on evaluation methods for automotive HMI. In 2009, the HVR Lab began conducting user interview studies on automotive cockpit functions. In 2014, in collaboration with the Groupe PSA, our team conducted usability tests with a customizable simulated driving cockpit to explore future trends in automotive HMI. We benefited greatly from the HMI research and testing methods of PSA France. In 2018, we developed an HMI evaluation system and testing method for mass-produced vehicles. In collaboration with Banma, we carried out comprehensive evaluations on more than ten well-placed products in the market, and publicly released the test results. The same year, Shanghai AMMI Intelligent Technology Co., Ltd. was established to industrialize intelligent cockpit research and HMI evaluation. After six years of continuous development, this evaluation system has grown in its comprehensiveness and sophistication, evolving into the automotive HMI evaluation method introduced in this book.

While developing this evaluation method, a number of partners from the automotive industry, including Porsche, Groupe PSA, BMW, Volkswagen, Honda, Banma, and Great Wall Motor, among others, have provided us with many suggestions, which have helped us to gradually refine this method. In addition, the intercultural research achievements in non-automotive fields by some experts provided important insights for the development of this method, particularly Prof. Aaron Marcus, Mr. Egbert Schram, and Prof. Paulo Finuras. We would hereby like to express our sincere gratitude to all our partners and collaborators.

Many colleagues from AMMI and HVR Lab were involved in researching this evaluation method and have contributed to the writing of this book. Among them, Liu Dachuan, Lu Jin, Wang Xiaobin, and Hu Fen were intrinsically associated with the development of the evaluation system, while Lu Jin contributed to the writing of Chaps. 8 and 11.

Currently, the automotive intelligent cockpit and HMI industry are thriving, with automotive companies, industry associations, academic organizations, and evaluation agencies all showing keen interest in this area. As one of the earliest research teams in this field, AMMI and the HVR Lab are continuously promoting the application of our evaluation system in industry. Using this evaluation system as a base, the China Automotive Engineering Research Institute (CAERI) has started to implement the testing and certification of the "Intelligent Cockpit Interaction Experience", and the China Association of Automobile Manufacturers (CAAM) has released the "Automotive Intelligent Cockpit Interaction Experience Testing and Evaluation Procedures". With J. D. Power, we co-hosted the second China Intelligent Cabin Award (CICA) in 2023, in which the objective measurement portion was performed using our evaluation system. In the future, our team will further explore this research domain, and make additional contributions to the Springer "Research on Automotive Intelligent Cockpit" book series. We hope these evaluation methods and practical experiences will facilitate the development of automotive HMI in a more orderly, innovative, and sustainable manner.

Shanghai, China
November 2023

Jun Ma
Zaiyan Gong

Contents

1 HMI: An Important Trend in Automotive Development 1
1.1 Introduction: HMI and Automotive HMI 1
1.1.1 What is HMI? 1
1.1.2 What is Automotive HMI? 1
1.2 Automotive HMI Development Path 3
1.2.1 Development History 3
1.2.2 Mainstream Product Morphology 5
1.2.3 Future Development 8
References 8

2 Overview of Automotive HMI Evaluation 9
2.1 Development of Automotive HMI Evaluation 9
2.1.1 Automotive Human Factors 9
2.1.2 Usability Evaluation 11
2.2 Automotive HMI Testing Methods 12
2.2.1 Secondary Task Testing 12
2.2.2 Real Vehicle Driving Simulation Bench 17
2.2.3 Eye Tracker 18
References 20

3 Structure of Automotive HMI Evaluation Systems 23
3.1 Challenges in Automotive HMI Evaluation 23
3.2 Structure of Three-Dimensional Orthogonal Evaluation Systems 25
3.2.1 Interaction Tasks 26
3.2.2 Interaction Modalities 28
3.2.3 Evaluation Indexes 31
3.2.4 Evaluation Items 32
3.3 Advantages of Three-Dimensional Orthogonal Evaluation Systems 34
References 35

4 Formulation of Automotive HMI Evaluation Indexes 37
4.1 Design Objectives for Automotive HMI 37
4.1.1 Functionality 37
4.1.2 Usability 40
4.1.3 Imaginability 42
4.2 Evaluation Index System 48
4.2.1 Rational Indexes 48
4.2.2 Emotional Indexes 50
4.3 Correlation and Positioning of Evaluation Indexes 52
4.3.1 Rational and Emotional Indexes 52
4.3.2 Relatively Subjective Indexes 53
4.3.3 Inter-constraints Among Indexes 54
4.4 Differences in Demand Between the Chinese and European Markets 54
References 56

5 Utility 57
5.1 Development 57
5.2 Evaluation Indexes 58
5.2.1 Availability 58
5.2.2 Task Success Rate 64
5.2.3 Reachability 66
5.2.4 Stability 68
5.2.5 Modality Enhancement 70
5.3 Summary of Evaluation Results and Design Suggestions 72
5.3.1 Product Positioning and Design Strategies 72
5.3.2 Touchscreen Limitations 73
5.3.3 Button Development 75
References 78

6 Safety 79
6.1 Development 79
6.1.1 Driving Safety and Secondary Tasks 79
6.1.2 Types and Effects of Driver Distraction 80
6.2 Evaluation Indexes 82
6.2.1 Driving Performance Maintenance 82
6.2.2 Emergency Response 85
6.2.3 Gaze Diversion 86
6.2.4 Function Restrictions 88
6.3 Summary of Evaluation Results and Design Suggestions 89
6.3.1 Central Information Display 89
6.3.2 Buttons 94
6.3.3 Voice Control 96
References 97

7 Efficiency 99
7.1 Development 99
7.2 Evaluation Indexes 100
7.2.1 Task Time 100
7.2.2 Operation Complexity 102
7.3 Summary of the Evaluation Results and Design Suggestions 107
7.3.1 Comparison Among Typical Modalities 107
7.3.2 Relationship Between Efficiency and Safety 109
7.3.3 Suggestions for Interaction Modality Selection 110
References 112

8 Cognition 113
8.1 Development 113
8.2 Evaluation Indexes 117
8.2.1 Logical Structure 117
8.2.2 Element Visibility 121
8.2.3 Element Understandability 123
8.2.4 Element Memorability 128
8.2.5 System Feedback 129
8.3 Summary of the Evaluation Results and Design Suggestions 133
8.3.1 Trends in the Interaction Hierarchical Structure 133
8.3.2 Element Size and Esthetics 136
8.3.3 Does Learnability Matter? 136
References 137

9 Intelligence 139
9.1 Development 139
9.1.1 Definition of Intelligence 139
9.1.2 Automotive Cockpit as the Best Carrier of Intelligence 140
9.2 Evaluation Indexes 143
9.2.1 Comprehension 143
9.2.2 Functional Intelligence 144
9.2.3 Contextual Intelligence 147
References 153

10 Values 155
10.1 Culture and Values 155
10.1.1 Cultural Influence on Automotive User Experience Design 155
10.1.2 Values as the Core of Culture 157
10.1.3 Hofstede's 6D Cultural Model 159
10.2 Typical Values of Intelligent Vehicle Users 162
10.2.1 Companionship 163
10.2.2 Honor 167

10.2.3 Surprise and Delight 170
10.2.4 Reassurance 172
10.3 Other Reasons for Differences in Automotive User Experience 175
10.3.1 Generational Differences 176
10.3.2 Habit Differences 177
References 177

11 Aesthetics 179
11.1 Development 179
11.1.1 Aesthetics in Interface Design 179
11.1.2 Aesthetic Evaluation 181
11.2 Major Aesthetic Styles 184
11.2.1 Sense of Luxury 184
11.2.2 Simplicity 187
11.2.3 Sense of Technology 189
11.2.4 Warmth 193
References 194

12 Application of the Evaluation System in the R&D Process 195
12.1 Application of the Three-Dimensional Orthogonal Evaluation System 195
12.1.1 Suggestions for Evaluation Item Distribution 195
12.1.2 Score Processing Methods for Multiple Interaction Modalities 196
12.1.3 Limitations of the Evaluation System 199
12.2 Testing and Evaluation Throughout the R&D Process 200
12.2.1 Concept Definition Phase 202
12.2.2 UX/UI Design Phase 204
12.2.3 Prototype Module /Prototype Vehicle Validation Phase 206
12.2.4 Mass-Produced Vehicle Benchmarking Phase 207
12.3 Avoiding “Pretend” Digitalization 208
12.4 Future Development Directions for Automotive Experience Evaluation 210
References 211

About the Authors

Prof. Jun Ma is a professor and doctoral supervisor of School of Automotive Studies, Tongji University, founder of HVR Lab, double-hired professor and doctoral supervisor of College of Design & Innovation, Tongji University, and founder and director of Innovative Design and Entrepreneurship Faculty. He is the deputy director of Intelligent Cabin Division of China SAE, board member of XuanYuan University and judge of XuanYuan Award, and founder of China Intelligent Cabin Award (CICA) with J. D. Power.

He has about 30 years of research and industrial practice experience in automotive product R&D, human-machine interaction, and innovative design. He focuses on the user experience of the automotive industry and improved the academic infrastructure by combining inter-disciplinary cooperation and in-depth industrial practice. He proposed the concepts of "Human-Vehicle Relationship" and "Car Experience Management", established the development process of DDP double-diamond process for intelligent automobile products, and created the C-HVR evaluation system, which is the core content of the cockpit-related group standards of the China SAE.

Professor Jun Ma lived and worked in Germany for 15 years. He graduated from Technical University Darmstadt in Germany with a major in electronic engineering and automation. After graduation, he worked in Germany for Continental, BMW, and Audi with responsibilities in active safety product R&D, project management, Chinese marketing, and strategy.

Dr. Zaiyan Gong is the Director of HVR Lab, Tongji University, General Manager of Shanghai AMMI Intelligent Technology Co., Ltd., Associate Partner of Hofstede Insights, and DUXU board member of HCI International. He holds a Ph.D. of Automotive Engineering from Tongji University.

His current research activities are focused on the definition, analysis, design, and evaluation of the automotive intelligent cockpit. The research covers both rational and emotional fields. In the rational aspect of his work, he created the real-vehicle driving simulation platform, which can do the usability test with objective quantitative data for any mass-produced cars in a virtual driving scenario. In the emotional aspect, he introduced the Hofstede 6-D culture model into automotive UX definition, to show the distinctive user requirement among various target groups.

He has rich experience in automotive industry and worked in Porsche China.

Chapter 1
HMI: An Important Trend in Automotive Development

1.1 Introduction: HMI and Automotive HMI

1.1.1 What is HMI?

Human–machine interaction (HMI) is the study of the design, evaluation, implementation, and other related aspects of interactive machine systems intended for direct use by humans [1].

Human–computer interaction (HCI) is also used in computer science. In theory, the scope of machines is wider than that of computers; accordingly, the scope of HMI is wider than that of HCI. However, pure mechanical interaction systems (e.g., combination locks on safe boxes) are becoming increasingly rare in everyday life and are not the focus of HMI research. Therefore, at present, the scopes of HCI and HMI are essentially the same in both academic research and engineering applications, excluding the need for distinction. In the field of automotive, the term "HMI" is widely used.

HMI is applicable to not only computers, cell phones, and automobiles but also various other fields, including household appliances, industrial equipment, and large interactive facilities in public places. Therefore, the definition of HMI involves a certain vagueness. Nevertheless, for only automobiles, we can provide a precise definition to determine what automotive HMI is and what it is not.

1.1.2 What is Automotive HMI?

Automotive HMI is a system that enables the transmission of dynamic information and emotions between a human and a vehicle, except for the main driving task.

J. Ma and Z. Gong, *Automotive Human-Machine Interaction (HMI) Evaluation Method*, Research on Automotive Intelligent Cockpit,
https://doi.org/10.1007/978-981-99-9951-4_1

Information transmission is the fundamental function of automotive HMI, where the information includes both the instructions input into the vehicle by the driver or passengers and the texts, images, and voice outputs by the vehicle to the driver or passenger. For example, when setting the navigation destination, the information transmitted between the human and the vehicle mainly includes the driver saying "navigate to location X." Then, a list of relevant destinations is presented on the central information display and the driver selects the correct address from this list. Subsequently, navigation commences and the driving direction is shown on the central information display. When designing specific interactions, the information for each step in this example needs to be clarified in a more detailed manner.

Emotion transmission is a relatively new aspect of automotive HMI. Interactions for conveying emotions usually contain little information or no explicit information at all; however, they can express emotions in more complex forms. Such emotions may be the sense of technology, luxury, warmth and comfort, and natural relaxation, as well as more specific and explicit emotions. The main interactions that convey emotions are the in-vehicle dynamic ambient lighting and animations on a screen that create an aura. In other HMI tasks, the interactions for transmitting emotions are usually not emphasized, but their role in automotive HMI is vital and increasingly important.

The information or emotion must be dynamic to meet the definition of automotive HMI. For instance, although a line of words on a door sill plate is considered as information, it is static information; therefore, it does not belong to HMI. The exquisite stitching on the seats, albeit creating a luxurious atmosphere, is also static, and thus, it does not belong to HMI.

Automotive HMI does not include the main and most basic task of driving the vehicle. Specifically, it does not include the position and size of the steering wheel, the steering feel when driving, the foot feel on the clutch and gas and brake pedals, or the feel of shifting gears in a manual-gearbox vehicle. In fact, the main task of driving certainly requires communication between driver and vehicle, and this communication not only determines the driving characteristics of a car but may also affect the driving safety. However, the interaction in the main task of driving is an integral part of the car's dynamics and maneuvering, which is the responsibility of the departments related to the powertrain and chassis in automotive development. There is no need to include this century-old development area in automotive HMI, which is an emerging area in the automotive industry. Furthermore, some functions that are highly associated with the main task of driving are within the vague area of automotive HMI definition. In conventional designs, such functions are usually excluded from the scope of automotive HMI, including gear selection in automatic-transmission models, the turn signal lever on the steering wheel column, and wiper levers. Nevertheless, automotive HMI researchers should also pay attention to these functions if they are to be operated in innovative ways such as knob-type gear shifting and wiper control within the central touchscreen.

According to its definition, the scope of automotive HMI can be extended. A fitting example is an interior ambient light strip with no dynamic effects, which is not included in the scope of HMI; however, once it displays a flowing effect with the navigation direction, it belongs to HMI. In automotive HMI research and design, we should not only focus on conventional buttons, screens, and voice control but also consider how to incorporate more functions and hardware into the scope of HMI.

1.2 Automotive HMI Development Path

1.2.1 Development History

Over the past 100 years, automotive HMI functions have been gradually expanded and their popularity has progressively increased. In the past decade, starting from the 2010s, automotive HMI has experienced unprecedented rapid development and has become one of the most important modules in automotive product design.

Since the 1920s, radio sets have found their way into car cockpits. In 1923, American coachbuilder Springfield and British motor manufacturer Daimler provided original radios for cars at prices of up to approximately 25% of the total vehicle price. Drivers use knobs to adjust the volume and switch channels. In the late 1930s, car radios became interactive, with buttons to select specific pre-defined channels. In 1966, the Ford Thunderbird was the first to include buttons on the spoke of the steering wheel to control the cruising speed, as shown in Fig. 1.1. Subsequently, an increasing number of electronic components have been added to vehicle systems. A case in point: the integration of in-vehicle telephones, radio communication equipment, and satellite navigation devices has realized the electronization and electrification of the cockpit.

Since the 1970s, virtual display units have been widely used in all aspects of public life. In 1986, General Motors launched the Buick Riviera, which was equipped with a touchable central screen, named the "graphic control center", as shown in Fig. 1.2. and the HMI system with a central touchscreen as the control center began to take shape. However, the HMI central control screen was not initially popular due to the inadequate electronic and communication technology at the time. In 2001, BMW unveiled the 7-Series sedan, whose iDrive system was equipped with a non-touch color central screen. It abandoned the design idea of different buttons controlling their respective functions. Instead, all functions were controlled by a single knob, as shown in Fig. 1.3, marking an important milestone for in-vehicle HMI systems.

Automotive HMI's rapid development began in the 2010s. In 2011, the Ford Sync system, which is based on Nuance voice recognition technology, could support over 10,000 voice control commands, representing the transition of voice control from simple mechanical commands to natural language comprehension. In 2012, Tesla premiered its first mass-produced vehicle, Model S, whose central console featured only a 17-inch touchscreen, as shown in Fig. 1.4. This touchscreen integrated more Internet content and replaced the buttons and knobs in the traditional central console, symbolizing the central information display becoming the core of automotive HMI. In 2016, SAIC Motor released the Roewe RX5, which was positioned as "the world's

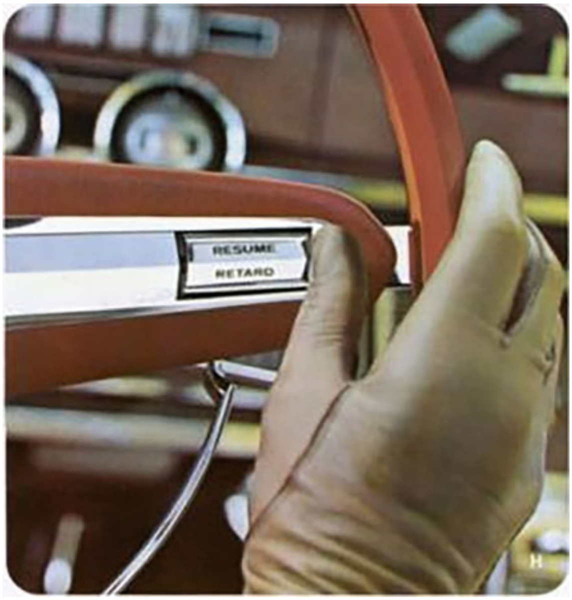

Fig. 1.1 Steering wheel buttons of the Ford Thunderbird (1966) (*Source* Ford Motor Company)

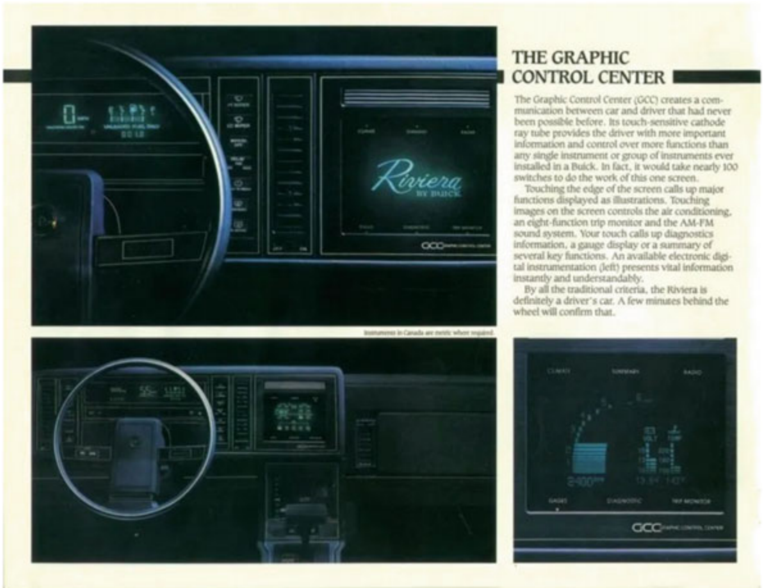

Fig. 1.2 "Graphic Control Center," the central touchscreen in the Buick Riviera (1986) (*Source* General Motors Company)

Fig. 1.3 iDrive system with a combination of knobs and a non-touch central screen in the BMW 7-Series (2001) (*Source* BMW Group)

first mass-produced Internet-connected vehicle." The Roewe RX5 was equipped with the Banma operating system, which was jointly created by SAIC Motor and Alibaba and enabled maps and entertainment content to be online in real time, as shown in Fig. 1.5. This system put forward an interaction framework "maps as the desktop". Its voice control system that could comprehend natural language, and it provided users with OTA upgrade services. Since 2020, HMI has become an important functional module in almost all available automotive products and has been among the most important purchase considerations for consumers. In 2021, among newly released and newly remodeled passenger cars in China, the penetration rate of central touchscreens and voice control was 92.5 and 86.0% [2], respectively. Even low-end models at the 7,000 Euros price range were generally equipped with central information displays and voice control systems.

1.2.2 Mainstream Product Morphology

Automotive HMI development is an extension of human sensory channels. The buttons involve minimal visual and tactile senses, and the central information display increases the information volume transmitted through the visual channel, whereas the voice control utilizes the auditory channel. Such evolution has improved the interaction efficiency, which embodies the people-centered design concept.

Currently, the HMI system of a typical vehicle comprises a central information display, an instrument cluster display, central console buttons, steering wheel buttons, and a voice control system, among other components, as shown in Fig. 1.6. The central information display is the core device in most automotive HMI systems. In

Fig. 1.4 Tesla Model S (2012) with a large 17-inch central information display (*Source* Tesla, Inc.)

Fig. 1.5 Roewe RX5 (2016) equipped with the Banma operating system (*Source* SAIC Roewe)

a hierarchical design, it has the capability of displaying an almost infinite amount of information in its limited area. The easy-to-operate touchscreen serves as both an input and output device. The instrument cluster display, which evolved from the mechanical dashboard of a conventional vehicle, displays maps, navigation, music, and other content in addition to the necessary driving information on traditional gauges. It enables the driver to access such information more efficiently. Central

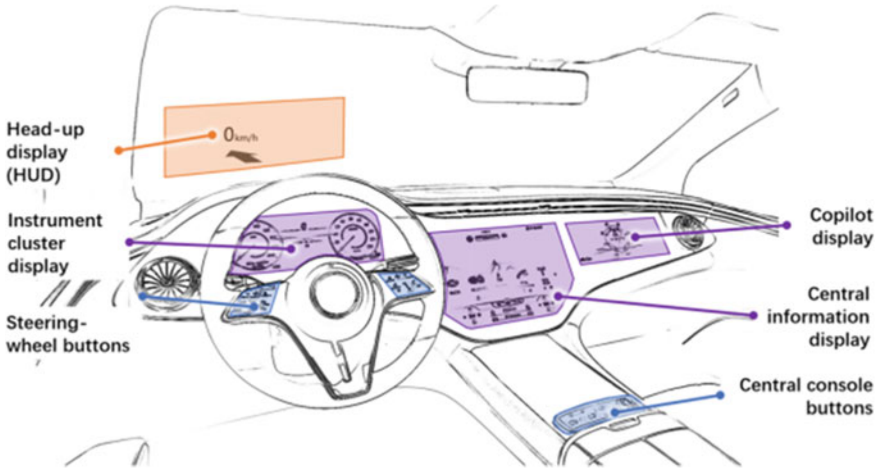

Fig. 1.6 Product morphology of a typical HMI system

console buttons constitute the most important part of traditional automotive HMI; however, as the size and functions of central touchscreens expand, physical buttons have been increasingly replaced by the central display, with some vehicles even completely replacing the buttons in that area. Steering wheel buttons allow drivers to operate by moving only their thumbs without taking their hands off the steering wheel, which enhances driver convenience and safety. Voice control is playing an increasingly important role in automotive HMI. The interaction is more natural because it is very similar to a human-to-human conversation. In some car models, almost all functions in the cockpit can be voice controlled.

Furthermore, the HMI system of some vehicles may include head-up displays (HUDs), lower control displays, and copilot displays. HUDs project information in a virtual image beyond the windshield through light reflection. The driver can read the information without taking their eyes off the road, thus improving driving safety. Via augmented reality (AR) technology, HUDs can superimpose virtual graphics on the road, providing the driver with a richer, more intuitive view of the information directly ahead. Lower control displays are displays below the central information display to replace most or all of the central control buttons. Their hierarchy is simpler, and their operational logic is closer to that of the buttons than to the central display. Copilot displays show information for the copilot, including music, videos, games, among other. As the copilot does not drive the car and can pay full attention to the display, its function and experience is similar to that of a tablet.

In a broad sense, HMI also includes the window actuation buttons on the doors, the seat adjustment buttons, and the light levers on the steering column. These functions are relatively independent and do not differ significantly in design among different car models; therefore, they are not usually the main object of automotive HMI research.