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Analysis of User Acceptance and Perception for External HMIs Based on Driving Situations

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ABSTRACT

With the advancement of automated driving technology, the role of vehicle drivers is increasingly shifting to that of passengers, necessitating a transformation in non-automated verbal communication methods among road users. In this context, visual communication through external Human-Machine Interfaces (eHMIs) on automated driving vehicles has emerged as a critical area of focus. This study systematically analyses user preferences for eHMI messages across various driving scenarios (normal driving, single-lane roads, adverse weather, branching roads, and mixed traffic conditions) and user groups (drivers, pedestrians, and automated ride-hailing passengers). Additionally, it examines the influence of demographic factors such as age, as well as user understanding and favourability toward automated driving technologies, on message preferences. Data were collected through an online survey involving 900 licensed drivers, who were asked to rank the top three most useful eHMI message types for each scenario. The collected data were analysed using cross-tabulation and regression analysis to identify variations in message preferences across different variables. The findings reveal that preferred eHMI messages vary significantly depending on the driving scenario. For instance, messages such as "Informaion for Rear Driver," "Intention to Proceed," and "Emergency Alerts" were highly favoured in vehicle-related scenarios. In pedestrian-related contexts, the "Pedestrian Detected" message was deemed most important, while in ride-hailing situations, user identification and risk alert messages were recognized as critical. Although age-related differences in preferences were observed, their effect sizes were relatively small. Similarly, understanding and favourability toward automated driving technologies exerted modest influences in certain scenarios. Based on these findings, the study highlights the need for situation-specific eHMI designs, standardized interaction cues that promote mutual awareness, intuitive designs accommodating older adults, and adaptive systems capable of responding to dynamic driving contexts. To further validate these findings, future research will involve experimental studies to assess the applicability and effectiveness of these eHMI messages in real-world driving environments.

Keywords: Automated vehicles, External human-machine interface (eHMI), Visual communication, Pedestrian safety, Survey analytics

INTRODUCTION

The advancement of automated driving technology is fundamentally transforming the role of drivers into that of passengers, thereby introducing significant changes to non-verbal communication methods on the road. In conventional manually operated vehicles, gestures and eye contact have historically served as primary means of communication between drivers, pedestrians, and other road users. However, with the increasing prevalence of automated vehicles, such forms of interaction are expected to diminish, leading to new challenges in road communication. This shift introduces uncertainty not only for pedestrians but also for drivers of manually operated vehicles, as the behavioural intentions of automated driving vehicles become more difficult to interpret. Such uncertainty has the potential to increase the risk of accidents and reduced trust in automated driving system. Empirical studies have highlighted the challenges posed by the absence of external Human-Machine Interfaces (eHMIs) in automated driving vehicles. For instance, Liu and Hirayama (2025) demonstrated the pedestrians experience difficulty in predicting vehicle intentions in the absence of eHMIs, perceiving such vehicles as less safe compared to manually driven vehicles or those equipped with eHMIs. This issue becomes particularly pronounced in low-speed scenarios, such as yielding or negotiation situations, where non-verbal communication tools are critical (Habibovic et al., 2018). While prior research has acknowledged the positive role of eHMIs in facilitating interactions between automated vehicles and pedestrians, there remains a lack of consensus on effective design elements (Rouchitsas et al., 2019). Moreover, some studies have raised concerns that pedestrians may become overly reliant on eHMI signals, potentially neglecting actual vehicle e behaviour (Kaleefathullah et al., 2020). As fully automated vehicles are not yet ubiquitous, roads are expected to remain shared environments where manually driven and automated driving vehicles coexist. This coexistence necessitates effective communication strategies that can accommodate diverse traffic contexts and road users. For example, Avsar et al. (2021) demonstrated that in T-junction scenarios, the expression of yielding intentions via eHMI significantly improved trust and perceived safety among drivers of manual operated vehicles. However, existing research has often focused narrowly on specific road users, such as pedestrians or rear drivers, or on limited traffic scenarios. In reality, road environments are characterized by complex mixtures of traffic density, speed conditions, and user types, requiring more sophisticated and adaptable communication strategies.

This study aims to address these gaps by conducting a comprehensive analysis of communication methods using front, side, and rear displays on automated driving vehicles. Specifically, it seeks to evaluate the preferred message types and perceived usefulness of eHMIs across a diverse group of road users—including pedestrians, drivers of manually operated vehicles, and users of automated ride-hailing service users—in various traffic situations. The findings of this study are expected to provide foundational data for the development of scenario-specific eHMI design guidelines, contributing to safer and more effective interactions in mixed traffic environments.

METHODOLOGY

To investigate user preferences for eHMI messages in automated driving vehicles, a structured survey was conducted targeting licensed drivers in South Korea. A total of 900 participants were recruited, with an equal distribution across three age groups: 300 respondents in the young adult group (aged 19–39), 300 in the middle-aged group (aged 40–64), and 300 in the older adult group (aged 65 and above). All participants were required to have prior driving experience to ensure the validity of their responses. The survey instrument comprised 30 items designed to collect data on demographic characteristics, driving behaviours, and preferences for eHMI message types across a range of driving scenarios. These scenarios included normal driving conditions, adverse weather, branching roads, single-lane roads, and mixed traffic environments. Additionally, the survey explored user preferences for external display messages in the specific context of automated ride-hailing services (see Table 1 for details). The survey was administered online via the OpenSurvey platform over two-day period, from December 10 to 11, 2024. The sampling methodology ensured a representative distributions of respondents, with a calculated margin of error of ±2.14 percentage points at a 95% confidence level.

Table 1: Survey questions.

No.	Questionnaire Items
Q1	Do you currently possess a valid driver's license?
Q2	How frequently have you driven in the past three months?
Q3	What is your total driving experience (in years)?
Q4	Have you been involved in any traffic accidents within the past three years?
Q5	What type of road do you primarily drive on?
Q6	How familiar are you with automated driving vehicles?
Q7	What is your general perception of automated driving vehicles?
Q8	How would you evaluate your own driving habits?
Q9	Which Advanced Driver Assistance Systems (ADAS) are installed in your current vehicle? (Select all that apply)
Q10	Do you believe a rear display installed on the vehicle ahead could obstruct your recognition of traffic situations (e.g., traffic lights, vehicles, pedestrians)?
Q11	Do you believe a rear display installed on the vehicle ahead could negatively affect your recognition of rear lamps (e.g., turn signals, brake lights, side lights)?
Q12	What type of information displayed on the rear of the vehicle ahead would you find useful while driving? (Select up to three in order of usefulness)
Q13	What type of information would be useful if displayed on a rear-mounted screen while driving? (Select up to three in order of usefulness)

Continued

Table 1: Continued

No.	Questionnaire Items
Q14	Under normal driving conditions, what information displayed on a rear-mounted screen would be helpful for your driving? (Select up to three in order of usefulness)
Q15	On a one-lane road, what information displayed on the rear of a large bus or truck would you find useful? (Select up to three in order of usefulness)
Q16	Under adverse weather conditions (rain, snow, fog), what information displayed on the rear of the vehicle ahead would you find useful? (Select up to three in order of usefulness)
Q17	When approaching a branching road, what information displayed on the vehicle ahead would be useful for your driving? (Select up to three in order of usefulness)
Q18	In mixed traffic environments (automated and non- automated driving vehicles), what information displayed on the rear of an automated driving vehicle would you find helpful? (Select up to three in order of usefulness)
Q19	Do you think external displays (front/side/rear) are necessary for communication with nearby automated driving vehicles?
Q20	Do you believe it is necessary for safety-related driving messages displayed on the front of automated driving vehicles to be continuously shown without blinking?
Q21	As a pedestrian, what type of message displayed on the front of an automated vehicle would be useful when crossing at a crosswalk? (Select up to three in order of usefulness)
Q22	At an unmarked crosswalk (without traffic lights), do you find it useful for an automated driving vehicle's display to indicate its direction or intention to decelerate/stop?
Q23	When crossing at a crosswalk, do you find it useful for an automated driving vehicle to display a message such as 'Pedestrian Recognized'?
Q24	What message do you think is most useful to display on the front of an automated driving vehicle when crossing at a crosswalk?
Q25	How much do you trust the information displayed on external displays of automated driving vehicles?
Q26	If you do not trust the information displayed by automated driving vehicles, what are the main reasons? (Select up to three in order of importance)
Q27	When a ride-hailing automated driving taxi approaches your pickup location, what type of information displayed would you find useful? (Select up to three in order of usefulness)
Q28	When boarding a ride-hailing automated driving taxi, what information displayed on the side window would be useful? (Select up to three in order of usefulness)
Q29	When disembarking from a ride-hailing automated driving taxi, what information displayed on the side window would be useful? (Select up to three in order of usefulness)
Q30	During boarding or disembarking from a ride-hailing automated driving taxi, what information displayed on the rear screen would be useful? (Select up to three in order of usefulness)

RESULTS

Below are the results of the most preferred eHMI message types categorized by driving scenario (refer to Table 2 for further information).

Table 2: Summary of most preferred eHMI messages by driving situation.

Question (Scenario)	Most Preferred Message Type	Response Rate(%)
Q14 (Normal driving)	Information for Rear Drivers (e.g., Overtaking Permitted Notification, No Overtaking Warning, Safe Following Distance Recommendation)	36.8
Q15 (Single-lane driving)	Information for Rear Drivers	49.7
Q16 (Adverse weather)	Emergency Situations (e.g., Stopped Due to Severe Weather, Vehicle Malfunction or Abnormal Conditions, Reduced Speed Inside Tunnel, Roadkill or Similar Hazards)	52.1
Q17 (Intersection merging)	Traffic Situation Information (e.g., Level of Traffic Congestion Ahead, Recommended Speed for Branching Roads)	58.1
Q18 (Mixed traffic)	Driving Intention (e.g., Turning Direction such as Left/Right Turn, Sudden Deceleration or Stop)	65.0

In the normal driving scenario (Q14), 36.8% of respondents identified "Information for rear drivers" as the most useful message, followed closely by "Vehicle behaviour information" (36.4%) and "Emergency alerts" (36.1%). When analysed by age group, respondents aged 60 and above exhibited the highest preference for "Information for rear drivers" (43.5%), whereas younger respondents in their 20s and 30s demonstrated relatively lower preference rates of 25.4% and 30.3%, respectively. In the single-lane scenario (Q15), "Information for rear drivers" remained the most preferred message (49.7%), followed by "Front traffic information" (41.2%) and "Vehicle behaviour information" (37.9%). In this scenario, the differences in preferences across age groups were relatively minor.

Under adverse weather conditions (Q16), "Emergency alerts" were the most frequently selected message type (52.1%), followed by "Road environment hazard information" (41.8%) and "Front traffic information" (39.2%). Respondents in their 30s showed the highest preference for "Road environment hazard information" (52.3%), while those aged 60 and above also demonstrated a relatively high preference for "Information for rear drivers" (42.3%) in addition to "Emergency alerts." In the branching road scenario (Q17), "Traffic situation information" emerged as the most preferred message type (58.1%), followed by "Driving intention information" (49.0%) and "Driving direction information" (48.0%). Notably, 66.7% of respondents in their 40s selected "Traffic situation information" as the most important message in this scenario. In the mixed traffic scenario (Q18), "Driving intention information" was the most frequently selected message type (65.0%), followed by "Risk alerts" (62.7%) and "Driving mode information" (45.9%). By age group, respondents in their 40s exhibited a particularly high preference for "Driving mode information" (54.4%), while those in their 50s showed the highest preference for "Risk alerts" (78.6%). Furthermore, differences in message type preferences across driving scenario-including normal driving, single-lane, adverse weather, branching road, and mixed traffic-were analysed by age groups and gender (refer to Table 3 for a comprehensive breakdown). This analysis highlights the variability in eHMI message preferences based on driving context and demographic factors, providing valuable insights for scenario-specific eHMI design.

Table 3: Effects of age, gender, and perception on preferred eHMI messages.

Variable	Question	Effect Coefficient	P-value	Interpretation
Age	Q14	-	0.032	Statistically significant
	Q15	-	0.020	Statistically significant
	Q16	-	0.011	Statistically significant
	Q17	-	0.001	Statistically significant
	Q18	-	0.045	Statistically significant
Gender(Sex)	Q14	-	0.039	Partially significant
	Q15	-	0.088	Marginal
	Q16	-	0.048	Partially significant
	Q17	-	0.092	Marginal
	Q18	-	0.051	Marginal
Knowledge(Q6)	Q14	0.411	0.057	Weak positive effect (10% significance)
	Q15	−0.133	0.605	No effect
	Q16	0.166	0.563	No effect
	Q17	0.133	0.414	No effect
	Q18	0.089	0.606	No effect
Preference(Q7)	Q14	0.204	0.276	No effect
	Q15	0.100	0.657	No effect
	Q16	−0.141	0.572	No effect
	Q17	0.027	0.850	No effect
	Q18	0.267	0.079	Weak positive effect (10% significance)

The analysis revealed that while differences in message preferences across age groups were statistically significant for all items, the effect sizes were small (ranging from 0.05 to 0.08), indicating limited practical significance. These findings suggest that although demographic factors such as age and gender may influence message preferences, their overall impact remains relatively minor. Additionally, the effects of participants' understanding of automated driving technology (Q6) and favourability toward it (Q7) on message selection across various driving scenarios were examined. In the normal driving scenario (Q14), understanding of automated driving technology (Q6) exhibited a weak positive effect on message preference (coefficient = 0.411, p = 0.057), whereas favourability toward automated driving (Q7) did not show a statistically significant impact (p = 0.276). For the single-lane (Q15), adverse weather (Q16), and branching road (Q17) scenarios, neither understanding (Q6) nor favourability (Q7) demonstrated significant effects on message selection (p > 0.05). These results suggest that in complex or high-risk situations, the immediate contextual information needs outweigh perceptions of automated driving technology as determinants of message preference. In the mixed traffic scenario (Q18), favourability toward automated driving (Q7) showed a weak positive influence on message selection (coefficient = 0.267, p = 0.079), while understanding of the technology (Q6) did not have a statistically significant effect (p = 0.606). Overall, understanding of automated driving technology had a modest influence in the normal driving scenario (Q14), and favourability toward it exhibited a weak effect in the mixed traffic scenario (Q18). However, across all scenarios, perceptions of automated driving technology alone appear insufficient to strongly predict message preferences. Instead, situational risk perception and the demand for contextually relevant information play a more direct and substantial role in shaping user preferences for eHMI messages. In the pedestrian crossing scenario (Q21), 68.7% of respondents identified the "Pedestrian Detected" message as the most useful, followed by "Pedestrian Detection Status" (64.4%) and "Driving Path Information" (e.g., going straight, turning left/right, U-turn) (54.6%). These findings highlight the importance of clear and actionable information in scenarios involving interactions with vulnerable road user (see Table 4 for detailed results).

Table 4: Summary of pedestrian-related eHMI messages preferences.

Question (Scenario)	Most Preferred Massage Type	Response Rate(%)
Q21 (Crosswalk)	Driving Intention (e.g., Starting, Stopping, Parking, Standing Still)	69.8
Q22 (Unsignalized)	Positive responses ("Agree" or "Strongly Agree")	74.7
Q23 (Utility of message)	Positive responses ("Agree" or "Strongly Agree")	76.0
Q24 (Most useful message)	"Pedestrian Detected" message	41.0

The analysis of eHMI message preferences by age group revealed notable differences. Respondents in their 50s demonstrated a relatively high preference for "Driving Path Information" (66.1%), whereas those aged 60 and above most frequently selected "Driving Intention" messages (e.g., start, stop, park, idle) at a rate of 74.7%. In the scenario involving unsignalized pedestrian crossings (Q22), 74.7% of participants indicated that messages conveying the vehicle's intended direction (straight/turning) and deceleration or stopping plans were useful. Respondents aged 60 and older showed particularly strong agreement, with 80.2% rating these messages as useful. Regarding the perceived usefulness of the "Pedestrian Detected" message (Q23), 76.0% of all respondents responded positively, with an even higher rate of 80.5% among those aged 60 and above. When asked to identify the most useful message at pedestrian crossings (Q24), the “Pedestrian Detected” message was selected most frequently (41.0%), followed by “Please Go Ahead” (24.4%) and “Remaining Signal Time” (14.2%). The findings related to information provision via eHMI in the context of automated ride-hailing service usage are summarized in Table 5. These results provide insights into user preferences for eHMI messages in scenarios involving interactions with pedestrians and automated driving vehicle services.

Table 5: Summary of preferred eHMI messages for automated taxi usage.

Question (Scenario)	Most Preferred Massage Type	Response Rate(%)
Q27 (Taxi approaching)	Destination	58.6
Q28 (Taxi boarding – Side display)	Final Destination Route Guidance (e.g., Estimated Travel Time, Traffic Congestion Level)	72.1
Q29 (Taxi alighting – Side display)	Rear-Surrounding Hazard Alerts (e.g., Bicycles, E-scooters, Motorcycles)	63.6
Q30 (Taxi boarding/ alighting – Rear display)	Passenger Boarding/Alighting Notification	72.1

In the taxi approach scenario (Q27), the most preferred information was the “Destination,” selected by 58.6% of respondents, followed by “Partial User Phone Number” (51.8%) and “User Nickname” (41.0%). These results suggest that passengers prioritize identification information that confirms the automated driving vehicle has accurately recognized their ride request. An analysis by age group revealed that younger respondents in their 20s (55.9%) and 30s (51.5%) showed a stronger preference for “User Nickname”, whereas respondents aged 60 and above exhibited a higher preference for “Destination” (64.4%). This indicates that younger users prioritize personal identification, while older adults place greater emphasis on confirmation of the intended arrival point. In the boarding scenario via side display (Q28), the most preferred message was “Final Destination Route Guidance” (e.g., estimated travel time, traffic congestion), selected by 72.1% of respondents. This was followed by “User Identification Information” (54.3%) and “User Authentication Method” (42.3%). Notably, preference for “Final Destination Route Guidance” was highest among respondents aged 60 and above (77.4%), highlighting a heightened need for clear trip-related information among older users. In the alighting scenario (Q29), “Rear-Surrounding Hazard Alerts” (e.g., bicycles, e-scooters) were most frequently selected message (63.6%), followed by “Forgotten Item Alerts” (60.2%) and “Fare Payment Information” (38.7%). These findings underscore the growing safety demands associated with the increasing presence of personal mobility devices in traffic environments. For the rear display used during boarding and alighting (Q30), “Passenger Boarding/Alighting Notification” received the highest preference (72.1%), followed by “Front-Surrounding Hazard Alerts” (54.7%) and “Driving Intention Display”

(36.9%). Interestingly, 66.1% of respondents in their 50s selected "Front-Surrounding Hazard Alerts," reflecting a strong awareness of the importance of communicating situational hazards to both users and nearby road participants. Lastly, user trust levels and perceived barriers regarding message provision via eHMIs installed on automated driving vehicles were analysed. These findings are summarized in Table 6, providing further insights into user perceptions and preferences for eHMI-based communication in automated vehicle scenarios.

Table 6: Trust level in eHMI messages and main reasons for distrust.

Question	Result Summary
Q25 (Trust level)	- Positive (4+5 points): 43.3%, Neutral (3 points): 50.6%, Negative (1+2 points): 6.1% - Average score: 3.41 (out of 5)
Q26 (Main Reasons for Distrust – Top 3)	1. Uncertainty about system performance (74.5%) 2. Lack of transparency in decision-making (58.2%) 3. Misrecognition risk (e.g., obstacle or pedestrian errors) (58.2%)

In response to the question regarding trust in eHMIs (Q25), 43.3% of participants provided positive responses ("Trust" or "Strongly Trust"), while only 6.1% expressed negative responses ("Do Not Trust" or "Strongly Do Not Trust"). The most frequent response was neutral ("Neither trust nor distrust"), accounting for 50.6% of the total. The average trust rating was 3.41 out of 5. These findings suggest that the majority of respondents perceive eHMI information either positively or neutrally, with instances of extreme distrust being relatively uncommon. However, the results also underscore the need for continued efforts to build and validate trust in eHMI systems. With respect to the reasons for distrust in eHMIs (Q26), "Uncertainty"—specifically, concerns about the reliability and proper functioning of automated driving technology—was the most frequently cited factor (74.5%). This was followed by "Lack of Decision-Making Transparency" (58.2%) and "Misrecognition" (e.g., potential errors in detecting obstacle or pedestrian) (58.2%). These findings highlight the importance of addressing user concerns regarding the perceptual accuracy and behavioural consistency of automated driving systems to establish a stronger foundation of trust in eHMI technologies.

CONCLUSION

This study systematically examined user preferences for external Human-Machine Interface (eHMI) messages in automated driving vehicles across diverse driving scenarios, including normal driving, single-lane roads, adverse weather conditions, branching roads, and mixed traffic environments. The findings revealed that preferred eHMI messages varied significantly by scenario, with "Information for Rear Drivers," "Driving Intention

Display," and "Emergency Alerts" identified as key message types. Age-related differences in preferences were also observed, highlighting the need for tailored eHMI desings. From the pedestrian perspective, the "Pedestrian Detected" message was rated as the most useful, while in automated ride-hailing contexts, users prioritized identification, route guidance, and surrounding hazard alerts. Although understanding and favourability toward automated driving technologies had weak effects in certain scenarios (Q14 and Q18), users' information needs were predominantly influenced by the specific characteristics of each driving situation. This study contributes to the literature by expanding the scope of eHMI research beyond pedestrian-vehicle communication to include rear drivers and automated driving taxi users, with a particular emphasis on ride-hailing scenarios. Unlike previous studies (Chen et al., 2021; Alhawiti et al., 2024) that primarily compared the presence or absence of eHMIs, this research quantitatively presents user preferences for specific message types, offering practical insights for eHMI design.

Based on the findings, the following design implications for external Human-Machine Interfaces (eHMIs) in automated driving vehicles are proposed:

1. Need for Scenario-Specific Message Systems

   eHMI design should evolve from simple status indication to context-aware systems that deliver messages tailored to specific driving scenarios (e.g., emergency alerts, directional intent). In complex traffic environments, messages such as driving intention and hazard alerts should be presented simultaneously, with clear prioritization to ensure driving safety.
2. Standardization of Mutual Awareness-Based Messages for Pedestrian Safety

   In pedestrian crossing scenarios, mutual awareness messages such as "Pedestrian Detected" and "Yielding Intention" should be standardized and clearly conveyed. This is particularly critical at unsignalized crosswalks, where pedestrian decisions rely heavily on vehicle behaviour, necessitating fast and unambiguous communication.
3. Enhanced User Identification and Hazard Alerts in Ride-Hailing Contexts

   For automated ride-hailing services, eHMIs should prominently display user identification information (e.g., nickname, partial phone number) and destination to reduce boarding errors and alleviate user anxiety. During drop-off, hazard alerts regarding nearby mobility devices (e.g., bicycles, motorcycles) should be implemented to enhance passenger safety.
4. Age-Specific Considerations in eHMI Design

   Older users (50s and above) demonstrated a preference for explicit displays of vehicle path and driving intention. eHMIs targeting older populations should utilize direct and clear expressions (e.g., "Stopping," "Turning Left"). However, given the coexistence of various age groups on public roads, universally intuitive messaging systems are necessary. Adaptive eHMI systems that dynamically prioritize messages based on real-time road infrastructure and environmental conditions (e.g., weather, road status) are recommended.

5. Strategies to Enhance Technology Acceptance

   Although most respondents expressed moderate or higher trust in eHMIs, this trust may be contingent on the assumption that the information does not interfere with their driving or walking behaviour. To improve technology acceptance, strategies should focus on (1) ensuring information reliability, (2) minimizing cognitive load, and (3) conducting repeated usability testing across diverse situational scenarios.

This study provides a multidimensional analysis of user perceptions and preferences regarding visual communication via eHMIs in automated driving vehicles. It offers foundational data to inform practical design guidelines based on information demands across different driving scenarios. However, several limitations should be noted: (1) The study relied on online surveys, which may not fully capture user responses in real driving or walking contexts. (2) The analysis focused exclusively on text-based messages, excluding other visual formats such as icons, colors, or animations. (3) The scope of driving scenarios was limited and did not include complex conditions such as accidents, road construction, or emergency vehicle approaches. Future research should employ driving simulators or real-road testing to quantitatively assess eHMI perception and behavioural outcomes. Comparative evaluations of various message formats (e.g., icons, colors) and detailed analyses of eHMI usefulness in complex scenarios are necessary. Additionally, research on universal eHMI design guidelines that accommodate users across diverse age groups and cultural backgrounds is recommended to ensure inclusivity and effectiveness in global applications.

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