HMI Rating

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1. Executive Summary

This deliverable condenses the findings on human-machine-interfaces (HMIs) during the HEIDI project.

It summarizes the studies on HMIs of the HEIDI project, the methodologies which were used and thus intends to give a high-level view on how to rate the effectiveness of HMIs as well as give guidance on what aspects lead to effective HMIs.

There are in total 12 studies to be conducted during the HEIDI project. As of submission of this deliverable 10 have been completed. The remaining two are field demonstrations which will yield no data collection but will be part of the final event to present the state of HMIs achieved during the project.

Based on this large number of investigations, clear conclusions can be drawn about key characteristics which are responsible for the efficacy of HMIs.

This deliverable then presents key aspects on which HMIs can be rated to evaluate their usefulness and impact on traffic safety.

Keywords: cHMI, eHMI, iHMI, safety, rating

2. Objectives

The primary objective of Deliverable 7.2 is to describe how to rate HMIs based on a comprehensive evaluation of the test results and experimental outcomes of the studies on HEIDI HMI solutions. This assessment aims to explore key aspects such as safety, with a particular focus on minimizing distraction, usability, and overall effectiveness.

A significant part of this evaluation involves analysis of the studies of these HMI solutions and their impact on different road users, including drivers and pedestrians. By considering the varied interactions and experiences of each group, this deliverable seeks to provide insights into how these solutions enhance safety and usability for all.

Each HMI solution developed under the HEIDI project will be assessed separately to ensure a thorough understanding of its performance and effectiveness. This evaluation is grounded in the foundational work conducted in Work Packages 3, 5, and 7, particularly drawing from evaluation studies 1, 2, 3, 5, 6, 7, 8, 10, and 12 which are presented in deliverables D2.3, D3.4, D5.3 and D7.1. These studies offer valuable insights and data that inform the overall assessment process.

The findings from these evaluations will be summarized and documented with the goal of an understanding of the project's impact on road safety and user experience.

Out of the studies we condense generally applicable premises and principles which allow us to formulate aspects with which to rate HMIs.

3. Description of Work

3.1 Overview of HMI studies

Below is a comprehensive table summarizing all the studies that have been conducted with focus on HMIs, highlighting their objectives, testing environments, and basic methodologies:

Table 3-1: Overview of HMI studies

Study	Objective	Testing Environment	Basic Methodologies
Study 1	Evaluate the usability, safety, and comfort of iHMIs for regular drivers in attentive and distracted states.	Simulator (Driving Simulator)	- Tested iHMI in various driving scenarios. - Participants: Regular drivers. - Data collection through objective driving metrics and subjective feedback (e.g., SUS[1], NASA-TLX[2]).
Study 2	Assess the usability, safety, and comfort of iHMIs for older drivers.	Simulator (Driving Simulator)	- Focus on older drivers. - Evaluation of iHMI versions. - Collection of both objective driving data and subjective feedback.
Study 3	Explore preliminary HMI concepts and user needs in HEIDI prototype designs.	Simulator/Controlled Environments	- Initial explorations and evaluations of HMI concepts. - Use of foundational methodologies for understanding user needs and HMI usability.
Study 5	Assess the revised version of the fluid internal HMI (iHMI) for regular, distracted, and elderly drivers regarding safety, comfort, and usability.	Simulator (Driving Simulator)	- Tested different iHMI variations (Non-fluid, Horizontal fluid, Vertical fluid, fully fluid). - Participants: Regular, distracted, and older drivers. - Various crossing scenarios. - Objective and subjective data collection (e.g.,

			braking behaviour, questionnaires).
Study 6	Evaluate the effectiveness of eHMIs for pedestrian-vehicle interactions, focusing on pedestrian decision-making and crossing initiation.	Simulator (VR and Motion Capture)	- Evaluated Short-Term and Long-Term eHMIs. - Participants included pedestrian groups, with VR used to simulate scenarios. - Measures: Time-To-Crossing, TTR, crossing speed.
Study 7	Test validation methods for the cooperative HMI (cHMI) system using networked simulators.	Simulator (VR and Driving Simulator with AR)	- Assess the interaction between driver and pedestrian with/without cHMI. - Mixed design with driver distraction task. - Collection of objective data and subjective evaluations.
Study 8	Evaluate the internal HMI for pedestrian safety and traffic flow from the driver's perspective.	Real World (Test Track)	- Real-time processing of GPS, CAN, and eye-tracking data. - Drivers guided by iHMI interventions. - Objective and subjective data (e.g., reaction times, questionnaires).
Study 10	Assess impact of eHMI on pedestrian safety and traffic flow, focusing on VRUs in urban traffic.	Controlled Environment (Motion Capture)	- Evaluated real test vehicle with integrated eHMI. - Objective measures: TTR, crossing speed. - Surveys and participant interactions with/without eHMI.
Study 12	Evaluate usability and effectiveness of cooperative HMI with drivers and pedestrians.	Simulator (Virtual Reality)	- Distributed simulation with synchronized driver and pedestrian scenarios. - Focus on interactions at

			unsignalized crossings. - Use of objective and subjective metric analysis.

This consolidated table provides a thorough overview of each study, outlining their unique goals within HEIDI's research framework and capturing the diversified methodologies and testing conditions leveraged for each.

3.2 Condensed findings of the studies

The following is a condensed summary of the findings which have been presented in previous deliverables, as they relate to the effectiveness of the HMIs which were investigated. Prior knowledge of the deliverables D2.3, D3.4, D5.3 and D7.1 is highly recommended as the summary below is in no way complete and shall not be construed to give the complete picture.

However, summarizing key aspects allows to find common denominators in what made these HMI solutions effective and where room for improvement can be found. Reiterating the findings in this brief way will lead to succinct rating and description in chapter 3.3.

3.2.1 iHMI simulator studies 1, 2, 5 & 8

The HEIDI project evaluated various iHMI versions for usability, safety, and comfort across diverse driver groups. For regular drivers, the iHMI reduced vehicle speed and reaction times and maintained vehicle control, receiving high usability and safety ratings. Older drivers favoured a tailored “older” iHMI solution for its safety perception. Recommendations included refining warning timing and duration. Simulator tests showed fully fluid iHMI enhanced slowing speeds, while real vehicle tests highlighted better safety perceptions. These studies stressed the need for interfaces tailored to different driver demographics and enhanced warning clarity and timing.

3.2.2 eHMI simulator studies 3 & 6

In the HEIDI project, the eHMI design proved effective yet faced challenges. Initially, complex and rapidly changing messages, (e.g. linked to Time-to-Collision - TTC), caused confusion. Simplifying messages to three levels ("I have stopped", "I will slow down / stop", "I will accelerate / pass") reduced confusion. Participants preferred messages based on distance rather than TTC due to speed sensitivity. Colour-based systems were confusing, leading to a focus on white and amber for urgency levels. Messages like "Crossing Detected" were misinterpreted, necessitating redesigns to ensure clarity and avoid liability issues. Realistic vehicle dynamics further improved predictability in pedestrian interactions. Two types / layouts were tested (“Short-“ and “Long-Term eHMI” displays) and both effectively communicated with pedestrians.

The original iHMI design underwent revisions for improvement. Warning levels were simplified to three with distinctive icons and tones, and the LED strip was omitted in simulations but deemed useful for real traffic. The display was centralized for an enhanced user focus, with future adaptations suggested based on gaze direction. Automatic deactivation was triggered by gaze return to the street view. Realistic validation beyond experimental conditions was urged. Older drivers were excluded initially for safety reasons.

3.2.3 cHMI simulator studies 7 & 12

The HEIDI project's cHMI analysis highlighted findings and insights from iHMI and eHMI implementations. Initially, Version 1 of cHMI had vague symbols and timing which confused users. A modified Version 2 improved clarity through simplified symbols, responsive timings, and animation. Enhanced usability was noted in user evaluations, showing increased trust and positive user experience ratings. Critical recommendations included using simple, necessary messages and animations to communicate effectively, and real-world applicability considerations for cHMI prompted adaptable, situation-appropriate communication strategies.

3.2.4 eHMI real world study 10

Preliminary internal investigations of the eHMI as implemented in the test vehicle included a lot of tuning of technical parameters, e.g. brightness of the display in relation to ambient light, framerate and animation speed. Special focus was put on the symbols to be displayed. Corroborated by the findings of the other HEIDI studies, the display only showed one symbol at a time and messages were optimized to be simple and clear. Messages were also chosen to only reflect the intention of the vehicle with no proposals to be discerned by pedestrians. Rather, pedestrians could quickly grasp this additional information for their own decision making. Results from the study confirmed that the choice of simplified symbols lead to good understanding and perception.

3.3 Rating HMIs

It is clear that a lot of the efficacy of HMIs will be relying on the underlying algorithms, like pedestrian recognition, driver monitoring, prediction algorithms etc. These are part of other deliverables, e.g. D2.2, D3.3. However, for the purpose of this deliverable, we consider these to be part of a “black box” and purely describe what aspects will result in HMIs which contribute to traffic safety.

Based on our findings HMIs should be rated according to the following criteria:

- Ease of perception
- Clarity of understanding
- Appropriateness to situation and user

All three criteria will be elaborated in the following subsections.

3.3.1 Ease of perception

For HMIs to be efficient, they need to be perceived. Thus, HMIs should be rated according to how easily and quickly a user can see the message displayed by the HMI. The studies show the importance of the following aspects.

- Position / Placement
  - is the HMI easily put into the user’s field of view?
- Size
  - is the HMI appropriately sized to be recognizable for a wide range of visual acuity and distance, especially for eHMI?
- Brightness & contrast
  - is the HMI sufficiently bright to be recognizable but not too bright to be glaring? Is the fidelity of the contrast sufficient to be recognizable for a wide range of visual acuity and distance?

- Attention grab
  - what draws the users' attention to the HMI? Might be supported with sound.

For real world examples, please refer to deliverable D6.1.

3.3.2 Clarity of understanding

When the HMI is perceived, its message needs to be understood. This presents a strong challenge, especially across cultures. However, our studies deliver strong recommendations for useful and effective messages. They should be rated according to the following aspects.

- Simplicity of messages
  - The studies showed that giving too much information is counterproductive. Complex situations must be reduced to its core aspect, e.g. "pedestrian detected" or "vehicle will slow down".
- Clarity
  - Different messages must result in clearly different symbols.
  - Related to simplicity, this will result in a small catalogue of messages, any new message must be learned by the user and must be justified. If different situations result in the same recommended behaviour, the same symbol shall be used.
  - Related to simplicity, with each symbol conveying one singular message, they are more clearly understood.
- Timing
  - Sufficient time to understand the information.
  - Appropriate timing, i.e. sufficiently early.
  - Back and forth changes must be prevented.
- Context
  - Related to timing. Other observations by the user must fit to HMI message. Especially for eHMI, vehicle behaviour is used by users to evaluate the situation.
  - Supporting hints e.g. audio, can be carefully tailored to support understanding.
  - Colour, if used, must follow established precedent, i.e. amber and red as warning colours.

Examples for these key aspects of simplicity and clarity are given in Figure 3–1 and Figure 3–2.

Figure 3–1: Complex pattern (left) vs simple symbol (right). For study 10, simple symbols were used and showed high efficacy.

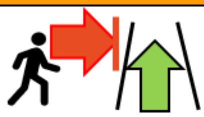
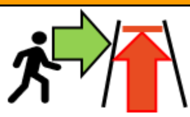
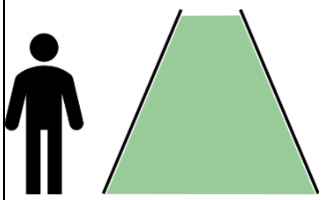
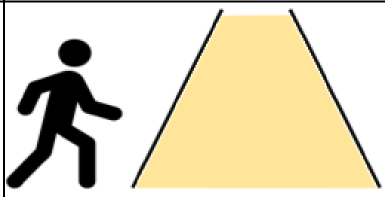
	Vehicle first	Yielding
Version 1		
Version 2		

Figure 3–2: Simplification of message (cHMI) lead to increased effectiveness. Version 1 was used in Study 7, showing low efficacy, whereas Version 2 was used in Study 12 showing improved effectiveness.

3.3.3 Appropriateness to situation and user

When the HMI is perceived and the message is understandable, there is still the question of appropriateness. While this sounds abstract, our studies, as well as deliverables on user needs show the benefit in considering the overall situation in a holistic manner. The appropriateness should be rated according to the following aspects.

- Age and fitness of users
  - All HMIs should be rated with a diverse range of users in mind. For iHMIs a different selection of parameters (size of symbols, audio signals) can tailor the messages according to audience and shows benefit in the aspects of perception and understanding.
- Evaluation of the traffic situation
  - Related to the “black box of algorithms”. Each message must be justified to benefit a user. I.e. no eHMI activation without VRU intending to interact present, similarly no HMI activation if many road users are present and an eHMI message might lead to distraction/confusion.
- Hierarchy within information ecosystem
  - The HMI must not interfere with emergency signals, i.e. it must either be switched off or be integrated into the emergency signals, e.g. collision warning, emergency braking etc.

4. Conclusion

During the HEIDI project, a vast area of expertise was deployed to investigate the role of HMIs in vehicle VRU interaction.

In order to benefit user experience and especially user safety we could identify clear aspects which HMIs have to fulfil. This enables rating HMIs for usefulness.

Therefore, HMIs should be rated according to their performance regarding ease of perception, clarity of understanding and appropriateness to situation and user.

These aspects and the elaborations given above can be used as checklist for technical investigators in judging the merits of an HMI, e.g. in the context of a test drive.

Table 4-1: HMI rating

Key aspect	Sub aspect	Rating (e.g. 1 to 10)
Perception	Position / Placement	
	Size	
	Brightness & contrast	
	Attention grab	
Understanding	Simplicity	
	Clarity	
	Timing	
	Context	
Appropriateness	Age & Fitness	
	Traffic Situation	
	Hierarchy	

A more detailed checklist can be created out of these aspects, adding measurements and legal requirements. The latter will have to be established out of deliverable D7.3.

5. Abbreviations

Term	Definition
CAN	Controller Area Network
cHMI	Cooperative Human-Machine Interface
EC	European Commission
eHMI	External Human-Machine Interface
GPS	Global Positioning System
HEIDI	Holistic and adaptivE Interface Design for human-technology Interactions
HMI	Human-Machine Interface
iHMI	Internal Human-Machine Interface
LED	Light Emitting Diode
NASA-TLX	Nasa Task Load Index
PU	Public
R	Document, Report
SUS	System Usability Scale
TTC	Time to Collision
TTR	Time to Resolve
VR	Virtual Reality
VRU	Vulnerable Road User
WP	Work Package

6. References

[1] Brooke, John. (1996). SUS -- a quick and dirty usability scale.

[2] NASA (1986) https://humansystems.arc.nasa.gov/groups/TLX/downloads/TLX.pdf