Exploring User Needs in Fully Driverless Robotaxis: A Think-Aloud Study of First-Time On-Road Rides

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Abstract

As fully driverless robotaxi services emerge, understanding user needs under real-world conditions is critical. This study employed the think-aloud method to capture real-time cognitive and emotional responses during users' first ride in a fully driverless robotaxi. Analysis of 30 participants' verbal reports revealed three key user needs: perceived safety, efficiency, and comfort. We found that users' trust can be enhanced by conservative driving behaviors and transparent human–machine interface (HMI) design. Conversely, inconsistencies between user expectations and driving behaviors, potentially stemming from technical limitations, and individual differences, can undermine trust. Further, while conservative driving enhanced perceived safety, it can also reduce efficiency, especially in time-sensitive scenarios. Finally, comfort can be shaped by both driving behaviors and HMI interactivity. These findings highlight the importance of user-adaptive interfaces and context-aware driving strategies to balance perceived safety, efficiency, and comfort, thereby supporting the acceptance and deployment of driverless mobility services.

CCS Concepts

• **Human-centered computing** → *Empirical studies in HCI*.

Keywords

Robotaxis, User experience, On-road study

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1 Introduction

Traditional taxi and car-sharing services are being transformed into autonomous ride-hailing services, commonly known as robotaxis, driven by the rapid advancement of autonomous vehicle (AV) technology. These services hold the potential to enhance traffic safety, reduce carbon emissions, and improve the overall efficiency of transportation systems [9, 10]. As access to robotaxi services expands, understanding and boosting user acceptance of AVs has become critical to the broad adoption of such a service. Prior studies have examined user needs and attitudes through questionnaires, interviews, and driving simulator experiments [3, 7, 12, 17], and identified several key factors, such as perceived safety, comfort, cost, and operational efficiency. However, these studies were based on hypothetical or simulated scenarios, which limited their validity and failed to capture authentic reactions to fully driverless experiences.

In recent years, commercial entities have accelerated the integration of AVs into mobility services. Since 2023, several companies have initiated pilot programs for fully driverless robotaxis in selected public areas in China and the United States [1, 8]. These robotaxis can be categorized as Level 4 AVs according to the Society of Automotive Engineers [13] and thus can operate without onboard safety drivers. Such a real-world deployment offers a timely opportunity to examine actual user experiences, uncover authentic user needs, and identify practical barriers to the broader adoption of robotaxi services.

In general, previous research identified four types of factors that can influence the users' or potential users' willingness to take a ride in robotaxis. First, the individual factors were identified. For example, younger adults, particularly those under 32, were found to be more willing to continue using robotaxis in the future [2]. Additionally, personal innovativeness and hedonic motivation were found to be positively associated with the acceptance of robotaxis [4]. Users experiencing social anxiety, such as avoidance of interactions with strangers, or those with weaker habitual travel patterns, were also more inclined to adopt robotaxis [16]. Second, vehicle-related factors were also found to be equally important. Dynamic driving performance was identified as a key determinant of user satisfaction with robotaxis [2]. Further, the design of human–machine interfaces (HMIs) can also shape the in-ride experience. Specifically, satisfaction with in-vehicle interactions can mediate the relationship between trip satisfaction and continued use [2], and interfaces that provide contextual explanations of robotaxi behavior can enhance perceived safety [5]. Third, business-related factors, such as competitive pricing comparable to or lower than traditional taxis, can also promote robotaxi adoption [2, 4]. Finally, social factors, such as peer opinions, have also been found to shape users' attitudes toward robotaxis [4].

However, these studies involving real-world robotaxi users were based on online questionnaire data. Thus, they had lower resolution on how AVs' responses to dynamic traffic events can affect users' attitudes toward the AVs. In our previous work, we investigated how the first ride in a fully autonomous robotaxis without a safety driver can affect users' trust in AVs [14]. However, it still only focused on the comparison between pre- and post-trust in AVs after taking a ride and provided limited information regarding how trust evolves during the ride and how users' riding experience is affected by dynamic traffic events. Thus, in our current study, we adopted a think-aloud method to capture real-time, moment-to-moment verbal reflections on AVs' responses to dynamic traffic events when the participants were invited to take a ride in robotaxis for the first time. To gain a deeper insight regarding user expectations, emotional reactions, and concerns regarding the AVs, we selected fully driverless robotaxis without safety drivers, which can offer a realistic preview of future AV deployments. By analyzing these in-situ verbal protocols within the context of commercial robotaxi services, this research aims to inform HMI design, optimize user experience in AVs, and promote a broader societal acceptance of fully autonomous mobility.

2 Method

2.1 Participants

We recruited 30 participants (10 females and 20 males, with an average age of 25.23 [Min-Max: 18–36; Standard Deviation = 3.63]) for our on-road study. All participants reported no sensory impairments and had no prior experience with robotaxis.

2.2 Procedures

Upon arrival, all participants signed a consent form. Then, each participant took a ride in a fully driverless robotaxi operated by Pony.ai in Guangzhou, China. To minimize the impact of traffic conditions, data collection was scheduled during two non-peak periods: 9:00 AM–12:00 PM and 2:00 PM–5:00 PM. The experimental route covered approximately 15 kilometers of urban public roads characterized by unpredictable and complex traffic scenarios, with each ride lasting around 40 minutes.

During the ride, one participant was seated in the rear left seat, while two experimenters were positioned in the front passenger seat and the rear right seat, respectively (Figure 1). While this configuration may have limited the participant's field of view, it was necessary to comply with the operator's safety regulations, which prohibited passengers from occupying the front row. To elicit quasi-naturalistic feedback, participants were allowed to freely observe both the in-cabin and external environments and interact with the onboard screen (which shows the perception of the environment and the planned trajectory of the AV), simulating natural attention shifts in a real vehicle. However, they were not allowed to use mobile phones or any other bring-in electronic devices, to avoid their attention being fully distracted by non-riding-related tasks.

Figure 1: The cabin environment of the robotaxi.

Participants were instructed to engage in a concurrent think-aloud protocol, verbalizing their thoughts and feelings in real-time. Additionally, every two minutes, they were audibly prompted to rate their dynamic trust in the vehicle using a 7-point Likert scale ("How much do you trust the current autonomous vehicle?", 1 = not at all, 7 = extremely). They were also informed that, when possible, they should explain the explanations for the change in their trust immediately after providing a rating. The whole ride was audio-recorded to facilitate later analysis. Ethical approval was obtained from the Ethics Compliance Committee of the Hong Kong University of Science and Technology (HREP-2023-0246).

2.3 Data Analysis

Following transcription and manual verification of all audio recordings, two researchers independently conducted open coding on the data. They then collaborated to discuss, reconcile, and iteratively refine these initial codes, developing them into the final themes. The entire analytical process was facilitated by MAXQDA software.

3 Results

The think-aloud data were categorized into trust-related themes (explanations provided by participants immediately after answering the trust-related question) and themes related to the general riding experience. The trust-related themes explained the events/reasons that are directly related to the change in trust rating, and riding-experience themes were also analyzed to provide a comprehensive understanding of the factors that influence the overall riding experience.

3.1 User Trust in Robotaxis

We observed four distinct patterns of changes in trust throughout the rides: fluctuation (16 participants), upward trend (11), downward trend (1), and constant (2). This indicates that trust in general increased after the first ride. Regardless of the patterns, all think-aloud explanations were further organized into three categories: increase, decrease, and unchanged, based on the changes of trust ratings (as compared to the previous rating) collected at 2-minute intervals. In the following section, we will discuss the explanations that led to these three trust changes.

3.1.1 Trust Increase. In total, 21 participants provided 31 explanations for the increases in trust. The most frequently mentioned reasons were conservative and smooth driving behaviors, such as maintaining safe following distances, honking appropriately, and yielding to vulnerable road users. These actions were perceived as evidence of the prudence and situational awareness of the robotaxi (P30: "Just now, this section of the road was quite complicated, and when the vehicle stopped, it must have gone through a lot of calculations to choose the far-right lane."; P28: "There wasn't much sharp braking, large steering, or lane changes along the way.").

In addition, the stable performance of robotaxis in complex traffic scenarios was another contributing factor (P19: "I think the traffic is relatively complex, and the experience is not obviously different from a human driver taxi"; P21: "Driverless vehicles show reliable results when avoiding pedestrians and two-wheeled electric vehicles and seem to be accomplished a more difficult task."). Finally, the onboard interactive screen contributed to trust enhancement by making the perception capabilities of the system visible (P8: " The driverless vehicle is very good at recognizing information on the road. When a small motorcycle rider appeared, it displayed it on the screen.").

3.1.2 Trust Decrease. In total, 12 participants provided 26 explanations for the decreases in trust. Inconsistencies between the driving behaviors of robotaxis and user expectations primarily triggered the decrease in trust. For example, P24 compared the robotaxi to a novice driver: "It feels like it likes to drive in the middle lane, not smart enough." P11 similarly remarked: "My trust decreased because it didn't slow down when going downhill." Confusing behaviors, such as lane changes and overtaking, also reduced trust (e.g., P16: "The reason for the decline is because of that lane change just now. I still think it's very incomprehensible; it slightly needs some training.").

Perceived unsafe behaviors were another factor. For example, P14 mentioned: "The driverless vehicle cut across the bus's path at the intersection." Additional trust-reducing factors included technical limitations (e.g., slow response times, inadequate adaptation to dynamic traffic conditions) and pre-existing personal mistrust toward robotaxis.

3.1.3 Trust Unchanged. In total, 15 participants reported 24 instances where their trust remained unchanged. Participants cited the conservative and predictable driving strategy of the AV as the reason. For instance, P6 said: "The driving strategy of this vehicle is relatively conservative; the highest speed is only 60 km/h, and it slows down or brakes when encountering potential dangers." Similarly, P28 stated: "There have been no incidents over the past two-thirds or three-quarters of the trip, and the vehicle has been very conservative. If I encounter some controversial situations, it may affect my trust, but the journey has been very smooth."

Additionally, the presence of consistent and relatively simple traffic conditions, mentioned in four instances, was a contributing factor. Prior knowledge of robotaxis or familiarity with the traffic environment also contributed to the constancy of trust. For example, P12 explained: "I am familiar with this road, because I live nearby, so my trust level stays the same." Likewise, P20 remarked: "I know that driverless vehicles operate in restricted areas, so I am more comfortable."

3.2 User Riding Experience in Robotaxis

Participants' comments on their riding experience were categorized into three primary themes: comments on HMI, perceptions of driving behaviors, and interest in technical details.

3.2.1 Comments on HMI. A total of 16 participants provided 36 statements regarding the onboard screen of the robotaxi, primarily focusing on its displayed content and interactive features. Over half of these comments were negative. Several participants criticized the onboard screen for its insufficient presentation of different road users. For example, they mentioned that while bicycles and tricycles differ significantly in size, they were displayed identically on the screen (P8, P27, P29). Others pointed out that the system failed to provide essential traffic information and observed delays in updating displayed content (P8, P33). A subset of participants expressed a desire for enhanced functionality and interactivity. Suggested features include music playback, personalized settings, and more detailed information about the robotaxi. Furthermore, while some participants initially found the visualized content difficult to interpret, they reported increased familiarity with the interface as the ride progressed. Finally, the screen appeared to play a dynamic role in shaping user trust, particularly during complex traffic scenarios. For example, P8 remarked: "The traffic seems to be getting complicated, I'm starting to become wary and start to look at the screen again." This observation echoes the findings on trust increases, suggesting that real-time HMI feedback may mediate trust development during rides.

3.2.2 Comments on Driving Behaviors. A total of 30 participants provided 143 instances of behavior-related comments. Participants, particularly those with prior driving experience, often evaluated robotaxi behavior by comparing it to that of human drivers. For example, P19 observed: "When approaching this traffic light, the vehicle decelerated in advance… there's not much difference from the behavior of a skilled human driver." However, several participants reported discomfort when the actions of robotaxis deviated from their expectations. Eleven participants described 14 specific instances involving sudden braking, emergency steering, or abrupt lane changes in response to unexpected obstacles such as large trucks or water-spraying vehicles. These events often startled participants and elicited emotional reactions. For instance, P23 commented: "There are a lot of big cars on this section, and I think it's a bit scary, like sandwich biscuits." P8 similarly remarked: "This vehicle hit a small bump. A human driver would have avoided it, but the vehicle didn't because it followed the established route." Individual differences also shaped the evaluation of AV driving behavior. While some participants, such as P22 and P20, reported that sudden maneuvers aligned with their expectations of robotaxis and did not affect their trust, others expressed concerns. P3 reported discomfort when the robotaxi failed to respond to impaired visibility caused by a sprinkler truck: "Although this doesn't affect the vehicle, it affects my feelings, just like there are no lights at night." Similarly, P17 criticized the AV's decision to wait behind a stopped vehicle rather than change lanes: "It was stupid."

Additionally, participants also speculated about how the robotaxi might behave in unencountered scenarios, raising two key themes: hypothetical decisions and unobserved traffic conditions. For example, P30 questioned: "Under what circumstances would an AV horn?" P26 wondered how the robotaxi would respond when surrounded by other vehicles. Others, such as P29 and P3, expressed interest or concern regarding the performance of robotaxis in construction zones or during peak-hour congestion, suggesting that overly conservative strategies could hinder punctuality.

Finally, fifteen participants provided a total of 20 comments on the conservative driving style of robotaxis. The majority viewed this characteristic positively, linking it to enhanced perceived safety and increased trust. For example, P18 remarked: "The vehicle conforms to public expectations and prioritizes safety." However, several participants also expressed concerns regarding the overly cautious driving style. P6 noted: "If I'm in a hurry, this conservative strategy might be one reason I wouldn't choose AVs." Similarly, P32 stated: "I can accept the rigidity because I only use it when I have enough time." Furthermore, some participants argued that excessive caution could compromise the performance of the transportation system. P16 observed that such behavior could lead to congestion: "It moves very slowly in one lane, causing traffic behind to overtake frequently." P28 added that conservativeness does not inherently equate to safety, emphasizing that in certain dynamic contexts, more adaptive or assertive strategies may be necessary.

3.2.3 Interest in Technical Details. A substantial proportion of participants (13 out of 30) expressed notable interest in the technical details of the robotaxi. Participants frequently posed questions regarding the perception ability of robotaxis, such as recognizing traffic signals (e.g., P29, P10, P23) and their navigation algorithms. For example, P27 inquired whether the robotaxi relied on simultaneous localization and mapping (SLAM) or a bird's-eye view (BEV) framework for its navigation. Further, this desire for deeper technical understanding extended to interface design. P17 explicitly advocated for integrating explanations of technical details into the HMI.

4 Discussions

This study examined user experiences during their first ride in a fully driverless robotaxi, employing the think-aloud method to capture real-time thoughts about the robotaxis. Informed by prior work on key factors influencing user needs and attitudes [3, 7, 12, 17], as shown in Figure 2, our qualitative analysis revealed that users' needs during the first ride can be categorized into three themes: perceived safety, efficiency, and comfort. These needs can be shaped by in-vehicle and external factors, including driving behaviors, HMI design, and surrounding traffic conditions, and were further moderated by individual differences, such as prior knowledge, familiarity with local traffic environments, and technical interest.

Safety emerged as the most salient theme, consistent with findings from prior simulator and questionnaire-based studies [17], which played a role in shaping participants' riding experience and their dynamic trust. In general, trust and riding experience can be reinforced by conservative driving behaviors and reliable performance, and transparent system feedback via the HMI, as these features conveyed prudence and situational awareness, reassuring users about the safety of robotaxis.

In contrast, a key factor contributing to the decline in perceived safety and trust was the inconsistency between user expectations and the actual behavior of robotaxis. This inconsistency stemmed from two main sources: (1) driving behaviors perceived as illogical or unsafe, such as ambiguous lane changes or abrupt maneuvers, which may reflect technical limitations, and (2) individual differences that led to divergent interpretations of the same behavior. These findings suggest that context-aware driving strategies, in which AV behaviors are tailored to specific road scenarios and drivers' customized needs [6, 11], may be critical for improving perceived safety in future AV deployments.

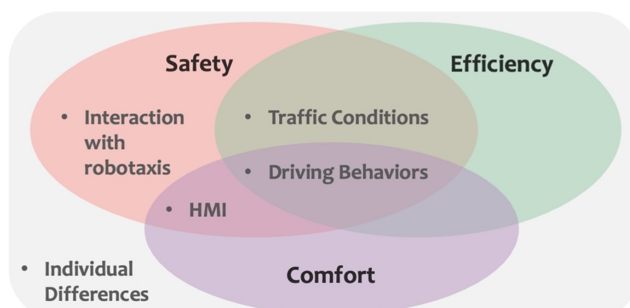

Figure 2: User needs and influential factors.

Further, although AVs are expected to improve the efficiency of transportation systems [10], our findings reveal that in mixed traffic conditions, their conservative strategies can introduce friction. Users placed strong emphasis on efficiency, especially when time constraints were involved. While cautious driving was perceived as "safe", it can also be regarded as overly rigid and inefficient. Participants reported that prolonged hesitations and slow responses could disrupt traffic flow and hinder the suitability of robotaxis for everyday commuting. These results underscore the need to balance between safety and efficiency, as an overemphasis on either dimension could limit the practical application of AVs. Notably, given that user trust may also increase as a result of conservative driving behavior, future systems may benefit from offering adaptive or customizable driving modes that respond to user needs.

Comfort was shaped by both emotional reactions to driving behaviors of robotaxis and user interaction with the HMI. Sudden actions and failure to respond to external traffic scenarios were frequently cited as sources of discomfort. Given that motion sickness is one of the major concerns in smart cabins in recent years [15], future AV control algorithms may also need to take the smoothness of AV reactions to traffic events into consideration, without compromising safety. In addition, participants emphasized the desire for more interactive and customizable HMI features, which could enhance transparency, engagement, and overall satisfaction during the ride. Together, these findings again highlight the importance of user-adaptive interfaces and context-aware, scenario-specific driving strategies in enhancing perceived safety, efficiency, and comfort, and in supporting broader acceptance of fully driverless robotaxi services.

Finally, the readers should be aware of some limitations of our work. First, although this study revealed how dynamic traffic and driving behaviors can shape users' trust in and attitude toward robotaxi services in an on-road study, we primarily based our findings on narratives provided by participants in a qualitative manner. Future research should better quantify the relationships between vehicle behaviors, traffic events, and users' subjective feelings, potentially in controlled experiments. Second, we only had 30 participants, mainly recruited in a single region. Drivers in different countries or regions may have different expectations of the AV behaviors due to various driving cultures. Future research with a larger sample size and a cross-cultural study may provide a more informed design for robotaxi services. Finally, we only considered the first riding experience of non-users. Future research may need to explore the needs of long-term robotaxis users.

5 Conclusions

In an on-road study with real driverless robotaxis, we identified factors influencing users' dynamic trust when they took a ride in a robotaxi for the first time. Our research revealed the factors affecting users' needs for AVs, including more customized and adaptive driving style, HMIs with higher transparency, and a balance between safety and efficiency. The findings from this study can provide insights for future robotaxis service promotion and more socially acceptable AV designs.

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