Co-Creating Future Autonomous Vehicle HMIs: A Mixed-Methods Exploration of Passenger Information Needs

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ABSTRACT

This paper investigates passenger information needs concerning the behavior of autonomous vehicles (AVs; SAE L4 and L5) in urban driving scenarios. Understanding these needs is essential for designing effective in-vehicle human-machine interfaces (HMIs) that foster trust and acceptance. A mixed-methods approach was employed to conduct co-creation interviews (*N* = 15), combining semi-structured interviews, quantitative questionnaires, real-world videos to contextualize critical scenarios, and a mix-and-match co-creation method where participants designed their own AV HMI concepts. The findings highlight key information needs related to AV decision-making, feedback, and safety, offering valuable insights for future HMI development.

Keywords: Autonomous Vehicles, Human-Machine Interfaces, Explainable AI, Co-Creation.

1 BACKGROUND & OBJECTIVES

Autonomous vehicles (AVs; SAE L4 and L5; SAE International & ISO, 2021) are about to transform urban transportation (Litman, 2024). Beyond technical advancements and challenges, their successful integration depends on user acceptance and trust (Chen, 2019; Kaur & Rampersad, 2018; Pigeon et al., 2021). These factors are greatly influenced by the clarity of information provided by the AV and occupant comprehension of its actions (Flohr et al., 2023; Oliveira et al., 2020), particularly in complex urban environments. In line with human-centered AI principles (Riedl, 2019), this research explores user information needs and the collaborative design of interaction concepts aimed at explaining autonomous driving behavior. The goal is to optimize acceptance, trust, and the feeling of safety among occupants. A key challenge lies in presenting information and explanations about the AV's behavior in a clear and efficient way that does not annoy or irritate passengers (Flohr et al., 2023; Kim et al., 2023, 2024). This may include using dynamic elements to convey the constantly changing environment and the AV's understanding of other road users' intentions (Colley et al., 2021, 2022; Manger et al., 2023). In urban areas, this is particularly crucial in critical, multi-agent scenarios involving vulnerable road users, such as an evasive maneuver triggered by a cyclist violating the right of way. By understanding how passengers perceive such situations and what their information needs are, we can design HMIs that foster trust and ensure a smooth transition towards higher levels of automation. This research, therefore, investigates the following questions:

- What information do passengers need regarding the system behavior of AVs?

- How should this information be presented?
- And do these information needs vary across different scenarios?

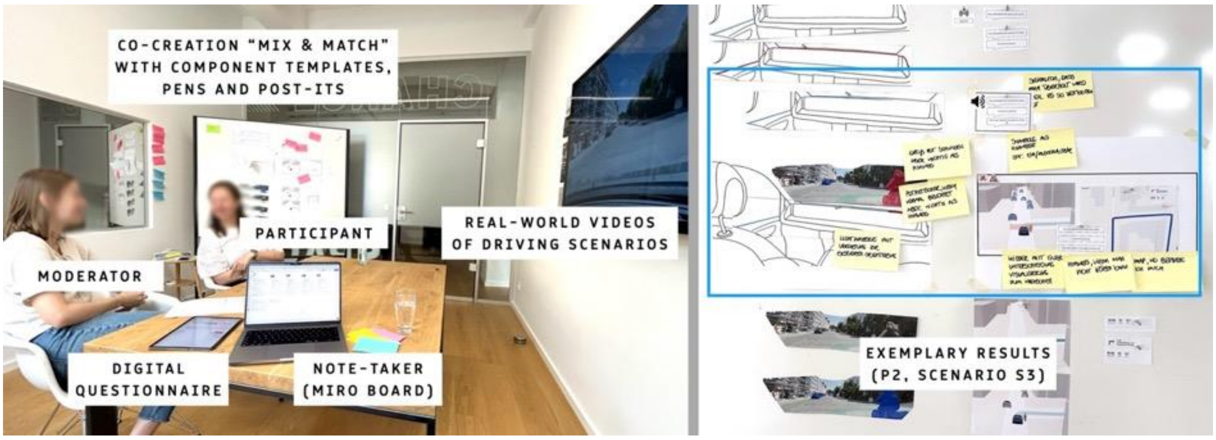

Figure 1 – Setup of the co-creation interviews (left) and exemplary mix-and-match result of participant P2 for scenario S3 (right).

2 METHOD

By employing a mixed-methods approach (Creswell, 2014), we aimed to gain a comprehensive understanding of these needs, informing the design of human-centered HMIs for AVs. The sessions were conducted in an office meeting room (Figure 1). Each of the fifteen individual sessions lasted about 60 min and consisted of four phases:

1. Introduction with a general briefing and an informative participation consent (~10 min).
2. Semi-structured (pre-)interview regarding previous experiences in (co-driver / passenger) experiences, propensity to trust and feeling of security (~10 min).
3. Co-creation interview with a participatory "mix and match" method where participants watched real-world urban driving scenarios, assessed them with quantitative (standardized) questionnaire scales and then designed their own AV HMI concepts for each scenario. Scenario order was randomized (~8 min for each scenario; ~30 min in total).
4. Outro with a final survey and debriefing (~10 min).

2.1 Participants

Fifteen participants (7 female, 8 male, 0 diverse, 0 n/a; age M(SD) = 37.6 (14.4)) were recruited for the co-creation interviews via online postings, mailing lists, and advertising posters. Thirteen held driver's licenses, while two did not. Prior automated driving experience included systems with SAE L1 (*n* = 11), L2 (*n* = 4), and L3 (*n* = 3) driving capabilities, but none with L4 or L5. Participants showed high technology affinity (ATI-S (Wessel et al., 2019): *M(SD)* = 4.73 (0.99); 1 = min, 6 = max) and moderate propensity to trust (Körber, 2019: *M(SD)* = 3.13 (0.61); 1 = min, 5 = max). All participants expressed a general willingness to use AVs, though some emphasized the need for prior testing and market presence (*n* = 6) or suggested introductory test drives in less challenging environments (*n* = 6).

2.2 Scenarios & Real-World Videos

To contextualize participants in the situation of riding in an AV, we used real-world videos. Previous work found that real-world representations can increase participants' familiarity with the context and lead to rich(er) feedback (Flohr & Wallach, 2023; Hoggenmüller et al., 2021). Multiple videos of driving scenes were also used in previous works to create (immersive) video-based simulations (Flohr et al., 2020). This study used a straightforward setup with one TV screen representing the view through the AV's windshield and four real-world video sequences of (critical) urban driving scenarios (Figure 2).

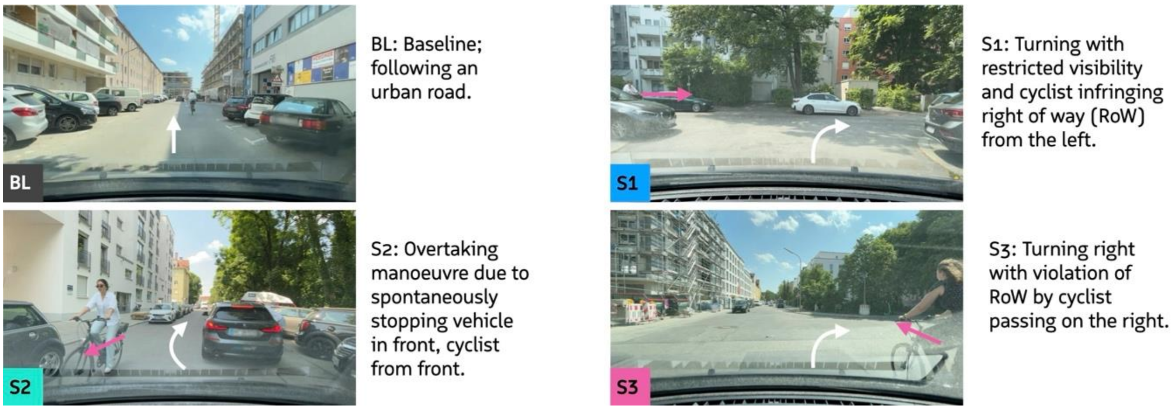

Figure 2 – Descriptions and screenshots of the four scenarios.

The videos were recorded with actors staging other (vulnerable) road users such as pedestrians, cyclists, and other vehicles. Participants were instructed to imagine sitting in an AV and observing the vehicle's behavior. Each sequence was anonymized and about 30 s long.

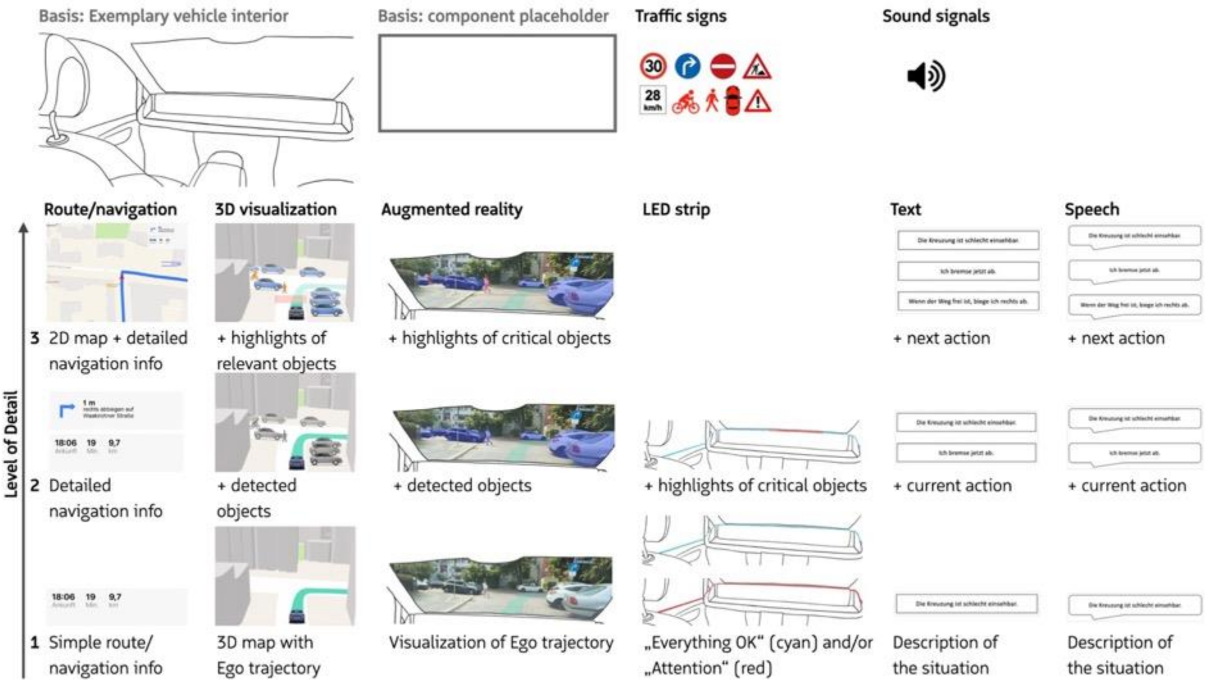

Figure 3 – Prepared library of HMI components with different levels of information detail used in the "mix and match" co-creation activity.

2.3 Mix-and-Match Co-Creation

The core of the interviews was the mix-and-match co-creation activity. Since the design space for in-vehicle interaction (Jansen et al., 2022) is vast, participants were provided with an exemplary "library" of HMI components (e.g., navigation information, 3D map, augmented reality display, LED strip, sound; Figure 3) with varying levels of information detail and tasked with designing their ideal AV in-vehicle interface for each scenario on a physical whiteboard (Figure 1). They were also free to add and create other elements not included in the library or change existing ones. While the moderator was discussing certain aspects of the design process, the note-taker documented the reasoning behind the design decisions on sticky notes (Figure 1). This allowed us to directly observe and discuss the prioritization of information and their presentation. The sessions were recorded. Transcripts and notes were analyzed thematically, while HMI designs were evaluated for recurring patterns and information preferences.

3 RESULTS

This section presents the findings from the semi-structured co-creation interviews, highlighting specific feedback specific HMI components and overall communication preferences.

3.1 Scenario Assessment

After watching a sequence, participants assessed the respective scenario with a digital questionnaire in terms of risk and safety perception (e.g., Flohr et al., 2023), trust (Körber, 2019), and understandability/predictability (Körber, 2019) before discussing each scenario with the moderator and creating a fitting HMI concept with the co-creation activity. The scenario assessment (Figure 4) illustrates significant differences in risk and safety perception between the scenarios, with S3 seeming to be the most critical scenario.

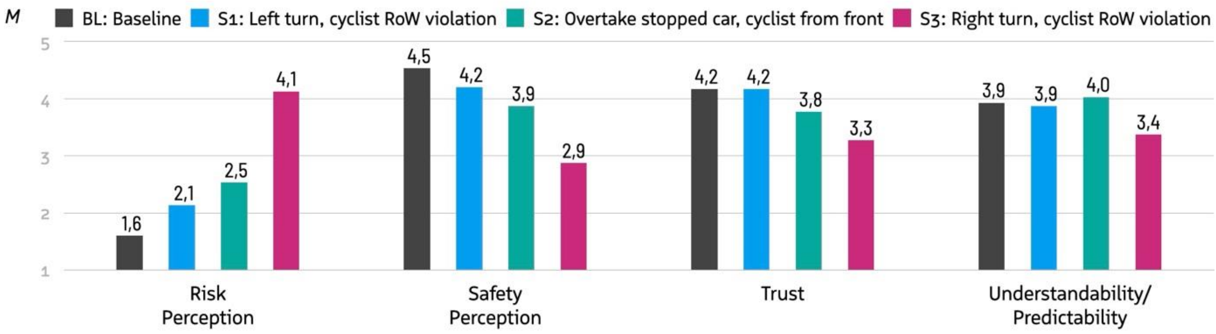

Figure 4 – Participants' assessment of the four scenarios (*N* = 15).

3.2 HMI Component Preferences

3.2.1 Route/Navigation Information

Route information was desired by an average of fourteen participants across all scenarios. In more critical situations, this information could be temporarily hidden. The majority (n=8) preferred the map-based variant (Detail Level 3) for orientation. P6 emphasized the importance of geographical information during initial adaptation to AVs. Two participants (P4, P11) suggested using the map view by default, overlaying it with a 3D visualization in critical situations. However, P11 cautioned against frequent switching. Participants also highlighted the significance of displaying route-related information, such as construction sites, traffic congestion, disruptions, or points of interest (P5, P10, P14, P7).

3.2.2 3D Visualization

The 3D visualization was selected by an average of eight participants with selection increasing as scenario criticality increased. Beyond enhancing perceived safety (e.g., by visualizing rearward objects; P9, P12, P14), it was also seen as providing valuable contextual information about position and route (P13, P14, P15). Participants expressed mixed opinions regarding color coding and the level of detail of object highlights.

3.2.3 Augmented Reality (AR)

Across scenarios, an average of ten participants chose the AR display. Four preferred Detail Level 1 (trajectory only), and six preferred Detail Level 3 (highlighting of relevant objects). Several participants (P3, P4, P11, P15, P14) suggested object coloring only in hazardous situations, as it provided a sense of safety and clarity during critical moments. The color-coding of objects based on their criticality was deemed useful by several participants (P1, P2, P3, P14).

3.2.4 LED Strip

An average of eight participants selected the LED strip across all scenarios. Detail Level 2 (with partial red coloring of critical objects) was the most popular choice. P3, P9, and P11 felt more reassured, knowing the vehicle had detected potential hazards. P6, P11, and P14 suggested extending the strip along the vehicle's sides to detect objects approaching from behind or the sides, such as cyclists in S3, to minimize surprises. P5, however, considered the LED strip unnecessary and distracting.

3.2.5 Textual Information

Most participants (n=8) rejected text cues. However, the demand for text-based information increased in situations with unexpected dangers (S2). Participants suggested that text could explain sound signals (P11) or provide easy-to-read information (P3, P15).

3.2.6 Speech & Sound Signals

Only four participants integrated acoustic cues in the form of speech output into their display concept across the scenarios, particularly in more critical scenarios. Seven participants desired a warning signal in hazardous situations, with some (P4, P10, P12, P14) emphasizing it should not occur too frequently or include additional maneuver explanations. Two participants preferred a voice assistant acting as a companion. In contrast, P9 considered acoustic cues unnecessary.

3.2.7 Symbols & Signs

An average of ten participants selected the display of symbols and traffic signs across scenarios. These ranged from traffic signs and speed indicators to icons representing other road users. Participants noted that symbols contributed to a sense of safety by confirming the vehicle correctly detected its surroundings and potential hazards without being overly intrusive (P2, P3, P9, P11, P12). P1 suggested positioning symbols on the display according to the actual location of the hazard. Another (P10) recommended highlighting particularly relevant symbols by making them blink. While most preferred displaying symbols on the screen, P15 preferred displaying them on the windshield.

3.3 Overall Communication Preferences

Thirteen of the fifteen participants wanted the AV to actively communicate its intentions, with five specifically requesting advance notice of maneuvers. Participants emphasized the need for simple, clear, and easy-to-understand explanations of the system's actions (e.g., P1, P9, P14). A distinct link emerged between perceived risk (how critical a scenario seemed) and participants' desire for more information. This correlation was supported by an exploratory analysis using Spearman's rho, which revealed a significant correlation between the number of HMI components participants selected in the mix-and-match activity and perceived risk in a certain scenario (r_s =.54, p =.039, n = 60). Twelve participants stated that explanations of the system's behavior would increase their trust in the AV. However, the exploratory analysis did not find significant correlations between the number of selected components and trust (r_s =.45, p =.090, n = 60).

Eight participants (P1, P2, P3, P4, P5, P9, P11, P15) wanted an overview of the current situation and the vehicle's planned actions. Four (P7, P10, P13, P14), however, didn't think this was necessary, explaining that their confidence in the system meant they didn't need that information. P5 suggested that all manufacturers use the same (standardized) display designs to improve understanding and usability. Regarding how much info they wanted, participants generally seemed to fall into two groups: those who needed a lot of information to trust the system, and those who needed very little or none.

3.4 Information Overload and Redundancy

Some participants felt that certain HMI components, like AR displays, were generally unnecessary in AVs, arguing that they contradict the idea of effortless autonomous driving. Several participants (P1, P4, P9, P14) suggested avoiding redundant displays altogether, while a few (P2, P3, P5) preferred slightly more information. Generally, information overload was a major concern. Most participants (P1, P2, P7, P9, P11, P12, P13, P14, P15) considered it potentially disruptive and distracting, potentially causing them to miss important information (P8, P13).

3.5 Customization and Familiarity

Thirteen participants wanted customizable displays, consistent with other studies (e.g., Flohr et al., 2023). Participants wanted to adjust the information shown dynamically/automatically depending on the situation – e.g., temporarily turning off sound alerts. Some participants (P6, P8, P15) thought their need for information would decrease with increased familiarity with the vehicle.

4 CONCLUSIONS

The participatory co-creation interviews proved valuable for understanding passenger information needs in the context of AVs. By empowering participants to actively design their preferred HMI concepts, we gained direct insights into their priorities and preferences regarding information display. The results highlight the potential of transparent and adaptive information delivery in fostering trust in AVs. As the criticality of a driving situation increases in terms of perceived risk, the need for information among vehicle occupants seems to increase too. Although the type and level of desired information vary greatly among individuals. While most participants confirmed that explanations of system behavior positively influence their trust, it is paramount to avoid information overload and not give passengers the impression that they need to monitor or control the AV. Therefore, a personalized and/or situation-adaptive approach to information dissemination is promising. This may include allowing users to configure their preferred level of detail. Consequently, the communication of system information can be tailored to individual needs and designed to minimize unnecessary anxiety whilst promoting a sense of control. Future research should focus on investigating the interplay of various HMI components and developing and evaluating adaptive information systems to optimize user experience and build confidence in the safety and reliability of AVs.

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