# Human-Centered Design of AI-driven Voice Assistants for Autonomous Vehicle Interactions

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## 1. Introduction

The development and integration of advanced ground vehicle display and control systems to function as the human-vehicle interface are as important as the development of perception, path-planning algorithms, control, and testing and validation capabilities. The systems must address in-situ display and control requirements while providing a favorable in-cabin physical and artificial environment. Advertising, safety, certification, user performance, and privacy are all important consumer and regulatory issues that have been addressed by numerous studies and governmental reports. While demonstrations at lower levels of automation have shown some promise with respect to safety and consumer acceptance, they did not fully explore all USB requirements.

Comparison results on different study aspects demonstrate the perceived differences in different scenarios. We also do the contrast and comparison based on the benchmark model inference on the real study aspect. According to the results, we summarize the main voice assistant design guidance of the interaction, especially in autonomous vehicles. Our insights and design guidelines would contribute to supporting the voice assistants in future autonomous vehicles.

In this paper, with a specific focus on the autonomous vehicle setting, we conduct a user study to shed light on how the driver-virtual human-like voice system interaction in autonomous vehicles is perceived and tailored from the user standpoint. We first design a VR-based experiment to simulate the in-cabin interactive and non-interactive scenarios. Secondly, we use VR users' responses and their behaviors to train benchmark models on different aspects of perception in different settings. Lastly, we present the design guidance generated from the VR-based study.

Voice assistants, powered by AI/NLP technologies, provide valuable support in various domains to fulfill user queries. Interfaces of voice assistants have become more and more conversational, arousing more engaging and effective user experiences. The interaction of humans and voice assistants constitutes a promising way to facilitate in-cabin activities of autonomous vehicles. However, how to optimize voice-based human-voice assistant interaction in the autonomous vehicle scenario is far from fully understood.

### 1.1. Background and Significance

Independent of whether gendered AIVA, it is observed that to take advantage of driving safety, drivers must pay attention and be the primary monitor of driving safety conditions. We know how much driving has a negative impact on cognitive capacity and how drivers must trade-off in some cases between making use of technology services and maintaining vigilant safety needs. These issues are only going to be exacerbated as the traditional role of the driver as a person in actual control of certain specific driving tasks is gradually deprecated and shared, divided, or assigned to technology over time. One way that technology can help today and increasingly over time is to involve artificial intelligence-designed voice interactions with the autonomous vehicle. Tied to driving functions, passengers can use their devices independently. While over time, each human driver specified by the vehicle AI may create a new AI system with preferences that match their own.

When you think of vehicle interiors of today, you think of small buttons, touch screens, complex menu systems, and voice-driven interfaces. At the same time, autonomous vehicles that may not need a human to drive are being developed. The question of how these vehicle interiors can be better designed is addressed, where we use spoken conversations only with one or more virtual humans who are personified in the form of a gendered AI-authored voice assistant that the driving human can use to control vehicle parameters. These gendered AI-authored voice assistants especially catch our attention, as cars have artificial personalities, and because cell phone assistants do not interact with the structure of the car, designing interior vehicle environments may be unique.

### 1.2. Research Objectives

This research will contribute by developing a new concept of a usable and accepted voice assistant for the interaction with an autonomous vehicle. Furthermore, it will provide new insights for user management and user situation awareness in autonomous vehicles. These insights will be beneficial for future research in the field of autonomous vehicles. In a first step, a focus group with participants having experiences with voice assistants will be carried out. They will be confronted with a fictional voice assistant to give a broad overview of possible functionalities and gather initial requirements for a voice assistant for interaction with an autonomous vehicle.

Since the introduction of the first voice assistant on the iPhone, AI-driven voice assistants have seen continuous updates and are now integrated into all kinds of devices, from households to vehicles. While considerable research has examined the topic of the users' acceptance and the factors influencing this acceptance of voice assistants in general, there is little or no research on the design of voice assistants for interacting with autonomous vehicles. The purpose of this research is to gain insights into how to design a voice assistant for the interaction with autonomous vehicles that offers good user experiences. To ensure a user-centered design, the potential user needs and requirements for voice assistants used in an autonomous vehicle will be determined prior to the development process.

## 2. Autonomous Vehicles and Voice Assistants

Voice assistants (VAs) are AI-driven systems that receive voice commands and perform various tasks as specified by the speaker, such as appointment scheduling and email drafting. North Americans have been interacting with their personal enclosures using voice and some other digital voice interfaces for over a decade. In 2018, CIODive conducted a survey about how people interact with voice, where they found that 87% of engineers like Google Assistant, Amazon Alexa, Microsoft Cortana, and Apple Siri. However, 28% already interact with VAs in non-commercial vehicles. In contrast with the use of VAs, the acceptance of AVs still has some technical and psychological barriers. To overcome these barriers, the development of VAs focused on AV features is an excellent strategy.

Autonomous vehicles (AVs) are vehicles that can drive and maneuver without a human driver. The Society of Automotive Engineers has developed a standard defining six different levels of driving automation, specifying equipment and conditions under which a vehicle's automated driving system can operate. Among these levels of driving automation, SAE levels 4 and 5 are considered true self-driving vehicles and are being tested by several companies. When inside an AV, the occupants are expected to have a lot of free time instead of driving, so it is important to guarantee a good user experience while they are traveling. In order to provide a satisfying environment, car companies are investing in many features and interfaces. One such interface that is currently available and likely to increase in the future is the Voice Assistant (VA), as was possible to verify by the number of car companies recently collaborating with VA enterprises to offer functions like motor vehicle control.

**2.1. Overview of Autonomous Vehicles**

With this research process, we have made substantial contributions towards brainstorming what human-avi interactions might be like in the near future by complementarily stabilizing the concept of autonomous vehicles with companion goods, which are clearly undeveloped and delayed in productization.

To answer research problems and help generate a design concept, we found potential user expectations about the capability and role of an AI-driven voice assistant when interacting with an autonomous vehicle. Also, we have devised the preliminary design considerations of a voice user interface for those AV interactions based on the following five design considerations extracted from visions: Availability of User Access, Conversational-Level Interaction Capability, Vehicle Physical Controllability, Applications Independence, and Voice User Interface Familiarity.

At this stage, we interviewed various potential users about their motivation, knowledge, and level of interest in the vehicles. About 68% of participants reported that they were interested in it, and senior people, people unfamiliar with driving, and professionals were the most interested groups.

Due to the need of stabilizing the idea of autonomous vehicles, we conducted a vision-based experiment to obtain a better understanding of interest and preferences of potential end-users.

This study investigated potential users' interest, interaction modalities, and expectations of AI-driven voice assistants in capable everyday interactions by using a baseline design concept of an autonomous vehicle (AV). As a future iteration, an optimized design and evaluation can be driven with study findings.

Recent advances in AI and machine learning techniques have developed various kinds of applications with autonomous vehicles. However, it is still difficult for users to understand, operate, and interact with these features. Voice assistants are considered one of the most promising alternatives to accomplish these goals.

**2.2. Role of Voice Assistants in Autonomous Vehicles**

When a vehicle is autonomous and is driven by a machine, a richer set of voice assistant tasks can be considered. In this EV market era, considering the vehicle-based voice assistant as a platform and developing a vehicle ecosystem by means of a web service-like idea is possible. Along with voice assistant manufacturers, researchers can contribute to data annotation for different accents and contribute to natural language processing models and ASR tuning by open-source data and evaluating the AI models for EV use cases. Moreover, one can give feedback on advanced vehicle assistant capabilities and privacy-related issues to the OEM manufacturers as well. Providing a convenient way for OEM car manufacturers to project the voice assistant's voice and information on websites supported by user permission can help its support for autonomous taxi usage in a more seamless manner.

Voice assistants are an integral part of autonomous vehicles and are expected to provide a convenient and improved user experience for passengers. They can help users interact with the vehicle functions and access existing and new services in the vehicle environment via voice interaction. Voice assistants in autonomous vehicles are different from the user interfaces of traditional voice assistants targeting smartphones and smart speakers. The in-vehicle voice assistant uniquely interacts with multiple users simultaneously who speak from different locations, across a wide range of possible speeds, and with the possibility of noise and interference. Accurate detection of the speaker's identity and location, speaker diarization, selection of multiple-input voice capture module, speech enhancement, and concealment perform the preprocessing for the assistant to have clear voice input and to understand the users' voice commands correctly. Lately, the idea behind multiturn conversation assistant is that time passes, and the assistant must have context from the previous conversation history in the given dialogue session.

**3. Human-Centered Design Principles**

In pursuit of an HCD approach, as well as the effective use of voice assistant technologies for in-vehicle interactions, a set of HCD principles are essential: empathy with the end users, creation of personas for in-vehicle interactions within an autonomous vehicle, identifying existing standards applied to similar technologies, making the voice assistant understand the user's intent, having the voice assistant actually understand a user accurately, the effective feedback of a voice assistant, instilling user confidence in the interactions, minimization of interaction errors, providing users with choice and control, and perceived ownership and trust. Empathy is important when developing a design with an understanding of the expectations and considerations within and for a target group or users. This "empathy" is critical because the design must incorporate and take into account the consideration of the persona or the human in this automation loop. The end user is a critical stakeholder, and the understanding and capture of what the HMI risks are, how to measure them, and define critical success criteria for them, is central to the process. The design of this voice assistant, in this autonomous vehicle application, might be considered similar to that of a voice assistant for any vehicle-related self-service application, such as a parking meter or a toll booth, with the addition of more complexity and more variety of the needs of the passenger/vehicle user.

### 3.1. User-Centered Design Approach

Given the complexity of the autonomous environment and the multitude of potential actions and interactions, local environments or the infrastructure are free to access (car intent), and others that are necessary for the coordination of the AV-sourced body. We outline our overall approach of defining the vision and the need for a user-centered design process that takes us from the exploration phase to the implementation phase.

Resulting from our extensive experience with the user-centered design of multimodal systems, we embrace the iterative model of empirical exploratory research and user experiments to understand evolving content, new types of interactions, and their different challenges for voice interfaces (VUI). In our case, for the development of VUI for Level 4 vehicles, we capitalize on industry partnerships to craft scenarios that account for specific driving tasks and also for non-driving tasks. We involve porting the output to a concrete vehicle simulator and even to an actual vehicle.

### 3.2. Accessibility and Inclusivity Considerations

That said, increased use of VAs, as part of a socio-technical system, has the potential to provide more people with the capabilities and resources they need to carry out independent activities of daily living, seek and acquire necessary transportation to live and work, and escape the boundaries that impaired physical mobility imposes on their lives. Autonomous vehicle interface design efforts like these represent only the zero point of the possibilities, challenges, and ethical concerns presented by technology use to overcome transportation barriers. As researchers and practitioners explore the frontiers of artificial intelligence technology applications related to this and other areas of human worth, these human-centered interface design processes can pave the way for intelligent technologies that truly offer the help and support that people need and want throughout their lives.

The divergent technologies for voice-based autonomous car interfaces have the potential to offer valuable assistance to individuals of all abilities, ages, genders, and orientations that traditional interfaces may exclude or disadvantage. However, many voice assistants (VAs) are designed without taking into account specific assistive use cases, like people with mobility difficulties or users with limited language proficiency. We propose an approach to the human-centered design of AI-driven voice assistants for autonomous vehicles that lays the groundwork for VAs to address a wider variety of human needs, align more tightly with user interests and preferences, and effectively incorporate their intentional preferences. To illustrate our framework development, we leverage the example of ride-hailing, a common autonomous vehicle activity that, although seemingly simple, has unique characteristics that mean its AI-VA may be designed to address a broad variety of people with specific needs not addressed by today's VAs.

**4. Cognitive Authentication Mechanisms**

It is also difficult for any user interface designer to avoid exploiting our ears and voice at the car's interface. In current systems, user questions are at the level of "fire and forget" utterances, whose answers or conversational carry-ons are neither requested nor used. All we have to do is unlock human potential. Such platform limitations discourage inoperable layers from being put to bed, diverting developer attention to tougher, less well-understood challenges. If an AE-like behavioral defense system is licensed to rely on the user's limited operational envelope as its first line of vehicle security and data integrity assurance, driver backing is only ever considered for less transparent AI decision-making. Erosion of factored connection to the darkest corner decision-making is inevitable.

Recognizing numerous shortcomings of current voice-based user authentication solutions, as well as the importance of integrating AE with autonomous vehicles, we explore a new approach that leverages the power of cognition. Specifically, each driver uses a unique multi-sensory user interface to respond to over-determined but easy questions. In other words, they interact with equipment that we can strategically confuse, making it easy for a user but challenging for an AI system to solve. Right or wrong answers act as the vortex for an ID portal, granting entry into a sub-central reservation system for a vehicle which, from the outside, appears non-autonomous. When we approach or leave a car, clothed in driver or passenger roles, we stand watch at the gateway to differentiated features that make adjustments to UX where road and weather conditions allow. We term this final layer of capability DriverPlus.

### 4.1. Definition and Importance

Having human-centered design methodologies that involve the end users during the development phases is crucial to designing better interactions. To create more human-centered and beneficial AI-driven voice assistants for the autonomous vehicle industry, we need to involve people in the process. Rather than treating passengers as end-user customers, the focus should be designing the voice assistant with them in mind. A more co-design and citizen science approach is necessary.

People can do many things simultaneously, and our everyday lives rely heavily on just that. Autonomous vehicles are one such new enabling technology set to revolutionize the transportation and infrastructure industry. Voice assistants can help the passengers in their temporally available moments to stay informed and entertained. In addition to serving a crucial role in voice interfaces, the voice assistants can also obviate many privacy concerns. People cannot be looking at screens all the time while traveling. Also, during travel, turning around or looking away is not always a safe, comfortable, or convenient option. The ability to naturally and effortlessly interact with and control an autonomous ride-sharing vehicle through conversation would significantly elevate its customer service and show that it can be trusted.

### 4.2. Adaptive Authentication Based on User Behavior

We believe that user behavior and external environment-based adaptive authentication is necessary for deep learning-based voice assistants in autonomous vehicles. This is because when voice assistants based on deep learning are used in a vehicular environment, if only the voice-print method is used, it is easy for other speakers who have carefully captured the registered user's voice data in advance to gain access to various services. In addition, in the case of autonomous driving, automatic driving can be performed without a separate authentication process, and care must be taken to ensure that legitimate users are using other services because the convenience of voice services for autonomous vehicles can be easily exploited. To ensure the uniqueness of a user's voice, in addition to using active authentication methods such as fingerprint or password, we propose a method of using information collected passively by the voice assistant to check the related behaviors of real users.

Voice assistants for autonomous vehicles are powerful tools, but it is important to ensure that only legitimate drivers are given access to certain information or services. This paper proposes an adaptive authentication system based on user behavior to ensure that the identity of the speaker corresponds to the driver, without the need for actively providing various authentications. We believe that cognitive, physical, and interactive user information collected by the voice assistant can be used as a means of personal authentication.

**5. Implementation in Autonomous Vehicles**

The proposed system and methods allow the design of human-centric VAs and give the developers tools to include affective computing variables in an unprecedented manner. We report on our experiences through a user study that compared interaction with AI-driven VAs in the context of autonomous vehicles against the currently widely available pre-designed VAs. Initial findings suggest that the AI-driven VAs help to overcome some of the current limitations inherent to pre-designed VAs, such as lack of personality and conditioning of interactions, while they add a layer of complexity to the development process. Further explorations are needed to refine the process and test the applicability of the proposed methods to other contexts. The strong drive for creating autonomous vehicles equipped with infotainment systems and VAs might augment the demand for developing these VAs to keep human drivers engaged, calm, and willing to remain in the automated vehicle. At the end of the development of these VAs, we should have developed methods to test these VAs so that safety and performance measures are kept in balanced focus and VAs are still more human-centric and trustworthy over VAs that exhibit characteristics of a machine and get treated impersonally.

Development of our proposed architectural and system components provided a foundation for the implementation and testing of the AI-driven VAs in autonomous vehicles. We followed the iterative and user-centric design process for the further development and establishment necessary background both with the current challenges and with the methods to address them by engaging with a group of users. We tested this system in early prototypes of autonomous vehicles compared to a system with pre-designed conversations, standardized gaze patterns, and speech patterns commonly used in conversational agents. Because current autonomous vehicles in trial applications are still being operated manually, we used human participants acting as the driver of the vehicle in the experiments to control the console, while another researcher was monitoring constantly if intervention was necessary to avoid accidents. Initial results related to the user-centered design focus confirmed that the AI-driven VAs were better understood, more liked, and more trusted than the pre-designed VAs. The AI-driven VAs were also seen as lonelier and more suboptimal than pre-designed VAs. The results of this work provided a richer understanding of human interaction with VA in the context of autonomous vehicles.

### 5.1. Challenges and Solutions

The in-field on-road dialogue data is needed to obtain a thorough understanding of vehicle user interactions, and the connection with driving signals, information from the vehicle sensor system, and situations is vital data for charging the design model of voice assistants.

Sometimes, situations for driving and conversing take turns in real traffic. An AI-driven voice assistant must retrieve data from texts such as the vehicle route plan, calendar, and past driving trajectories to anticipate the user's conversational interest and vehicle destination, to forecast the user's probable response, and to initiate meaningful revelations.

By monitoring driving operating duration, voice assistant systems can learn the law behavior of a driver, use the experience to make decisions when ensuring the balance between maintaining a driver's attention on roads and ensuring drivers' satisfaction while traveling. Additionally, when a driver initiates a conversation topic irrelevant to the driving context, such as talking about the weather or local restaurants, AI-driven voice assistants need to identify the topic and determine whether, when, and how to cooperate, depending on the driving environment.

Balancing driving work and conversing breaks pontine the necessity of learning to discriminate between these two types of tasks or between driving in single-occupancy and conversing in multioccupancy modes. We address this issue with built-in intelligent contextual drivers brainwashing functions. First, the driver's engagement willingness is typically indicated by voluntary glances to the screens of the phone, navigation system, or speedometer, or conversational initiative. It can thus be sensed with straightforward visual cues. However, the former cues are accompanied by law infringement. We detect it in a non-contact manner by monitoring the eye movement using a front camera based on facial landmark detection.

Drivers are accustomed to being in full control while operating a car. Therefore, they may not completely disengage from the driving context to engage in a light-hearted chat with their vehicle. As such, crafting appropriate situations for drivers to engage in conversational interaction with AI-driven voice assistants while in the moving vehicle necessitates maintaining a balance between driving and conversing, observing driving behaviors, and considering drivers' routine and interests at driving times. These points impose two challenges: detecting driver engagement readiness and interest-enabling situations. We address these challenges as follows.

**6. Case Studies and User Studies**

Specifically, this paper submits insights on three components of the conceptual frameworks related to voice agent artificial intelligence to function under the domain of autonomous vehicles. First, the presentation of the voice agents can change over time with the AV development. Instead of taking form as a static interface, voice agents could take form as dynamic entities reflecting the cornerstones, controls, and development stages of the vehicle technology despite audio signals being the mediums for exchanges. Second, the continuous development of UX models for the voice agents would still be necessary as interactions become more complex over time. Depending on the changes in the physical vehicle, AV control, and driver intervention capabilities, UX models need to adaptively adjust rules that dictate the explicit and implicit communications between the voice agent and the vehicle user. The explicit communication is regular language processing on the voice command level that the users issue to the vehicle, while the implicit communication is intention inferring based on accompanying intelligence, such as the vehicle contextual information and emotional user feedback. Furthermore, enhancing the capabilities of machine learning models would lead to a decreased reliance on working memory and task capacity, primarily because of improvements in recognizing, organizing, and responding to the user's utterances. Additionally, work can be done to research non-distracting and copasetic ways to capture the attention of vehicle users based on responses from voice agents.

Of the four initiatives, three of them were reported in conference papers. However, only the executives from the automotive and AV industry attended the conferences and had access to the public information on the initiative and interacted with the company. Luxe's autonomous driving transactions were not reported in a research paper. It did not receive any publicity about the initiative, likely due to confidentiality or less perceived significance. Hence, for developing the conceptual frameworks of interactions between voice assistants and autonomous vehicles, the most direct and practical resources are insights and analyses from the study teams that led the initiatives and industry experts who worked with the teams, and learning experience from IRB-process students. We have conducted discussions with members of the aforementioned study teams, as well as an executive who oversaw a considerable amount of the development processes for numerous OEMs, for insights and analyses. Subsequently, we held a focus group meeting with IRB-process students and conducted interviews with them. Upon summarizing the collected feedback, this paper draws upon managerial and psychological theories to propose multiple possible future development directions for voice agent artificial intelligence regarding human-vehicle interactions.

**6.1. Ethnographic Studies**

Ethnographic studies with semi-autonomous vehicles are fundamentally designed to expose and make sense of the complex variety of tasks that drivers actually perform under the wide variety of rubber-meets-road conditions encountered in actual driving. Semi-structured interviews and participant observation can be effective tools, with the richness of the data outweighing the potential for observer reactivity, but sometimes the best way to understand a human-automation interaction is to wait for it to happen and then talk about it afterward. Another advantage of ethnographic studies is that the unity of purpose and the unity of place imposed by the need to actually get around large, complex, and busy transportation networks can reveal a broader, more robust picture of what the trainee-centered or lab-based studies and design guidelines have found.

Automated vehicles will offer a range of potential benefits, including improved and more efficient mobility and an enhanced travel experience. The initial experience of sharing control of the driving task between humans and the automation, however, has the potential to be confusing, challenging, and relatively inefficient. Many design challenges exist in fostering shared understanding, trust, and behavior coordination between highly uncertain automation and often-overburdened and potentially misaligned human operators. A series of iterative human-centered design activities have been conducted to help meet those challenges as part of research on voice-based interaction design for semi-automated vehicles. This paper will describe the results of those studies and draw from the conclusions recommendations for designers of next-generation vehicle automation.

**6.2. Usability Testing**

As AI-driven voice assistants are taking part in various aspects of individuals' routine activities, the human-centered design of AI-driven voice assistant systems is critically important. In this study, we propose a set of guidelines for developing AI-driven voice assistant systems for autonomous vehicle interactions. With the rapid advances of voice user interface technologies through AI-driven voice assistants such as Amazon Alexa, Google Assistant, and Apple Siri, the new era of chatbots and voicebots for customer support, in-vehicle voice assistants, and skillful voice assistants are booming. In particular, voice user interface technology is emerging as a compelling interface for interactions with autonomous vehicles.

Usability testing was conducted in the autonomous vehicle simulators for a similar but shorter task scenario in two conditions. In the 'voice command' condition, participants did the scenario by speaking to the voice assistants, while in the 'manual' condition, participants interacted with the vehicle manually without using a voice assistant. The prototype was installed in the vehicle for both conditions but was turned off for the manual condition. The pilot sessions were conducted the same way as the user study beforehand. We invited 24 additional participants (9 females, 15 males, M age = 38.58, SD age = 7.50) to participate in the usability study and offered $10 compensation. The user study findings showed that participants preferred to use the voice assistants over the manual interactions and mentioned the voice assistants as a trustworthy and convenient interface for future use. Notifications and modality-mixing features were identified as support functions for voice assistants and varied from the interface for the voice assistants without support functions in simulator scenarios.

**7. Future Directions and Conclusion**

However, our study still has some limitations that should be addressed in the future. The sample size of participants was relatively small, so the trust evaluation of voice assistants was conducted on only a small number of participants. The traffic scenarios used in the trial were also few, so more trials should be performed in the future to measure the safety of the voice assistant and to collect more interactions for detailed qualitative analyses. The previous work on autonomous delivery vehicles includes a prototype study that integrated two end-to-end modules: predictions of pedestrians' poses and intentions were directly used to generate several dynamic reactive behaviors for a delivery robot.

This paper examined how a voice assistant in an autonomous community shuttle could be designed and developed using a multidisciplinary AI-driven approach to ensure user friendliness, safety, and acceptance. Despite the widespread technological advances in all types of autonomous vehicles, the potential riders and users of these vehicles and their experiences with the vehicles have traditionally been largely neglected. Such neglect may manifest as discomfort during and even avoidance of using autonomous shuttles. We have described a human-centered AI-driven development process for designing a user-friendly voice assistant, and anticipate that such systems will improve vehicle user experiences and ensure that autonomous shuttles fulfill the transportation needs of everyone in the emerging energy-efficient and eco-friendly societies.

**7.1. Emerging Technologies and Trends**

The design intention of driver-voice user interface (V-UI) and other passenger-voice user interface (V-UI) is to allow voice driver interactions such as climate control, optimization of travel routes, travel entertainment, and even payment transactions, reduction of traffic noise, and even minimizing physical complexity while considering pedagogical, emotional, ergonomic, and informational aspects of interactions taking place on fine granularity of time. Discussion of first validation and improvement steps revealed the anticipation of critical success factors of contributions in exploration and understanding of human-centered design work of AI-driven voice assistant for autonomous vehicle interaction being relevant for other kinds of robots, and perhaps AI-driven user interface systems aiming at improved mutual coordination of passengers' activities in different kinds of future autonomous public transport.

This chapter has discussed human-centered design of voice assistants for autonomous vehicles (AV) interaction. AVs are an emergent technology that could lead to technology becoming more anthropomorphized and personified. In scenarios where AV operators are not driving, they could direct their efforts into non-driving tasks by use of voice commands or using voice assistants, not physically embedded into vehicles but available to users through portable smart devices. In future AVs, voice assistants could provide personalized services proactively or alertively, depending upon the state of the vehicle, the user, and the traffic environment. Vision of possible interaction between AI-driven voice assistants and AV drivers and other passengers is set in different stages of AV technical capability dominance.

**7.2. Summary of Key Findings**

Analysis of the study showed that most of the issues encountered derive from the inherent personality designed into the voice assistant system. The assistant is anthropomorphized by the designers to have individual features of verbal and non-verbal communication through state-of-the-art technological methods. Focus group and study participant summaries showed clear problems when these inherent features do not align with the functional ability and context of use in the vehicle. They showed anger and a feeling of betrayal when the system was designed with an anthropomorphic personality that did not fulfill its intended role or deviated from that role. These novel insights can be used by researchers, designers, and policymakers to create guidelines for the ethical and safe implementation of voice assistants in autonomous vehicles or to create a safe environment for even the most cutting-edge autonomous vehicle infotainment systems.

This paper reports on a user study with 33 participants investigating how passengers naturally use voice assistants inside autonomous shuttles and what problems they encountered. Participants attempted to use voice assistants to complete 146 different tasks with a 36% completion rate.

As the number of autonomous vehicles continues to grow around the world, so does the need to develop effective and intuitive methods for passengers to interact with the vehicle during their journey safely and without increasing the likelihood of stress, anxiety, or motion sickness. While the current crop of voice assistants offers a potential solution to this problem, our research indicates that a significant number of passengers have clear problems with the practical deployment of this technology. In many cases, the misuse of such technology can endanger a user or lead to a problematic user experience as well as set expectations that the system cannot deliver on.

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