Improved Autonomous Trucker-Vehicle Dialogue under Critical Scenarios through fluid-HMI

Kabbani, T.; Kim, S.; Serbes, D.; Ozan, Berzah; van Egmond, R.; Hartavi, Ahu Ace

DOI
10.1016/j.trpro.2023.11.454

Publication date
2023

Document Version
Final published version

Published in
Transportation Research Procedia

Citation (APA)
Kabbani, T., Kim, S., Serbes, D., Ozan, B., van Egmond, R., & Hartavi, A. A. (2023). Improved Autonomous Trucker-Vehicle Dialogue under Critical Scenarios through fluid-HMI. *Transportation Research Procedia*, *72*, 674-680. https://doi.org/10.1016/j.trpro.2023.11.454

Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 72 (2023) 674–680

Transportation Research Procedia

www.elsevier.com/locate/procedia

Transport Research Arena (TRA) Conference

Improved Autonomous Trucker-Vehicle Dialogue under Critical Scenarios through fluid-HMI

Tarek Kabbani[a], Soyeon Kim[b], Duygu Serbes[c], Berzah Ozan[c], René van Egmond[b], Ahu Ece Hartavi[a]*

[a]*University of Surrey, Department of Mechanical Engineering Science, Centre for Automotive Engineering, GU2 7XH, Guildford, UK*
[b]*Delft University of Technology, Faculty of Industrial Design Engineering, Landbergstraat 15, 2628 CE, Delft, The Netherlands*
[c]*Ford Otosan, Research, and Development Center, Autonomous Driving Systems, 34885 Istanbul, Turkey*

Abstract

Automation of vehicles not only provides greater safety, but also many previously unimagined opportunities, such as less inequality, less stress, and more meaningful activities while driving. However, the uptake and implementation of automated driving have been falling short of its promise, due to challenges in identifying safe and acceptable ways for humans to interact with automated vehicles. The human-machine interface (HMI) in vehicles plays a more critical role today than ever before. The main research question addressed in this study, as part of the EU-funded HADRIAN project, is: What steps need to be taken to achieve effective fluid HMI (*f*-HMI) design for improved driver-vehicle dialogue, especially in critical scenarios?

Keywords: Fluid human-machine interface; Visual cues; Human-centric design; Minimum Risk Manevour; Critical scenario; Trucker Automated vehicle.

1. Introduction

It is argued that vehicle automation will positively enrich the overall transportation system, improve safety, reduce road congestion, increase economic competitiveness, and enhance driver comfort. However, automation also brings numerous disadvantages that impact drivers. Loss of situational awareness, loss of skills, and limited system capabilities are some of the disadvantages that negatively impact the benefits of automation. Depending on the level of automation, these perceived disadvantages differ (Harre and Feuerstack, 2018). Unfortunately, the impact of low-probability but high-consequence events on human-machine interface (HMI) design is either neglected or misunderstood by organizations (Roush W., 1993). Especially at higher levels of automation, the vehicle is expected to perform the dynamic driving task with a minimum number of interventions. However, given the complexity of the

---

* Corresponding author. Tel.: +44 (0)1483 682895.
E-mail address: a.hartavikarci@surrey.ac.uk

10.1016/j.trpro.2023.11.454

vehicle's operating design domain, and environmental conditions, the possibility of flawed intervention can increase significantly. Depending on the challenges of the situation and the varying degrees of driver inattention and distraction, the driver may either not be properly informed of the critical situation (e.g., overtaking manoeuvre, MRM) or may fail to act properly, which can have catastrophic consequences. Therefore, the proposed HMI should be designed to minimise driver errors to avoid all possible negative consequences through improved dialogue. This even leads to the design of the HMI for automated vehicles becoming as important as the skills and abilities of the driver controlling "the vehicle" (Fank et al., 2021).

Regardless of the vehicle type, this is performed via several types of cues based on the event's occurrence and conditions. Some of which are visual, auditory and haptic cues. Visual cues are presented to the driver, usually on an interface with helpful information needed to continue the correct functioning of the system. On the other hand, auditory cues are sounds typically played by the system to draw the driver's attention to other cues, including visual ones. Many studies in the literature have addressed the visual cues design of the HMI for passenger vehicles (Blakeney, 2020, Krömker, 2020, Kim,2021). Auditory cues have been used along with visual and tactile interfaces to provide autonomous passenger vehicles with information on the road and mode transition alarms (i.e., take-over requests) (Mirnig et al. 2017, Ayoub et al. 2019, Zhang et al. 2019).

Although several HMI design approaches have been presented in the literature (Bavendiek, 2020), in the case of HMI design for automated commercial vehicles, the literature is further limited. This is mainly because, the responsibilities of drivers of automated trucks and passenger vehicles differ significantly, e.g., the need for a change in role from operators to system supervisors. Furthermore, in most cases, it is not always the truck drivers who select and evaluate the vehicles they drive or the distance they travel; instead, this is done by the fleet owners and managers (Harre and Feuerstack, 2018). Therefore, the system designed for automated trucks should take into account the roles and needs of truckers, which are different from those of passenger vehicle drivers. In line with that Larsson and Press (2020) presented a holistic HMI concept to show the possibilities of monitoring the driver's state. A particular emphasis was given to the selection and displayed the correct information about the driver's current state, while the works of Harre and Feuerstack (2018) and Borojeni (2016) were more focused on the design of HMI for platooning. They used a heuristic metric to estimate and evaluate the driver's perceptual accuracy and reaction time following a human-centred design (HCD) approach. Apart from the literature, several EU-funded projects aimed to improve user experience (UX) and acceptance of automated trucks, such as Tango (2017) and TrustVehicle (Tarkiainen, 2019).

Since an automated/autonomous system can be defined as a set of interdependent elements, namely the vehicle and the driver, interacting in a complex environment to perform dynamic driving tasks and make strategic and/or tactical decisions, the HMI should ensure the flow of information between these elements. Therefore, the HMI should have a "fluidity" feature to continuously adapt itself to the physical and mental state of the driver, as well as to the vehicle and the environment, and to ensure a safe and smooth transition. This is due to the fact that the concept of fluidity provides a "flow" in the interaction between the driver and the vehicle and introduces a data-dependent nature (Pretto, 2020). Therefore, the aim of this study is to define the design steps required to implement the *f*-HMI for Level 3+ AD long-haul heavy-duty vehicles (ADL3+) within the EU-funded Hadrian project. In this context, the rest of the paper is organized as follows. In Section 2 the methodology and the fluidity concept is given. In Section 3, the wireframe of the *f*-HMI is provided, and the fluidity approach is demonstrated. Finally, the conclusion is given in section 4.

2. Methodology

2.1. Design approach

The HCD approach is used in this work. It is based on the ISO 9241-210 (2010) and aims to make interactive systems more usable by exploiting them and applying human factors/ergonomics and usability knowledge and techniques. This approach does not assume any design process or describe activities necessary to ensure effective design. It complements existing design methodologies and provides a user-centered perspective that can be integrated into different design and development processes appropriately to the context. All the HCD activities apply (to a greater or lesser extent) at any stage in developing a system. There are three main human-centered evaluation methods; user-based testing (used for this work), inspection-based evaluation using usability and accessibility guidelines, and long-term monitoring. Moreover, to implement the fluidity concept, an iterative process is used. Iterative processes are based on a cyclical structure, where a sequence of steps is systematically repeated until predefined results are obtained. As these processes iterate inconclusively, incrementing their results can be called iterative or incremental. Scrum, LeSS, SAFe, and Spiral are some of the iterative processes. Scrum is one of the pillars in the foundation of the new Agile methodologies, and less and SAFe are different approaches for scaling Scrum in big projects. Finally, Spiral is a traditional approach, used mainly in research and development. Given their iterative nature, all mentioned processes are time-intensive, as they require several iterations until a validated product is released. On the other hand, their nature provides them with more flexibility than linear approaches. Simultaneous tasks can also be performed, which may reduce project length if properly applied. Users and stakeholders are involved in each iteration, making user acceptance more easily measurable (Bavendiek (2020)). The Spiral approach is very suitable for this work as it focuses on user satisfaction and acceptance. Although it could be costly and complex, it has higher flexibility and risk handling in contrary to other approaches. For that, it is considered more suitable to accompany the HCD approach (Amlani, 2013, and Boehm, 1988).

2.2. Proposed HMI Design steps

A systematic approach to designing an *f*-HMI for trucks mainly for critical scenarios is proposed in this section. The steps for HMI design can be seen in Fig. 1. The innovative design concept of improving an HMI design is defined as a first step. In this work, the fluidity approach is considered. Then, as a next step, the drivers' needs, and requirements are collected using surveys. Subsequently, a wireframe to describe the flow of HMI states is designed, and visual and auditory cues are integrated. A baseline of the HMI is used during this step. The baseline design is primitive design which defines the structure and elements to be shown on the HMI in general. It is usually used to compare and evaluate a new proposed HMI design. In the third step, the initial design of the HMI is generated using the requirements of the drivers and the wireframe model of the human-machine interface to initiate the iteration process. In addition, the information selected from the driver monitoring system, the vehicle and the environment are fed into the HMI design to embody the proposed fluidity concept. To improve the driving UX of truck drivers, the fourth step was to conduct several studies with +20 participating professional drivers. Drivers were presented with the *f*-HMI during critical scenarios and asked to identify valuable and essential information to be shown. The results of these studies are extracted using the HCD approach and the subjective and objective KPI results are analyzed. With each study, a new design iteration is performed to address driver expectations and requirements. Finally, a final interface is defined with visual and auditory cues to increase driver trust in the system AD.

2.3. The fluidity concept for a HMI

The fluidity characteristics enable the integration of the four functionalities to the proposed *f*-HMI. The proposed HMI will fulfill the needed connections among the human, the vehicle, and the environment through monitoring guaranteed transition control and providing correct interaction based on the vehicle, environment, and driver state relevant to the driving mode (e.g., manual, MRM). The following properties characterize the fluid interface:

- Promoting flow through i) Provide the information based on the fitness level (Fit2Drive) and balance the challenge by matching situational awareness level and the required skill level; ii) Prompt feedback to the driver immediately after the hand-over, take-over, and the end of the trip; iii) Enhanced concentration to allow a high degree of focus (e.g., audio and visual warnings).
- Supporting direct guidance through i) Physical actions instead of complex syntax; ii) Continuous representation of the road actors (e.g., traffic signs, vulnerable road users); iii) Minimizing evaluation of the vehicle's current state and driver's understanding of the state (directness); iv) Minimizing execution of the action (activation/deactivation of the autonomous driving mode through a single-step solution) for less of the drivers' cognitive resources.

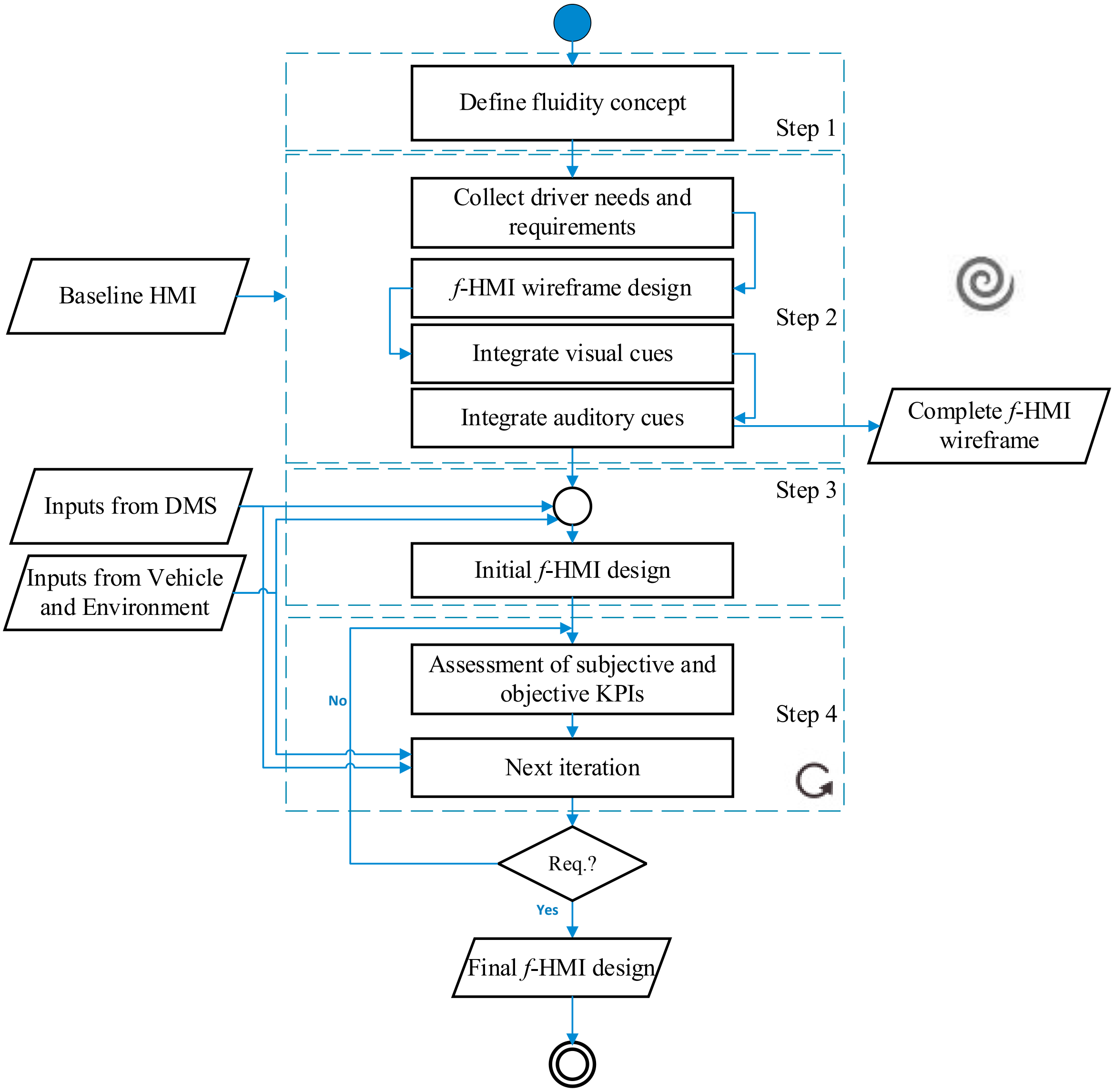

Fig. 1. Flowchart of the *f*-HMI design

Auditory cues are integrated into *f*-HMI to enhance visual and interactive aspects. Compared to visual cues, auditory cues cannot provide extensive and detailed information. However, they allow drivers to perceive information while monitoring the road. Designing fluid auditory cues helps to effectively draw drivers' attention on the visual interface and inform them directly about emergencies. An alarm sound is added to the existing audio system to adopt the fluidity concept. When urgency is high, the auditory cues are designed to be easily distinguishable from others so that drivers can recognize a situation based only on these cues. The frequency of the cues is edited to provide different levels of urgency within the same situation to increase fluidity. For example, if a situation becomes more critical and the driver does not respond appropriately, the frequency of the warning is increased. Fig. 2 shows the wireframe that describes the flow of states between the different interfaces of the proposed *f*-HMI. It contains interfaces and visual cues for each critical scenario that occurs while driving. Auditory cues are identified with a "wave" icon. It connects not only critical but also non-critical interfaces of the infotainment system. The blocks related to other critical scenarios are blurred because they are out of the scope of this paper. Since one of the critical scenarios that may occur during autonomous driving is the MRM, the following section very briefly presents the implementation of the *f*-HMI for this situation to demonstrate the fluidity concept.

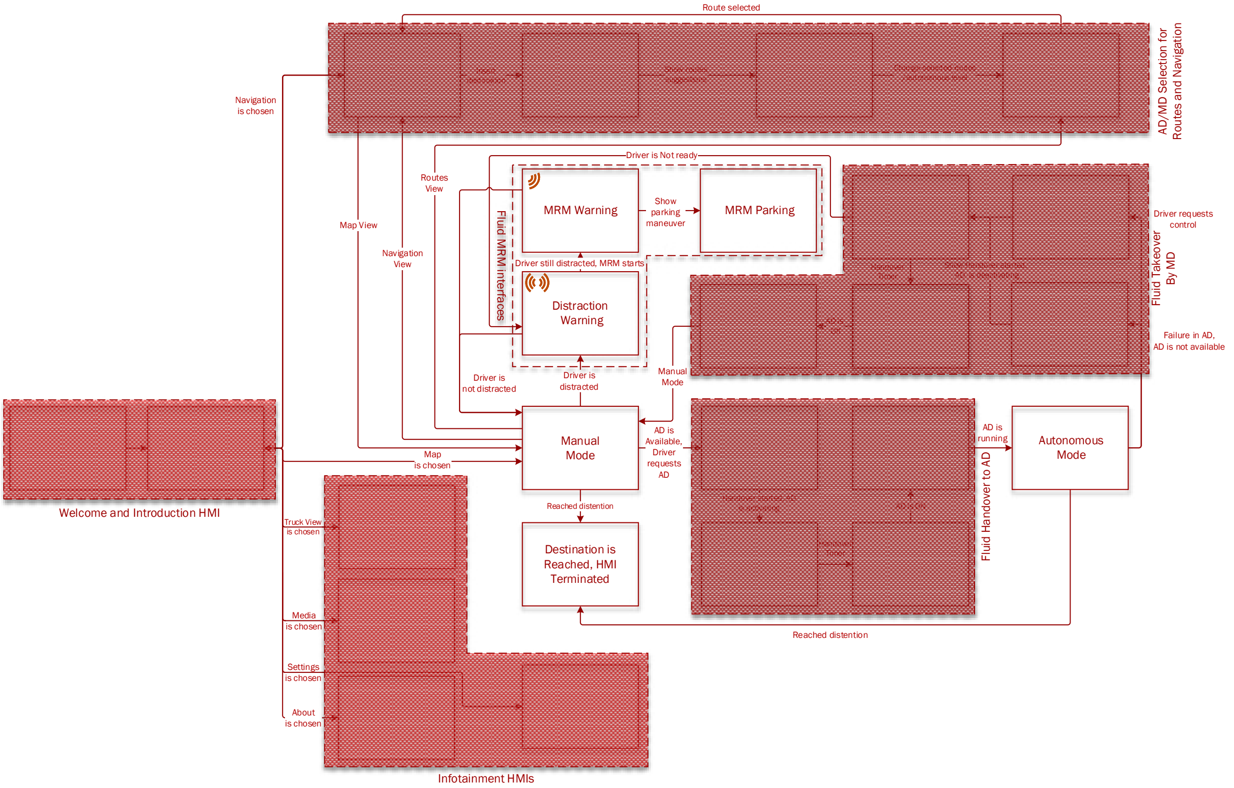

Fig. 2. *f*-HMI wireframe

3. Results

As part of gaining regulatory approval for an AD system, it must validate the ability to achieve a Minimal Risk Condition (MRC) in the event that the vehicle should no longer or can no longer complete its mission. The process of bringing the vehicle to this condition is known as the MRM. Different MRCs trigger MRM scenarios causing stops on a highway, including i) Hard shoulder, ii) Constraining area (e.g., high curve, low visibility area, tunnel, … etc.), iii) Safe area (e.g., refuge area, rest area, … etc.). An MRM scenario is used during the studies to show the *f*-HMI functionality. In particular, in case of failed Takeover condition, the MRM mode starts to bring the vehicle to stop in the nearest safe parking area. The system monitors the driver, and it detects that he/she is distracted or cannot take over the control of the vehicle as scheduled. Together with a pop-up, audio is used to warn the driver, as seen in the "Distraction Warning" block in Fig. 3. Distraction warning visual cue show the developed visual interface and the corresponding frequent emergency audio cues, respectively.

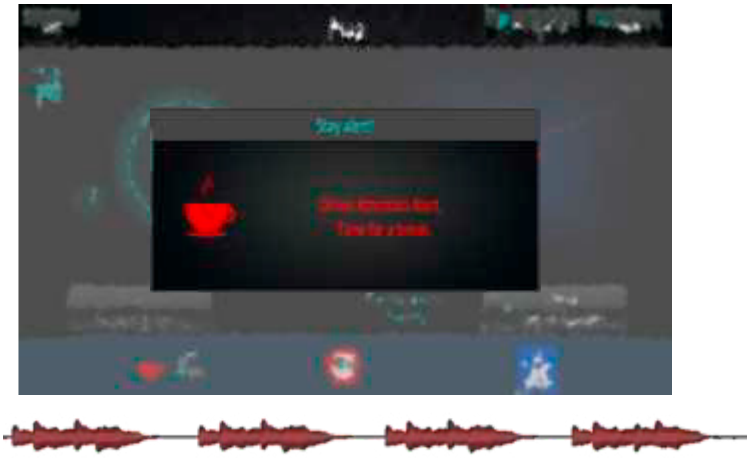
Stay Alert!

Fig. 3. Distraction warning visual cue (top); Frequency of emergency auditory cues (bottom)

If the situation persists (i.e., the driver cannot take the control), the system starts an MRM to park the vehicle in a safe area, Fig. 4 (a). In its turn, the HMI displays a pop-up on the HMI with different audio to inform the driver about the parking, Fig. 4 (b).


(a)

(b)

Controlled park is activated!

Take over is no longer possible!
System will perform a controlled parking.
Cause:
Driver is unavailable to control the vehicle

Fig. 4. (a) Critical scenario: starting an MRM to park the vehicle in a safe area; (b) MRM warning visual cue

4. Conclusion

The rapid development of AD technologies in autonomous vehicles, especially autonomous trucks, requires an accompanying interface that keeps the driver aware of the current situation and enables fluid interactions. This makes it necessary to introduce new concepts for designing innovative interfaces that take into account truck drivers' situational awareness and address their needs to improve their experience. This paper presents the fluidity concept for a multimodal (visual and auditory) human-machine interface and the associated design steps for integrating this interface following the human-centered design approach. It is important to note that auditory cues are adapted for critical situations to improve fluid interaction. The presented *f*-HMI improves driver-vehicle interaction, autonomous driving safety, and truck driver attention in critical situations.

Acknowledgments

This work has received funding from the European Union's Horizon 2020 research and innovation program for the project HADRIAN under grant agreement no. 875597.

References

Fank, J., Knies, C. and Diermeyer, F, 2021. Analysis of a Human-Machine Interface for Cooperative Truck Overtaking Maneuvers on Freeways: Increase Success Rate and Assess Driving Behavior during System Failures. Multimodal Technologies and Interaction, 5(11), pp. 69.

Blakeney, R.A., 2020. A Systematic Review of Current Adaptive Human-Machine Interface Research (Doctoral dissertation, Embry-Riddle Aeronautical University).

Krömker, H. ed., 2020. HCI in Mobility, Transport, and Automotive Systems. Automated Driving and In-Vehicle Experience Design: Second International Conference, MobiTAS 2020, Held as Part of the 22nd HCI International Conference, HCII 2020, Copenhagen, Denmark, July 19–24, 2020, Proceedings, Part I (Vol. 12212). Springer Nature.

Kim, S., van Egmond, R. and Happee, R., 2021. Effects of user interfaces on take-over performance: A Review of the Empirical Evidence. Information, 12(4), pp.162.

Mirnig, A.G., Gärtner, M., Laminger, A., Meschtscherjakov, A., Trösterer, S., Tscheligi, M., McCall, R. and McGee, F., 2017, September. Control transition interfaces in semiautonomous vehicles: A categorization framework and literature analysis. In Proceedings of the 9th international conference on automotive user interfaces and interactive vehicular applications, pp. 209-220.

Ayoub, J., Zhou, F., Bao, S. and Yang, X.J., 2019, September. From manual driving to automated driving: A review of 10 years of autoui. In Proceedings of the 11th international conference on automotive user interfaces and interactive vehicular applications, pp. 70-90.

Zhang, B., de Winter, J., Varotto, S., Happee, R. and Martens, M., 2019. Determinants of take-over time from automated driving: A meta-analysis of 129 studies. Transportation research part F: traffic psychology and behaviour, 64, pp.285-307.

Harre, M.C. and Feuerstack, S., 2018. The Konect value–a quantitative method for estimating perception time and accuracy for HMI designs. Behaviour & Information Technology, 37(9), pp.894-903.

Larsson, E. and Press, W., 2020. Exploring how Driver State Monitoring can be Utilized in Heavy-Duty Trucks: Designing a HMI Concept for 2035 with the Driver in Focus.

Harre, M.C. and Feuerstack, S., 2018, September. A Heuristic for relative Perception Accuracy and Reaction Time Estimation for HMI Designs. In Proceedings of the 36th European Conference on Cognitive Ergonomics, pp. 1-4.

Sadeghian Borojeni, S., Friedrichs, T., Heuten, W., Lüdtke, A. and Boll, S., 2016, May. Design of a human-machine interface for truck platooning. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, pp. 2285-2291.

projekt-tango-trucks: Project (2017). https://projekt-tango-trucks.com/en/. Accessed 10 May 2022

Tarkiainen, M., Kauvo, K., Penttinen, M., Sahimäki, S. and Sözen, E., 2019, June. Automated driving and HMI design for city bus and truck with professional drivers. In 13th ITS European Congress: Fulfilling ITS promises.

Pretto, P., Mörtl, P. and Neuhuber, N., 2020, July. Fluid interface concept for automated driving. In International Conference on Human-Computer Interaction, pp. 114-130. Springer, Cham.

Bavendiek J., Koch T., Sarabia J., Marcano M., 2020. D3.6 - Initial Report on the Human Systems Integration Guidelines for AD Development, Hadrian project deliverable.

EN ISO 9241-210:2010 - Ergonomics of human-system interaction - Part 210: Human-centred design for interactive systems, Obtained online: https://standards.iteh.ai/catalog/standards/cen/3a4f0948-9050-4a33-91c5-330979a5b91d/en-iso-9241-210-2010.

Amlani, R.D., 2013. Analysis and comparative study of various software development process models (Doctoral dissertation, Saurashtra University)..

Boehm, B. W. A spiral model of software development and enhancement, ISSN: 0018-9162, Volume: 21, Issue: 5, on page(s): 61-72, May 1988.