# Designing Multi-Modal Communication for Merge Negotiation with Automated Vehicles: Insights from a Design Exploration with Prototypes

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## Abstract

Deciding whether to allow an automated vehicle (AV) to merge in front can present a complex negotiation for human drivers. To address this, we explored the human-machine interface (HMI) design for merge negotiation between a manually driven vehicle and an AV from the human driver's perspective. We developed five HMI designs, each integrating different combinations of visual cues, haptic alerts, and explicit approve and reject controls. They were evaluated together with two baseline conditions in a video-based driving simulator. The results of Likert-scale ratings indicated that HMI designs with explicit accept and reject controls received higher mean ratings in communication clarity, perceived adequacy, safety perception, trust in AV behaviour, and decision-making efficiency than those without such controls. Open-ended feedback further suggested that these HMIs may foster a stronger sense of control and reduce perceptions of aggressiveness. Based on the findings, we outlined three preliminary design considerations for HMIs that support merge negotiation between AVs and human drivers. This work offers early guidance and sets the stage for future research on integrating diverse modalities and driver inputs (e.g., explicit approve and reject controls) into HMI design for merge negotiation.

## CCS Concepts

• **Human-centered computing** → *Interaction design process and methods.*

## Keywords

Human–Machine Interaction, Automated Vehicles, Merge Negotiation, Explicit Driver Input


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## 1 Introduction

Traffic environments are increasingly characterised by mixed traffic, where automated vehicles (AVs) and manually driven vehicles (MDVs) share the road [7, 16]. Since AVs inherently lack traditional human-centred communication cues [3]—such as eye contact or hand gestures—shown to be important for close and ambiguous encounters, it is critical to develop Human-Machine Interfaces (HMIs) to promote safe and smooth interactions between AVs and MDVs. This paper explores HMI designs that support human drivers in interactions with an AV attempting to merge in front of them. Merging is a manoeuvre initiated by the 'merging vehicle' (in this case, the AV) that changes from its current lane into an adjacent lane of the 'receiving vehicle' (in this case, the MDV)[9]. In conventional MDV–MDV merge scenarios, drivers of both merging and receiving vehicles need to continuously adjust their behaviour to negotiate and maintain a smooth traffic flow. For AV-MDV merge scenarios, however, it can become complex for a human driver when an AV attempts to merge into their lane, as the absence of human-centred communication cues[8] can make it harder to interpret the AV's intent. Previous research has shown that, in some cases, human drivers may experience increased anxiety and discomfort when interacting with AVs[12].

### 1.1 Interaction Design for a Merge Scenario

For interactions in merge scenarios, previous research has investigated HMI designs that provide warning or guidance information. For example, Duan et al. [5] investigated the effects of audio warning messages on drivers' merging performance, while Wang et al. [18] studied HMIs offering guidance and warning information through displays. The study of Gwak et al. [10] showed that an external HMI on an automated truck, indicating its merging area, helped surrounding drivers avoid collisions. Overall, these studies have focussed on one side (either merging or receiving vehicles) of the merging interaction: HMIs for merging vehicles provide cues to help drivers assess merge opportunities and improve merging performance, while HMIs for receiving vehicles aim to reduce potential conflicts and maintain smooth traffic flow by providing information about the merging vehicle.

Bengler et al. [1] define cooperation in human-machine interaction as "*a relation between human and machine where the interaction or interference between the two (or more) partners occurs with shared authority in dynamic situations*". Building on this definition, Zimmermann and Bengler [19] proposed a cooperative interaction concept for the lane-change scenario between two highly automated vehicles using a prototypical multimodal HMI, allowing the receiving party to approve or reject the other vehicle's lane-change request. While focussing on the interaction between highly automated vehicles, the cooperative interaction concept and the use of multimodal HMI offer insights that may also be relevant to AV–MDV merge scenarios.

## 1.2 Modalities in HMI Design for AVs

HMI modalities have been explored in AV interactions. However, the effectiveness of modalities can vary in different contexts. For example, in AV-pedestrian interactions, Dey et al. [4] investigated the effect of multimodal external HMIs on pedestrians' willingness to cross the road by comparing different modality conditions: light, sound, and their combinations. They found no objective change in pedestrians' willingness to cross the road regarding different eHMI modalities, although subjective preferences varied, and some participants even disliked multimodal eHMIs. In driving scenarios for drivers in highly automated vehicles, Manawad et al. [13] developed and evaluated a multimodal HMI that integrates touchscreen, hand gesture, and haptic inputs for tactical driving tasks (e.g., lane changing, overtaking, and parking). In the driving simulator study, the multimodal system reduced driver workload, improved interaction efficiency, and minimised input errors compared with unimodal interfaces, demonstrating its effectiveness in supporting complex driving manoeuvres. These studies indicate that the role of HMI modalities can vary across contexts, underlining the potential and need for exploration in different AV interaction scenarios.

## 1.3 Aim of this Study

Building on previous work, this study focusses on the human driver's perspective in AV–MDV merging interactions. The aim of this study is to explore how explicit approve and reject controls over an AV's request to merge, together with multimodal HMI designs, influence drivers' experience in AV–MDV interactions in a merge scenario. The insights aim to inform future research and HMI design for AV–MDV interactions in mixed-traffic scenarios.

# 2 Method

A simulator study was conducted to examine HMI designs for merge scenarios. The study was approved by the Ethical Review Board of Eindhoven University of Technology.

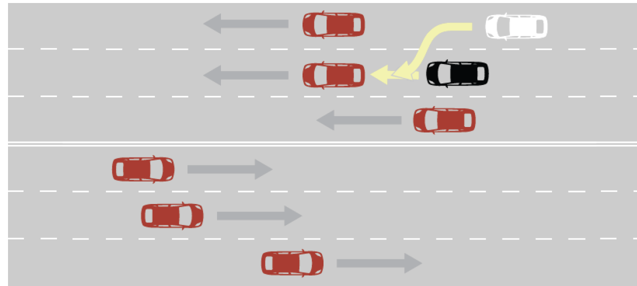

**Figure 1: Schematic diagram of a merge scenario on a two-way, six-lane urban road. Speed: 30 km/h; black car: the participant's MDV; white car: the merging AV; red cars: other vehicles on the road.**

## 2.1 Apparatus and Study Setup

As shown in Figure 1, the merge scenario took place on a two-way six-lane urban road: the participant's car (an MDV) occupied the centre lane, while an AV in the adjacent right-hand lane prepared to merge into the participant's lane.

To simulate the merge scenario, we developed and rendered videos using Unity 2022.1.23f1 (https://www.unity.com). The environment and the generated videos are available in Supplementary Material. The videos depicted a vehicle in the adjacent right lane initiating a merge in front of the participant's car, presented from a first-person perspective. To reflect participants' input in the interaction, two types of videos were created showing different outcomes: one in which the merging vehicle completed the manoeuvre, and another in which the merge request was rejected and the vehicle remained in its lane. The videos also included other vehicles, pedestrians, and roadside architecture, representing daily driving environments. These videos were integrated into a stationary driving simulator setup using a single forward-facing screen (see Figure 2). The simulator included a car seat, a Ford steering wheel, pedals, and a gear shift (see Figure 2d). Among these, only the screen and the steering wheel were used for interaction; the other components were present to resemble an MDV interior.

## 2.2 HMI Concepts and Prototypes

We developed our HMI concepts into interactive prototypes using three modalities. As shown in Figure 3, the **head-up display (HUD)** was designed to help human drivers perceive the intentions of the AV by projecting the merge notification, intended merging path, and merge requests with corresponding approve and reject prompts in HMIs that offer this feature. In our design, the intended merging path was shown using a cyan overlay. This colour is selected for its contrast to the driving scene and its established use in automated driving communication[2].

A **haptic alert** in the steering wheel was designed to indicate the merging intention through vibration pulses using a vibration motor (with a frequency of approximately 490 Hz) driven via Arduino Uno (https://docs.arduino.cc/hardware/uno-rev3/). Each haptic alert consisted of two vibration pulses (150 ms duration, 100 ms interval). It provides a non-visual channel for communication. Previous research has explored such haptic cues in driving as a means

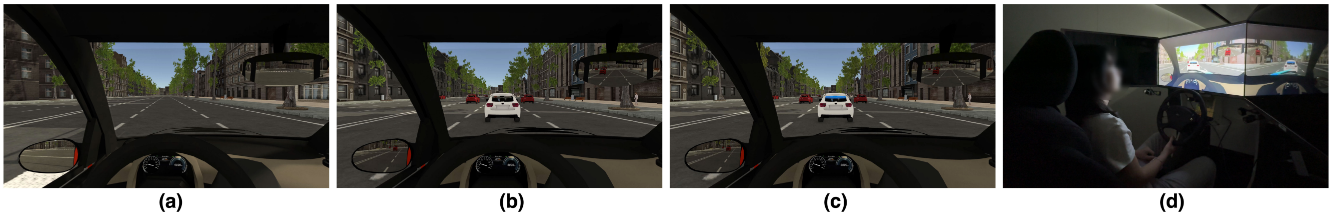


**Figure 2: Video-based driving simulator scenarios and setup: (a) participant's view; (b) an MDV without a blue overlay; (c) an AV marked with a blue overlay; (d) a participant seated in the simulator cabin, interacting with the steering wheel HMI while viewing the scene on the front screen.**

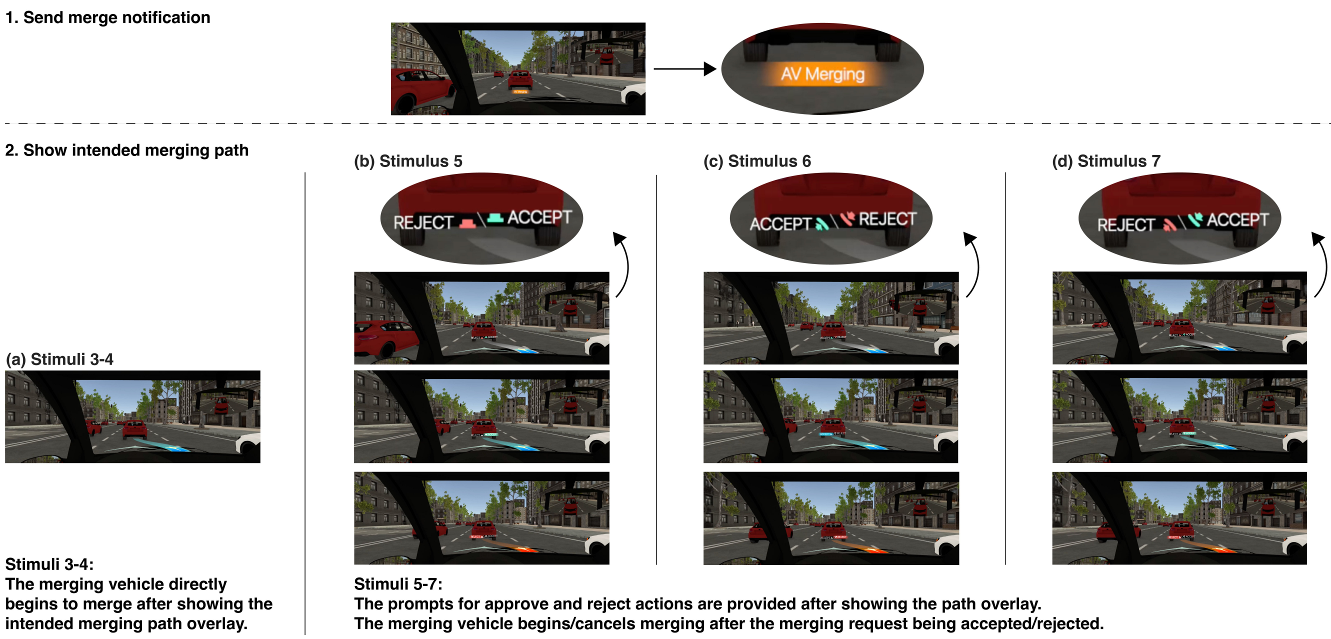


**Figure 3: HUD concepts of different stimuli shown in two parts: merge notification (common in stimuli 3-7) and intended merging path. (a) Intended merging path in stimuli 3–4: ; (b-d) Intended merging path with corresponding prompts for approve and reject actions (for stimuli 5–7).**

to supplement visual information when attention is divided[17]. To allow participants to respond to a merge request, we designed three **input interfaces** and integrated them into the steering wheel. As shown in Figure 4a, two thumb-accessible buttons for 'approve' and 'reject' enable drivers to communicate their decisions on the merge request. The buttons were positioned to allow operation while holding the steering wheel, with the two commands placed in separate locations. The 'approve' button was cyan (see Figure 4a and 4d) to achieve greater visual contrast with the dark steering wheel surface and to maintain visual consistency. The 'reject' button was red. The other two designs of the input interface were gesture-based, both using four 3D-printed paddles integrated in the lower front and rear positions of the steering wheel rim (see Figure 4b and 4d). The gesture-based interfaces were both operated using two gestures: pulling ( Figure 4b) and pushing ( Figure 4c). **Push–Pull Gesture Interface A** mapped pushing as reject, mirroring the driving action of pressing the accelerator to speed up and block a merge, while pulling to approve corresponded to decelerating to yield. **Push–Pull Gesture Interface B** inverted this mapping to control for potential biases in evaluating gesture-based HMIs due to mapping preferences, while retaining the same hardware layout. Both designs allowed drivers to respond without moving their hands away from their grip positions, aiming to support steering stability and reduce reaction time. Conditions **'No HMI'** served as baseline conditions, in which there are no additional HMIs except for the conventional indicators.

These interfaces were combined into five distinct HMI systems and integrated into the driving simulator using ProtoPie(https://www.protopie.io/) and Arduino(https://docs.arduino.cc/hardware/uno-rev3/) setup. The corresponding Arduino code is provided in Supplementary Material. In addition, two baseline stimuli were included—one in which the merging vehicle is an AV and the other in which the merging vehicle is an MDV. In all cases, the AV was visually identified by a semitransparent blue overlay, while the

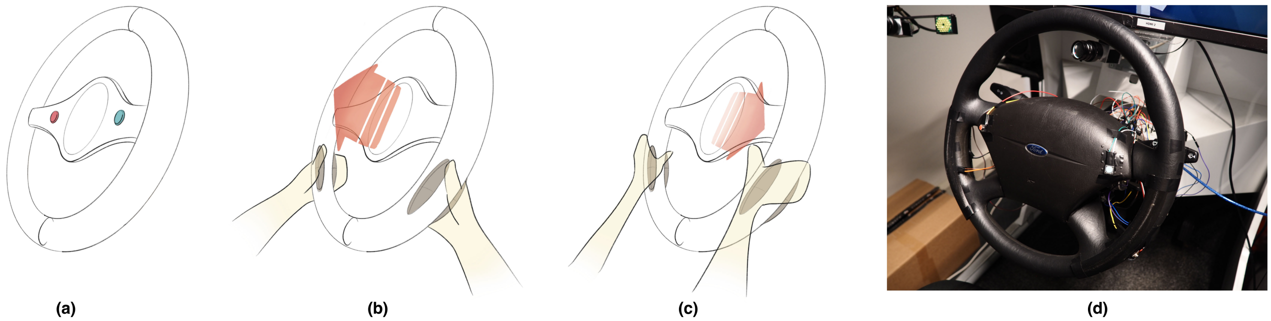


**Figure 4: Input interfaces and the physical implementation on the steering wheel: (a) thumb-accessible buttons; (b) pull gesture; (c) push gesture; (d) physical prototypes mounted on a steering wheel.**

MDV did not have any overlays (see Figure 2 b-c). For each stimulus, the detailed combinations of modalities and the information and controls included are summarised in Table 1.

## 2.3 Procedure

Fifteen participants (9 females, 6 males; all holding a valid driver's licence) took part in the study. Three participants were between 18 and 23 years old, 11 between 24 and 29 years old, and one between 30 and 39 years old. Twelve participants were from East Asia, one from South Asia, and one from Europe. Eight participants had a bachelor's degree, and seven had a master's degree as their highest level of education.

Upon arrival, participants completed a consent form and a brief demographic questionnaire. They were then briefed on the purpose of the study and the operation of the HMIs. The AV was described to participants as a vehicle operating without direct human intervention. Before the experiment began, they watched and experienced two first-person driving perspective videos featuring ordinary driving as test trials. The experiment started after the test trials. Each participant experienced all seven stimuli in random order. Each trial (one stimulus presentation) lasted approximately 30 seconds.

## 2.4 Measurements

After each trial, participants completed a post-stimulus questionnaire. The questionnaire consisted of five statements rated on a five-point Likert scale (1 = Strongly disagree, 5 = Strongly agree), with items adapted from Matthews et al.[14] and Liu et al.[11]. It assessed communication clarity ("*The communication is clear.*"), perceived adequacy ("*The communication is adequate.*"), safety perception ("*I feel safe about the interaction with the target car in this situation.*"), trust in AV behaviour ("*I trust the AV will take appropriate actions.*"), and decision-making efficiency ("*This interaction/communication is efficient for me to make decisions.*").

In addition, participants were invited to provide open-ended feedback after each trial, where they shared general remarks and described what they liked and disliked about the interaction. All feedback was recorded using a GoPro HERO 13 action camera and transcribed using the OpenAI Whisper speech recognition model[15].

# 3 Results

## 3.1 Post-stimulus Questionnaire Responses

Figure 5 presents the mean ratings (± SE) for the five post-stimulus items of the seven stimuli. The results showed that stimuli 1-4 (S1-S4), which lack explicit accept and reject controls, received lower mean ratings than S5-S7, in which the HMIs include HUD, haptic alert, and explicit accept and reject controls. Among S5-S7, the HMIs that used the button configuration for explicit accept and reject controls yielded the highest mean ratings across all five items, followed by the ones that used two gesture-based interfaces.

## 3.2 Feedback from open-ended questions

To summarise open-ended feedback, we synthesised participants' responses into six preliminary themes that captured their user experience (see Table 2). Mentions of *Perceived safety and trust* appeared in all stimuli except Stimulus 6 (S6). The mentions ranged from feeling unsafe—e.g., "*It's dangerous to let it merge into my road*" (S2)—to increased feeling of safety and trust in interaction—e.g., "*I feel safer since it provides more information (through HUD)*" (S3). *Perceived aggressiveness and rudeness* was mentioned only in S1–S4 (e.g., "*This AV is aggressive since the AV should be conservative and should not cut in line (without permission)*"), which were stimuli without explicit accept and reject controls, suggesting that the merging vehicle in these conditions may be interpreted as less considerate or less cooperative in merge negotiations. While *Lack of control* was mentioned in S1–S4, *Sense of control* appeared only in S5–S7. This suggests that HMI designs in S5-S7 may foster a greater sense of control. Participants also mentioned *Clarity of interaction* (5–10 mentions across all stimuli). These ranged from perceived clarity of the interaction (e.g., "*The options to accept and reject are clear and direct*" in S7) to perceived lack of clarity in interaction (e.g., "*I'm not sure when the vehicle will merge*" in S3). Mentions of *Placement and ergonomics* were observed only in S5–S7, mainly referring to explicit accept and reject controls regarding their location, the clarity of the mapping, and the possibility of accidental activation. For example, "*Moving your hands somewhere else to operate (buttons) can be bothersome*" (S5); "*I need to think for a long time about which button is reject*" (S6); "*I may press the button by mistake when holding my steering wheel tightly*" (S6).

| No. | Modality Combination | Information and Controls |
|---|---|---|
| 1 | No HMI, the merging vehicle is an MDV | Merging intention |
| 2 | No HMI, the merging vehicle is an AV | Merging intention |
| 3 | HUD | Merging intention |
| 4 | HUD and Haptic | Merging intention and intended merging path |
| 5 | HUD, Haptic, and Buttons | Merging intention, intended merging path, and explicit approve and reject controls |
| 6 | HUD, Haptic, and Push–Pull Gesture Interface A | Merging intention, intended merging path, and explicit approve and reject controls |
| 7 | HUD, Haptic, and Push–Pull Gesture Interface B | Merging intention, intended merging path, and explicit approve and reject controls |

**Table 1: Overview of modality combinations and information and controls across stimuli.**

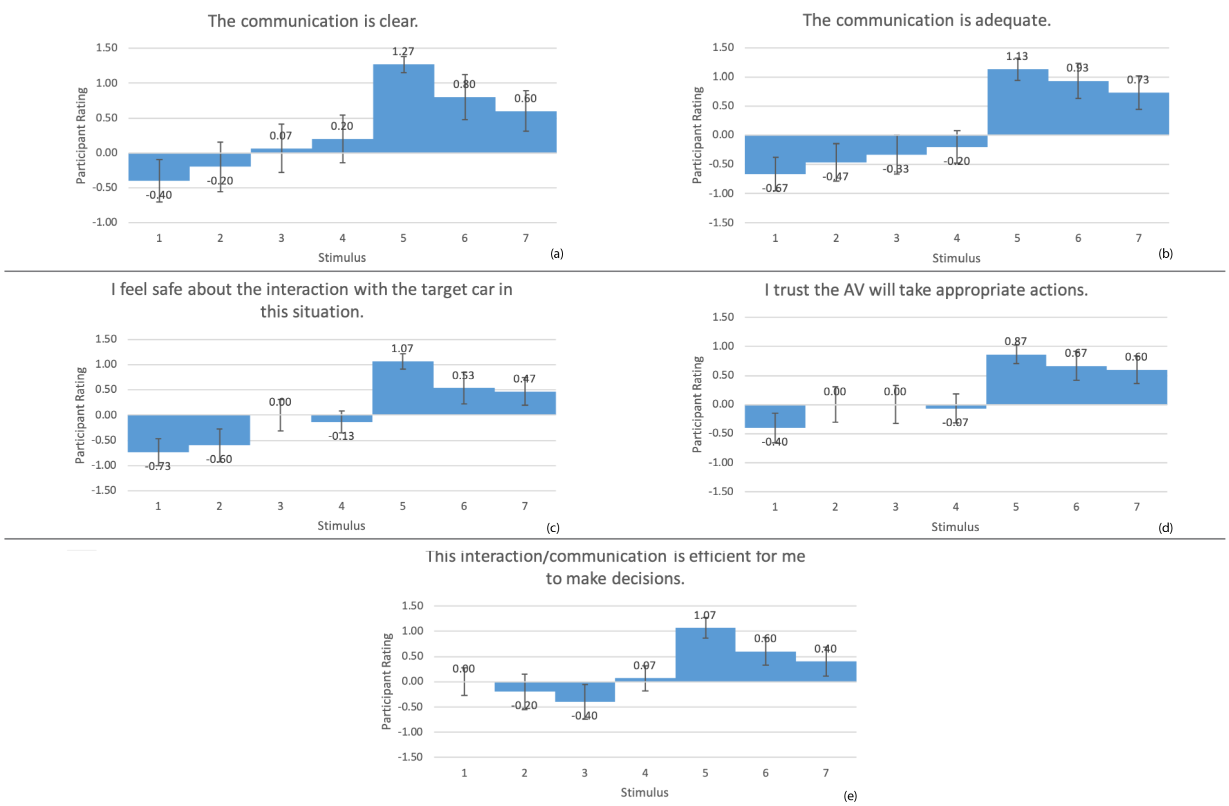


**Figure 5: Mean ratings with standard error (SE) across five post-stimulus questions for each of the seven stimuli. Ratings were given on a 5-point Likert scale (-2 = Strongly disagree, 2 = Strongly agree).**

In addition to the general themes discussed above, we separately report haptic-specific feedback, as these mentions were both concentrated on a single design feature (the haptic alert) and reflected different interpretations. Some participants described it as "*improving the clarity of the interaction*" and "*resembling a direct message from the merging vehicle*", indicating that the haptic alert may help them recognise the intent of the AV. However, some participants found it unclear, distracting, or even misinterpreted it as a vehicle malfunction.

## 4 Discussion and Conclusions

The post-stimulus questionnaire ratings indicated that the HMI designs in stimuli 5-7, which featured implementation of visual cues, haptic alerts, and explicit approve and reject controls, may perform better in communication clarity, perceived adequacy, safety perception, trust in AV behaviour, and decision-making efficiency. Open-ended feedback, particularly the mentions of *sense of control*, *lack of control*, and *perceived aggressiveness and rudeness*, further suggests that such HMI designs may enhance sense of control and reduce perceived aggressiveness and rudeness of AVs, while other factors, such as clarity and placement, remain critical.

**Table 2: Preliminary summary of open-ended feedback across all stimuli (S1–S7). Numbers show the frequency of mentions for each theme per stimulus.**

| Theme | Description | Number of mentions | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
| Perceived safety and trust | Perceived safety and trust in the interaction. | 3 | 4 | 4 | 2 | 1 | 0 | 1 |
| Perceived aggressiveness and rudeness | Perceived rudeness and aggressiveness of the merging vehicle. | 3 | 2 | 1 | 2 | 0 | 0 | 0 |
| Lack of control | Feeling of not being able to influence the merging interaction. | 4 | 6 | 5 | 4 | 0 | 0 | 0 |
| Sense of control | Feeling of being able to influence the merging interaction. | 0 | 0 | 0 | 0 | 3 | 4 | 2 |
| Clarity of interaction | Clarity or the need for clarity of the HMIs. | 5 | 6 | 10 | 7 | 8 | 5 | 5 |
| Placement and ergonomics | Placement, mapping, and ergonomics aspects of HMIs. | 0 | 0 | 0 | 0 | 7 | 10 | 5 |

Drawing from the results, we outline preliminary design considerations for HMIs in AV-human driver merge negotiation:

- **Consideration for explicit driver input**: Explicit accept and reject controls may foster a sense of control and reduce negative interpretations of AV's intention, but need to be ergonomically placed, clearly mapped, and appropriately combined with other HMI elements to ensure clarity of the interaction and avoid accidental activation.
- **Consideration for placement and ergonomics**: Especially for input HMIs, the placements should be easily reachable without disrupting the steering grip. The mapping should be visually and/or tactilely distinct to ensure clarity and reduce cognitive load.
- **Consideration for the integration of different modalities**: Multiple modalities may complement each other, but the HMI design should account for the specific strengths and limitations of each modality to avoid cognitive overload or distraction.

In summary, this work explored how different combinations of visual cues, haptic alerts, and explicit approve and reject controls in HMI design shape human drivers' experience in merge negotiation with AVs. The study also raises design considerations regarding explicit driver input, placement and ergonomics, and integration of different HMI modalities. These design considerations contribute to the design of HMIs to better study and support AV-MDV merge negotiation.

## 5 Limitations and Future Work

As a preliminary investigation, this study offers early insights into integrating explicit driver input and multimodal design in HMIs for AV-MDV merge negotiation. However, the observed effects cannot be disentangled from the influence of explicit driver input, different modalities, and their combinations. Future work will further investigate their respective and combined contributions and persue: (i) expanding and diversifying participant samples, (ii) incorporating objective measures (e.g., eye tracking and response times) alongside subjective measures to facilitate richer and more comprehensive data analysis, (iii) systematically examining the effects of individual modalities and their combinations, (iv) refining ergonomic placement and interaction mappings, and (v) conducting high-fidelity and on-road trials to assess safety outcomes such as gap acceptance and collision rates.

## Supplementary Material

For more details on the execution of this study, see the supplementary material (https://doi.org/10.4121/be60bbb2-5f7d-4ac9-b755-2fae8ffe061c). The material is made public to support open science practices in the AutomotiveUI community [6].

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## References


[1] Klaus Bengler, Markus Zimmermann, Dino Bortot, Martin Kienle, and Daniel Damböck. 2012. Interaction principles for cooperative human-machine systems. *it - Information Technology* 54, 4 (2012), 157–164. doi:10.1524/itit.2012.0680

[2] Debargha Dey, Azra Habibovic, Bastian Pfleging, Marieke Martens, and Jacques Terken. 2020. Color and animation preferences for a light band eHMI in interactions between automated vehicles and pedestrians. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3313831.3376325

[3] Debargha Dey, Andrii Matviienko, Melanie Berger, Bastian Pfleging, Marieke Martens, and Jacques Terken. 2021. Communicating the intention of an automated vehicle to pedestrians: The contributions of eHMI and vehicle behavior. *it - Information Technology* 63, 2 (2021), 123–141. doi:10.1515/itit-2020-0025

[4] Debargha Dey, Toros Ufuk Senan, Bart Hengeveld, Mark Colley, Azra Habibovic, and Wendy Ju. 2024. Multi-Modal eHMIs: The Relative Impact of Light and Sound in AV-Pedestrian Interaction. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 91, 16 pages. doi:10.1145/3613904.3642031

[5] Ke Duan, Xuedong Yan, Xiaomeng Li, and Junyu Hang. 2023. Improving drivers' merging performance in work zone using an in-vehicle audio warning. *Transportation Research Part F: Traffic Psychology and Behaviour* 95 (2023), 297–321. doi:10.1016/j.trf.2023.04.004

[6] Patrick Ebel, Pavlo Bazilinskyy, Mark Colley, Courtney Michael Goodridge, Philipp Hock, Christian P. Janssen, Hauke Sandhaus, Aravinda Ramakrishnan Srinivasan, and Philipp Wintersberger. 2024. Changing lanes toward open science: Openness and transparency in automotive user research. In *Proceedings of the 16th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Stanford, CA, USA). Association for Computing Machinery, New York, NY, USA, 94–105. doi:10.1145/3640792.3675730

[7] Daniel J. Fagnant and Kara Kockelman. 2015. Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice* 77 (2015), 167–181. doi:10.1016/j.tra.2015.04.003

[8] Berthold Färber. 2016. Communication and communication problems between autonomous vehicles and human drivers. In *Autonomous Driving: Technical, Legal and Social Aspects*, Markus Maurer, J. Christian Gerdes, Barbara Lenz, and Hermann Winner (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 125–144. doi:10.1007/978-3-662-48847-8_7

[9] Akinobu Goto and Kerstin Eder. 2024. Would you trust a vehicle merging into your lane? Subjective evaluation of negotiating behaviour in a congested merging scenario. In *Proceedings of the 2024 IEEE/SICE International Symposium on System Integration (SII)*. IEEE, Piscataway, NJ, USA, 1045–1051. doi:10.1109/SII58957.2024.10417246

[10] Jongseong Gwak, Keisuke Shimono, and Yoshihiro Suda. 2025. How encounter timing affects the impact of eHMI on surrounding drivers during automated truck merging. *Transportation Research Part F: Traffic Psychology and Behaviour* 110 (2025), 182–194. doi:10.1016/j.trf.2025.02.015

[11] Hailong Liu, Takatsugu Hirayama, and Masaya Watanabe. 2021. Importance of Instruction for Pedestrian-Automated Driving Vehicle Interaction with an External Human Machine Interface: Effects on Pedestrians' Situation Awareness, Trust, Perceived Risks and Decision Making. In *Proceedings of the 2021 IEEE Intelligent Vehicles Symposium (IV)*. IEEE, Piscataway, NJ, USA, 748–754. doi:10.1109/IV48863.2021.9575246

[12] Zheng Ma and Yiqi Zhang. 2024. Driver-automated vehicle interaction in mixed traffic: Types of interaction and drivers' driving styles. *Human Factors* 66, 2 (2024), 544–561. doi:10.1177/00187208221088358 arXiv:https://doi.org/10.1177/00187208221088358 PMID: 35469464.

[13] Udara E. Manawadu, Mitsuhiro Kamezaki, Masaaki Ishikawa, Takahiro Kawano, and Shigeki Sugano. 2017. A multimodal human-machine interface enabling situation-adaptive control inputs for highly automated vehicles. In *Proceedings of the 2017 IEEE Intelligent Vehicles Symposium (IV)*. IEEE, Piscataway, NJ, USA, 1195–1200. doi:10.1109/IVS.2017.7995875

[14] Milecia Matthews, Girish Chowdhary, and Emily Kieson. 2017. Intent communication between autonomous vehicles and pedestrians. *arXiv preprint* (2017). doi:10.48550/arXiv.1708.07123

[15] OpenAI. 2022. Whisper: Open-Source Neural Speech Recognition Model. https://github.com/openai/whisper. Accessed: 2025-08-14.

[16] Steven E. Shladover. 2018. Connected and automated vehicle systems: Introduction and overview. *Journal of Intelligent Transportation Systems* 22, 3 (2018), 190–200. doi:10.1080/15472450.2017.1336053 Special Issue: Connected and Automated Vehicle-Highway Systems.

[17] Jan B.F. Van Erp and Hendrik A.H.C. Van Veen. 2004. Vibrotactile in-vehicle navigation system. *Transportation Research Part F: Traffic Psychology and Behaviour* 7, 4 (2004), 247–256. doi:10.1016/j.trf.2004.09.003

[18] Yugang Wang, Nengchao Lyu, Chaozhong Wu, Zijun Du, Min Deng, and Haoran Wu. 2024. Investigating the impact of HMI on drivers' merging performance in intelligent connected vehicle environment. *Accident Analysis & Prevention* 198 (2024), 107448. doi:10.1016/j.aap.2023.107448

[19] Markus Zimmermann and Klaus Bengler. 2013. A multimodal interaction concept for cooperative driving. In *Proceedings of the 2013 IEEE Intelligent Vehicles Symposium (IV)*. IEEE, Piscataway, NJ, USA, 1285–1290. doi:10.1109/IVS.2013.6629643