

Eckl, Anna; Mertens, Svenja; Hillenmeier, Eric; Bengler, Klaus

Article — Published Version

Potentials and challenges of adaptive human-machine interfaces in commercial vehicles: results of focus groups with professional truck drivers and experts

Zeitschrift für Arbeitswissenschaft

Suggested Citation: Eckl, Anna; Mertens, Svenja; Hillenmeier, Eric; Bengler, Klaus (2026) : Potentials and challenges of adaptive human-machine interfaces in commercial vehicles: results of focus groups with professional truck drivers and experts, Zeitschrift für Arbeitswissenschaft, ISSN 2366-4681, Springer Berlin Heidelberg, Berlin/Heidelberg, Vol. 80, Iss. 2, pp. 250-263, <https://doi.org/10.1007/s41449-026-00522-8>

This Version is available at:

<https://hdl.handle.net/10419/342028>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<http://creativecommons.org/licenses/by/4.0/deed.de>



Potentials and challenges of adaptive human-machine interfaces in commercial vehicles: results of focus groups with professional truck drivers and experts

Anna Eckl¹ · Svenja Mertens² · Eric Hillenmeier¹ · Klaus Bengler¹

Accepted: 4 March 2026 / Published online: 16 March 2026
© The Author(s) 2026

Abstract

In recent years, vehicles have become increasingly intelligent and context aware. Studies in the passenger car and digital sectors show that systems which adapt to different situations and users can improve usability and safety. To identify the potential of adaptive human-machine interfaces (HMI) in the truck sector, this work presents three exploratory focus groups conducted with truck drivers and industry experts, involving a total of $N=19$ participants. Using qualitative content analysis, problem areas were identified to be addressed through adaptive functions. These problems included individual driver needs as well as complex menu structures and challenges in navigation and logistics. The proposed solutions, such as personalization, will be examined in more detail in further research. Furthermore, the study revealed challenges associated with the implementation of adaptive interfaces in trucks, particularly patronization through technology.

Practical Relevance: Existing adaptive solutions predominantly concern passenger car and digital domains and fail to take into account the particular requirements of the commercial vehicle sector. A commercial vehicle is a complex workplace, where drivers often operate under time pressure. Therefore, these insights provide a foundation for the user-centered design of future adaptive display and control concepts in the commercial vehicle domain.

Keywords Adaptive · Human-machine interface · Commercial vehicle · Professional truck drivers

Disclaimer AI tools were used for proofreading and rephrasing.

✉ Anna Eckl
anna.eckl@tum.de

Dr. Svenja Mertens
svenja.mertens@man.eu

Eric Hillenmeier
eric.hillenmeier@tum.de

Prof. Dr. Klaus Bengler
bengler@tum.de

¹ Lehrstuhl für Ergonomie, Technische Universität München, Boltzmannstraße 15, 85748 Garching bei München, Germany

² MAN Truck & Bus SE, Dachauer Str. 667, 80995 Munich, Germany

Potenziale und Herausforderungen adaptiver Mensch-Maschine-Schnittstellen im Lkw: Ergebnisse von Fokusgruppen mit Berufskraftfahrer/-innen und Expert/-innen

Zusammenfassung

In den letzten Jahren werden Fahrzeuge stetig intelligenter. Studien im Pkw- und Digitalbereich zeigen, dass Systeme, die sich an verschiedene Situationen und Nutzende anpassen, Bedienbarkeit und Sicherheit verbessern können. Um das Potenzial solcher adaptiven Mensch-Maschine-Schnittstellen (engl. human-machine interfaces, HMI) auch im Bereich Lkw zu identifizieren, wurden in der vorliegenden Studie drei explorative Fokusgruppen mit Lkw-Fahrer:innen und Branchenexpert:innen durchgeführt ($N=19$). Mittels qualitativer Inhaltsanalyse konnten Problemfelder festgestellt werden, die durch adaptive HMI adressiert werden sollen. Darunter fallen individuelle Bedürfnisse der Fahrenden sowie komplexe Menüstrukturen und Schwierigkeiten im Bereich Navigation und Logistik. Die erarbeiteten Lösungsvorschläge, beispielsweise Personalisierung, sollen in weiterführender Forschung betrachtet werden. Weiterhin konnten Herausforderungen abgeleitet werden, die adaptive HMI im Lkw mit sich bringen, insbesondere das Gefühl von Bevormundung.

Praktische Relevanz: Bisherige Ansätze für adaptive Lösungen stammen überwiegend aus dem Pkw- und Digitalbereich und bilden die spezifischen Anforderungen im Nutzfahrzeugbereich nicht ab. Ein Nutzfahrzeug stellt einen komplexen Arbeitsplatz dar und häufig arbeiten Berufskraftfahrer/-innen unter Zeitdruck. Somit dienen die gewonnenen Erkenntnisse als Grundlage für die Gestaltung zukünftiger adaptiver Anzeige- und Bedienkonzepte im Nutzfahrzeugbereich.

Schlüsselwörter Adaptiv · Mensch-Maschine-Schnittstelle · Lkw · Berufskraftfahrer/-innen

1 Introduction

Commercial freight transport represents a key component of the transportation sector and is likely to maintain this role in the future (Hoepke and Breuer 2010). Heavy goods vehicles account for over 70% of the total freight transport performance in Germany, showing a continuous upward trend since 2004 (Federal Office for Logistics and Mobility 2025). The significant market share of trucks is attributable to the temporal flexibility, the ability to reach remote locations directly, and point-to-point transport without the need for transshipment (Statista 2025). Thereby, truck drivers operate within a complex environment (de Winter et al. 2024). The functional spectrum of a truck is much broader than in a passenger car, and experts predict a further increase in system functionalities (Hilgers 2021). This results in ergonomic challenges: The relocation of control elements to areas that are difficult to reach (Schölkopf 2023), more frequent and prolonged glances away from the road, and a missing understanding of in-vehicle information technologies (Lohre et al. 2014). These factors should be avoided in light of driver distraction (Bubb et al. 2015). Hence, innovative interaction concepts are needed in order to increase safety as well as driver comfort (Meixner et al. 2017). Adaptive systems offer new possibilities in this context (Schölkopf 2023; Hartmann 2009). An adaptive vehicle system is defined as an “interactive system within a vehicle that can proactively change its behavior and/or content triggered by certain events without intervention from the user” (International Organization for Standardization 2025). Rapid progress in the area of artificial intelligence (AI) has enabled improvements in intelligent

adaptive systems. These can adapt to user data, environmental data, and system data, such as vehicle states in an automotive context (Graefe et al. 2022). In the digital and passenger car sectors the use of such adaptive systems has already been examined and implemented. In this context, Thompson et al. (2004) showed that adaptive navigation suggestions decreased interaction time. Similar results were obtained by Köhler (2019), comparing a driver state adaptive information concept in a passenger car to a non-adaptive concept. Furthermore, the ability of adaptive intelligent systems to learn and model user preferences enables them to respond more effectively to user needs. This can significantly enhance user experience compared to less intelligent systems (Rittger et al. 2022). The results by Köhler (2019) support this argument, indicating that the adaptive system received more favorable subjective evaluations than its non-adaptive counterpart. Similarly, Kiefer et al. (2017) demonstrated that adaptive map visualization, simulating intention recognition via graphical changes, improved user satisfaction. Additionally, positive effects of adaptivity on safety-related outcomes were found, including reduced distraction (Hajek et al. 2013; Köhler 2019) and improved driving behavior (Reinmüller 2019). Motivated by promising research outcomes, several adaptive features have recently been introduced in the automotive market. For instance, the Mercedes-Benz UX multimedia system is claimed to adapt to individual driver needs and give tailored suggestions, such as displaying a phone number that is routinely called at a certain time (Mercedes-Benz Group 2025). To summarize, adaptive interfaces can enhance safety, usability, and user satisfaction and are increasingly implemented in the passenger car and digital domain.

However, a research gap exists regarding adaptive HMI solutions in trucks (Schölkopf 2023). Findings from digital and passenger car domains cannot be directly transferred, as truck cabins represent highly complex work environments (Schölkopf 2023). Drivers frequently operate under tight schedules and bear significant responsibility, such as handling heavy vehicles and hazardous goods. Physical circumstances, including the air-sprung suspension seat and reachability, further influence interaction with the HMI. In addition, truck drivers exhibit a distinct demographic profile, such as a higher average age compared to the overall working population (Federal Statistical Office of Germany 2022) and a male-dominated gender distribution (Statista 2025). These aspects underscore the necessity of truck-specific approaches to adaptive strategies. Nevertheless, research on adaptivity in trucks remains limited. Seitz (2013) evaluated a concept that suppressed notifications during complex driving situations. While drivers expressed positive attitudes, no significant workload reduction was observed. Schölkopf (2023) proposed an approach where the functional range displayed in the HMI adapts to the current work phase, resulting in higher hedonic quality and lower error rates than a comparable static version. These studies have focused on situational adaptivity. The broader applicability of adaptivity in truck environments has not yet been addressed and deployment challenges have received little attention from a truck-centered perspective. To realize the potential of adaptivity in commercial vehicles, additional application areas should be identified. This requires a systematic analysis of truck drivers' daily work challenges. At the same time, it is essential to critically examine the challenges and risks that may arise when integrating adaptive interfaces into truck environments. Hence, we conducted three semi-structured focus groups to address the following exploratory research questions (RQ):

RQ1: Which challenges do truck drivers encounter in their work routines?

RQ2: Which adaptive human-machine interface solutions are suitable for addressing these challenges?

RQ3: Which concerns need to be considered when integrating adaptive HMI concepts into truck environments?

2 Methodology

2.1 Participants

To examine the research questions from multiple perspectives, three diverse stakeholder groups were identified and included in the study: Professional truck drivers as well as industry experts specializing in Human-Machine Interfaces, particularly for trucks, and Human Factors (see Table 1 for demographic data). In accordance with the recommended focus group size of four to eight participants (Krueger and Casey 2014), the study comprised a total of $N=19$ participants. Recruitment of participants was carried out via email.

2.2 Procedure

Focus groups enable participants to expand their own thoughts through mutual exchange (Beyea and Nicoll 2000). Therefore, this method is particularly well-suited for generating ideas (Schulz 2012). Accordingly, the method was chosen to gain multifaceted insights into the exploratory research questions introduced above. The focus groups were conducted based on the methods of Krueger and Casey (2014) and were approved beforehand by the independent ethical committee for non-medical research at the Technical University of Munich (reference no. 2024-112-NM-BA, October 17, 2024). To ensure a consistent and target-oriented conversation, the moderation team used a semi-structured interview guideline as described in the following. Providing a predefined structure and set of questions, the guideline ensured that all relevant aspects would be addressed and comparable. The sequence of questions was flexible and could be adjusted according to the flow of the discussion. Additional questions were posed if new insights emerged. The guideline also included instructions for moderation, such as encouraging participants to share their perspectives, or referring to visual aids when needed. This approach enabled consistent coverage of topics while

Table 1 Participant demographics of the focus groups
Tab. 1 Demographische Zusammensetzung der Fokusgruppen

	Professional truck drivers	HMI/truck experts	Human factors experts
<i>n</i>	7	7	5
Expertise	Heavy-duty driving (short- and long-haul)	HMI development for trucks	Human factors (mobility, human-AI interaction)
Experience [years]	M = 22.5	M = 8.3	M = 4.2
Age [years]	M = 46.6	M = 36.4	M = 30
Gender	7 male	1 female, 6 male	3 female, 2 male

preserving the exploratory and interactive quality of focus groups. Each of the three focus groups was scheduled for 120 min. Participants were welcomed and provided with an overview of the data collection procedure. This was followed by the reading and acceptance of the informed consent. Next, a round of introductions was conducted. For those groups without prior knowledge of commercial vehicles, a brief introduction to the topic was provided. The first block of questions focused on the challenges of truck drivers during their daily work, with an emphasis on the HMI. This set of questions was discussed extensively with the professional drivers and briefly with the experts. Subsequently, an introduction to the topic of adaptive systems followed to ensure a consistent knowledge base. The second block of questions aimed for the discussion of potential use cases for adaptivity. This was explored in more depth with the two expert groups. The preferred use cases were identified for each group, respectively, using a dot voting method. The third set of questions covered concerns regarding the implementation of the adaptive systems discussed.

2.3 Data analysis

The focus groups were recorded using the software Audacity (Muse Group & Contributors 2025) and transcribed using Condens (Condens GmbH 2025), following the guidelines of Rädiker and Kuckartz (2019). These recommendations included, for instance, for the transcription to be completed in literal rather than in summarized form. A qualitative content analysis approach with deductively derived main categories and inductively developed subcategories was employed (Mayring and Fenzl 2019). To begin with, the coders deductively defined overarching themes based on the interview structure and research questions. The following deductive categories were considered: Challenges in truck drivers' work routines (RQ1), potential for adaptive HMI solutions to address these challenges (RQ2), and concerns regarding the integration of adaptive functions in trucks (RQ3).

Considering RQ1 and RQ3, the material was then systematically categorized within the thematic areas using inductive category formation (Mayring and Fenzl 2019) as mentioned above. Coding was conducted on the level of meaning units using the software MAXQDA (VERBI Software GmbH 2025). All material was independently double-coded by two researchers. The category system was iteratively developed and refined during the coding process and documented in a codebook within the software. After independent coding, coder agreement was reviewed and divergent coding was resolved through consensus-based discussion following the procedure proposed by Rädiker and Kuckartz (2019). Coding and category development contin-

ued until no substantially new categories emerged. For the quantitative indication of category presence, mentions were counted per coded meaning unit, i.e., per utterance. Moderators' contributions were excluded from this counting. The resulting frequencies are therefore interpreted as an indicator of the salience of a topic within the group discourse and not as a measure of its objective importance.

As the statements regarding potential adaptive HMI solutions (RQ2) were evaluated using a dot voting system during the focus groups (as described above), the evaluation consisted of a quantification by the number of dots for each suggestion. These quantitative results were subsequently complemented by qualitative statements from the discussions, allowing for a deeper understanding of the respective functionalities.

3 Results

3.1 Challenges in truck drivers' work routines

As described above, the first set of questions concerned truck drivers' challenges in their daily work routines. Seven categories resulted from the content analysis. These will be elaborated in detail below, along with their respective subcategories, presented in ascending order of mention frequency. Since the respective research question targeted professional drivers' work experience, the identified challenges are mainly grounded in drivers' accounts. Statements from the expert groups are used to complement these perspectives rather than to represent an equally weighted multi-stakeholder synthesis. Statements of participants were translated from German.

1. *Cabin design* ($n=8$; n refers to the cumulated frequency of mentions across all subcategories within the respective category)

The first category refers to the design of the driver's cab and is based on the accounts of professional drivers. The unfavorable positioning of control elements was mentioned in this context. For instance, infotainment elements such as radio control were reported as being out of reach. Furthermore, the poor readability of displays and inadequate lighting was criticized.

2. *Complex driving situations* ($n=9$)

The category of complex driving situations was introduced by the expert groups. Traffic dense road segments, such as rest areas, construction sites, merging situations, or city traffic were described as difficult to navigate:

- “When you’re driving your truck in rush-hour traffic, you already have to pay attention to so many things at once that [...] it’s easy to become overwhelmed by the situation” (P6, truck/HMI expert).
- “You’ve got cyclists, you’ve got pedestrians, and then there are just so many external factors on top of that — plus you’re handling a very large vehicle. You have a very limited field of view because the vehicle is so long, you’ve got blind spots, and so on” (P4, human factors expert).

3. Psychological stress (n=20)

In the context of psychological stress, the feeling of surveillance and patronization was mentioned with the highest frequency, mainly by the professional drivers. This concerns the patronization through assistance systems as well as the surveillance by employers. For instance, drivers are under the impression that digital systems monitor their driving performance. These doubts are illustrated by the following statements of participants:

- “These days, a truck driver is mostly just expected to sit there and steer. I know a large freight company which closely monitors how often the driver brakes, how hard the driver brakes, and so on” (P2, professional truck driver).
- “One shouldn’t impose too many restrictions on me” (P3, professional truck driver).

In contrast, the issues of boredom, monotony, and loneliness were touched upon predominantly by the expert groups. They argued that for instance during a long traffic jam or a highway drive, the driving task will become monotonous.

4. Dissatisfaction with assistance and warning systems (n=31)

Dissatisfaction with assistance and warning systems emerged as a dominant theme from the experts’ perspective. Several interrelated factors contributed to this perception. First, the experts assumed drivers exhibit an aversion to technology, rooted in greater confidence in their own driving skills. Furthermore, they expected drivers to be annoyed by warnings, such as frequent alerts, and to regard them as redundant or unnecessary. A lack of transparency regarding system behavior, for instance concerning fatigue detection, was mentioned by the expert groups. In addition, they presumed a discrepancy between regulatory restrictions and practical working routines, such as inflexible driving time regulations. The drivers focused on the limited configurability of assistance functions being

a shortcoming, for instance regarding the ability to modify warning thresholds.

5. System errors and failures (n=33)

Reports of system errors and failures were shared by both drivers and experts. This entails malfunctions of display and control units, faulty lane detection by driver assistance systems, and false activations of assistance systems. Furthermore, faulty voice recognition, reception problems with radio transmitters and the failure of electronic mirrors were stated.

6. Issues related to route planning, infrastructure, and logistics (n=33)

Furthermore, route planning, infrastructure, and logistics represent a domain with several challenges being identified. Diverse operational purposes of trucks demand a specific functional spectrum for each area of use, as mentioned by drivers and experts. Hence, in certain scenarios a range of functions, which are not needed, might be displayed:

- “Every truck is needed for different purposes. For example, one standard tractor unit might drive long-haul routes across Europe, while another, also a standard tractor unit, operates in factory transport, maybe mostly in urban areas. That means the driver will need different functions, and ideally, the system should adapt so that the functions used most frequently can be operated with minimal interaction steps compared to those that are rarely needed [...] And those were just two examples of a standard tractor unit. We also have off-road traction vehicles [...] So, a huge range of applications, and depending on the use case, different functions in the vehicle will be important for the user” (P7, truck/HMI expert).
- “You can’t lump everyone together [...] because at some point, you’ll just end up with a flashing christmas tree on the dashboard” (P2, professional truck driver).

Similarly, frequent vehicle and driver changes complicate persistence of settings. In addition, problems with integrated navigation systems prevail. The professional drivers reported that truck-specific restrictions often lead to impractical routing decisions, such as detours that significantly disrupt the time schedule. Additionally, the absence of detailed topographical information was perceived as a limitation. Another concern was the lack of real-time traffic information, which impedes efficient rerouting. Furthermore, the absence of regular map data updates compromises reliability. Due to these difficulties, many drivers resort to using a combination of the integrated navigation system and an

additional third-party navigation solution. However, this approach introduces further complications, such as the need to operate a secondary device and the absence of vehicle dimensions in third-party systems:

“Sometimes I use the map data from my iPhone. You do have to pay more attention because the built-in navigation system includes the vehicle dimensions, which you can’t enter in the phone’s navigation app” (P2, professional truck driver).

Additional concerns include erroneous traffic information via radio and fuel card acceptance. Each driver uses different fuel cards, which are not universally accepted, restricting flexibility in route planning.

7. High operational complexity of the HMI (n=53)

The complexity of the HMI operation evinced the highest mention frequency and was predominantly described by professional drivers. Figure 1 indicates the mentions across all subcategories within this category. Most statements by truck drivers referred to nested digital menu structures. Long interaction sequences within submenus were critically discussed:

“They now cram all the controls — radio, climate, everything — into one display. So, you sit there when you want to start driving and it’s swipe, swipe, swipe, where is it? Ah, there it is! [...] You’re just searching all the time” (P2, professional truck driver).

The functions in question range from comfort and entertainment features to settings for driver assistance systems and hydraulics. Both drivers and experts assumed that functions are not only difficult to find but, in some cases, entirely unfamiliar to users. Additional aspects included problems with

touch operation, a broad range of functions, and the perception that advanced technical skills are required to operate the systems. One participant described that *“you almost become a systems engineer who [...] can configure the vehicle [...] through these systems”* (P1, professional truck driver).

Furthermore, the lack of menu customization options was criticized. For instance, according to P2 (professional truck driver) it is a *“problem [that] you can’t customize the menu. You can’t say, okay, I move the system settings all the way to the back. I want radio first and then air conditioning [...]”*. Finally, the distraction caused by HMI operation was highlighted. The following discussion between two professional drivers underlines this problem, whereby it is closely related to the nested menus and the touch operation mentioned above:

- P5 (professional truck driver): *“Especially for the older generation — young people grow up with it, so I don’t see it as that much of a problem — but for the older generation it’s a disaster —”*
- P4 (professional truck driver): *“Although, of course, even with younger people, there is the factor of distraction.”*
- P5 (professional truck driver): *“The factor of distraction is always there.”*

3.2 Potential adaptive HMI solutions

The second set of questions covered the potential of adaptive HMI solutions addressing the discussed challenges. The ideas were accumulated and subsequently rated using a dot voting method, as mentioned in chapter 2. Figure 2 shows the suggestions for adaptive solutions in commercial vehicles including the score derived from the voting process for each group. These will be outlined in the following chap-

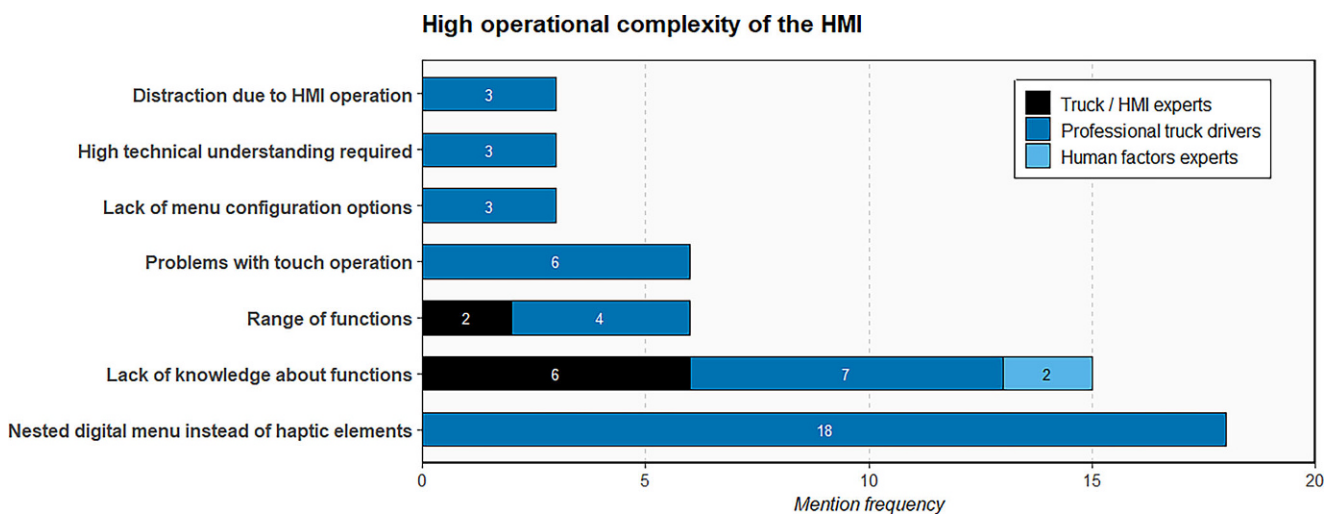


Fig. 1 Mention frequencies of the subcategories in the category “High operational complexity of the HMI”

Abb. 1 Nennungshäufigkeiten der Subkategorien in der Kategorie „Komplexität in der HMI-Bedienung“

ter, presented in ascending order of cumulative preference frequency according to the dot voting, referred to as n .

First, adaptive external camera activation was mentioned ($n=1$). P3 (truck/HMI expert) assumed that certain usage patterns regarding camera views exist. They suggested that drivers have “preferences, like in certain situations, they want specific cameras to pop up. If this can be detected, [...] these cameras can be shown in the respective situations without users having to manually select them.” According to the truck expert, an example is drivers using the backwards camera on the highway “in certain situations, such as a high traffic density. If this is learned, this can be set for this specific driver” (P3, truck/HMI expert).

Furthermore, user-adaptive behavioral suggestions were suggested by the experts ($n=1$). This could include well-being functions, such as relaxation or breathing exercises during breaks, when tiredness or stress is detected.

An additional proposal by the truck/HMI experts was a location-adaptive assistant ($n=2$). As truck drivers often operate internationally, the assistant should be capable of showing and using information about specific destination countries, such as load handling, custom duties, or road toll. This should ideally lead to “inexperienced drivers [being able to] make it to their destination without causing extra costs that might come up in other countries under certain conditions” (P1, truck/HMI expert).

Besides, adapting to the knowledge level of drivers was discussed ($n=3$). The HMI concept could offer an expert and an inexperienced mode, with the expert mode showing more complex functions. Moreover, explanations could be offered in the inexperienced mode. As suggested by P1 (truck/HMI expert), the vehicle should detect if a driver card is connected for the first time and in this case “functionalities on the display are described with an icon and a textual description. [...] When it’s clear that this vehicle is operated every day with this driver card, then at some point the text disappears.”

Other concepts mentioned by the expert groups included situational complexity reduction of the HMI in situations provoking high workload ($n=3$). According to the expert groups, less functions should be displayed in these situations.

Further ideas included tailoring the range of available functions to the specific truck type ($n=4$). Depending on the area of application, functions such as fatigue detection or certain driver assistance systems should be displayed or hidden.

The truck/HMI expert group advocated for adaptive warnings ($n=4$). P6 (truck/HMI expert) referred to drivers’ “feedback that there are too many warnings, the vehicle makes warning sounds continuously”. This could be improved by warnings that are displayed when urgent and

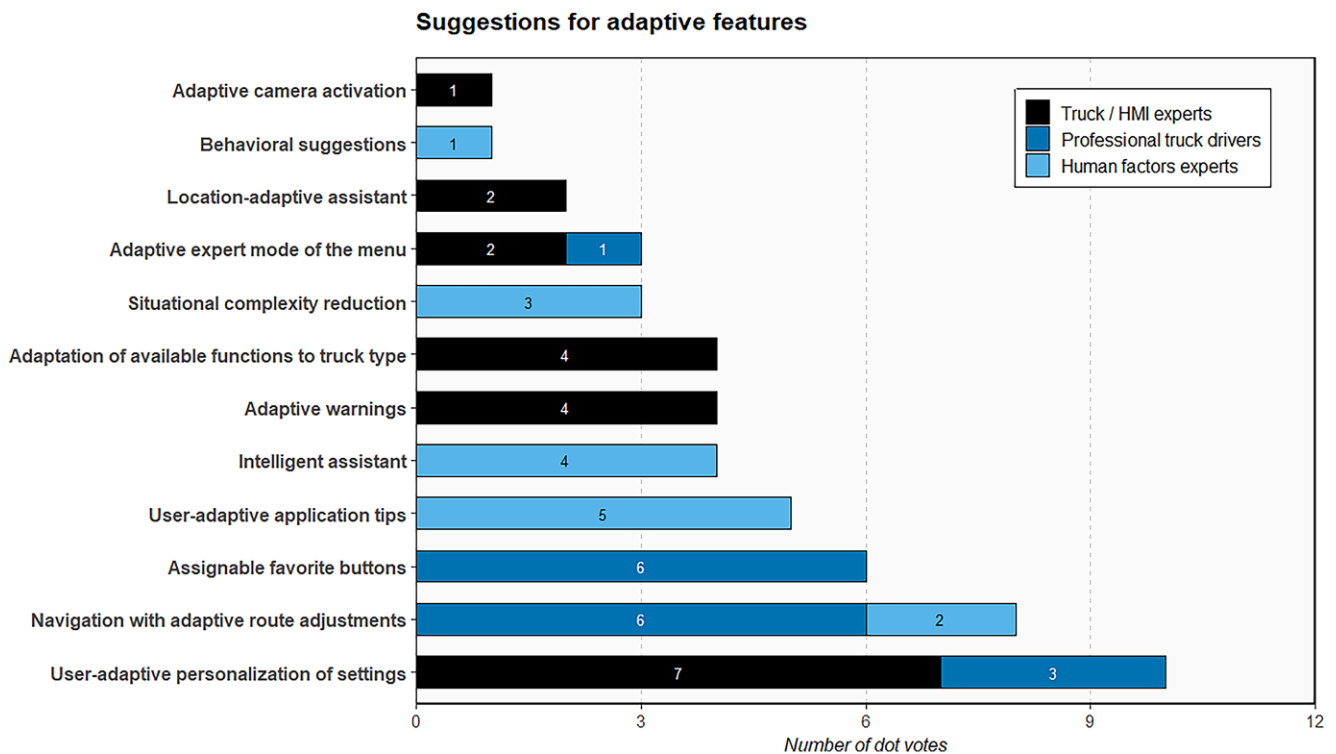


Fig. 2 Suggestions for adaptivity in commercial vehicles and frequency of expressed preferences per group

Abb. 2 Vorschläge für Adaptivität im Nutzfahrzeug und Häufigkeit geäußerter Präferenzen pro Gruppe

suppressed when not urgent. For instance, a warning that the *“driving period ends within 30min should not be displayed if the navigation destination will be reached within 15min”*. The goal should be to *“develop systems that predict whether a warning is relevant or not”* (P6, truck/HMI expert). This was confirmed by drivers.

Furthermore, an intelligent assistant based on large language models (LLM), potentially realized as an avatar, was suggested by the human factors experts ($n=4$). This assistant could be a conversation partner for entertainment or to counteract *“loneliness [...], maybe even sleepiness”* (P4, human factors expert). Furthermore, it could act as a guide and give information about the surroundings and landmarks. The experts emphasized that avatars are a major trend in the automotive sector at the moment.

Experts additionally proposed user-adaptive application tips ($n=5$). This idea aims to propose functions that are rarely or never used by the respective user. The human factors experts assumed that this could work well *“especially for trucks, [...] because there are so many different functions”* (P1, human factors expert). They recommend giving *“simple tooltips like: ‘Do you know this [function]?’”* (P1, human factors expert). This concept should also analyze *“users’ routines to identify what is not effective, and then suggest how they could improve it”* (P1, human factors expert). This could for instance apply to suggesting assistance systems such as trailer maneuvering assistance or automated parking spot search.

Among truck drivers, in contrast to the expert suggestions, there was a demand for assignable, tactile push buttons ($n=6$). These should be customizable as favorites through linkage with the driver card. This could apply for example to preferred radio channels or lighting settings:

- *“Having a certain number of customizable buttons where I can assign my preferred functions to a physical switch would be great”* (P1, professional truck driver).
- *“For example, lighting or similar settings, [...] you take half an hour once to set everything up, and then it’s done. And maybe, if possible, transferable. Because I work at a company that has ten trucks of the same type, and I drive wherever needed. It would be great if I could just plug something in and all ten trucks know my preferred settings. [...] I’d find that practical”* (P5, professional truck driver).

Adaptive navigation with route adjustments based on battery or fuel level, personal routines, driving times, and real-time traffic information received approval from both driver and expert groups ($n=8$).

The highest dot voting number was achieved by smart user-adaptive function access, mentioned by both experts

and drivers ($n=10$). This could range from rule-based adaptive behavior to self-learning systems adapting to user preferences. P5 (professional truck driver) argues it would be useful for the vehicle system to adapt to routines concerning, e.g., climate control operation. The system should *“store such preferences, for example if someone does something about 80% of the time, it could automatically adjust to my needs, the way I usually handle things”* (P5, professional truck driver). This could also apply to other functions, such as *“making a shortcut to one’s favorite playlist or shortcuts to navigation routes, if [they] always take the same route and add the navigation system for traffic information”* (P1, human factors expert).

3.3 Concerns regarding the integration of adaptive HMIs in trucks

The last block of questions referred to concerns of drivers and experts regarding the discussed adaptive HMI solutions for commercial vehicles. Four main categories were derived. These are outlined in the following. They are presented in ascending order of mention frequency.

1. Economic challenges ($n=4$)

Mainly the expert groups emphasized economic aspects, such as the cost-benefit relation. They clarified that this might be industry-specific for the truck sector: Innovations must be profitable, as the sector is not a luxury segment as it might be the case for several brands in the automotive sector. Furthermore, they pointed out the risk of image problems in the case of malfunctioning adaptive systems, whereby this topic is intertwined with legal issues:

“I could also imagine that it could easily tip in the other direction. As we said, if something is interpreted incorrectly, it could quickly become a reputational risk for [the respective truck brand]. A driver arrives late to a customer or even causes an accident and then it’s no longer ‘my fault’, but ‘[the brand] messed up’. [...] One really must ask where the boundary lies” (P1, truck/HMI expert).

2. Technical challenges ($n=26$)

Technical challenges were identified as a critical aspect, with system reliability being a major concern. The experts emphasized the necessity of evaluating which adaptations could pose safety risks in case of system errors. For instance, P3 (truck/HMI expert) suggested that *“on the one hand, it could make sense for driver assistance functions to adapt to the context, such as road type or traffic situation. On the other hand, this might be critical, since it is something safety relevant”*. Another key issue is the lack of interaction data for training personalized systems in trucks.

P1 (human factors expert) argues that it is easier to personalize certain content sharing platforms, as users interact continuously with the content, enabling the inference of interaction patterns. In contrast, the proportion of interactions with an infotainment system was argued to be comparatively small. Consequently, these patterns are significantly harder to learn. P4 (human factors expert) adds that frequent vehicle changes, as mentioned in chapter 3.1, further complicate this process. Furthermore, the complexity of handling large quantities of heterogeneous data was viewed critically. P3 (human factors expert) states that the difficulty lies in leveraging these data meaningfully, while P5 (truck/HMI expert) notes that the background processes required should not be underestimated, particularly the fusion of multiple input sources, such as sensor data.

3. Legal and ethical challenges (n=27)

The implementation of data-driven technologies in commercial vehicles introduces legal and ethical challenges. A central issue is data protection and driver privacy, particularly in a context where performance-related data might be collected and analyzed. The monitoring of work performance raises ethical concerns regarding surveillance, creating unease among professional drivers. They expressed the preference for local data processing, which reflects concerns about minimizing external data transfers and safeguarding sensitive information. Transparency in the data collection process is closely related. P2 (professional truck driver) voices the request to receive information, for instance in the user manual, *“what data does the vehicle collect from me and what does it do with my data? [...] Maybe that you somehow get the information about what data is being collected in the first place and what data is being forwarded.”* Experts raised concerns regarding non-transparent consent mechanisms in the context of algorithmic training. They argue that users often decline data collection in similar scenarios when the consequences are unclear, yet subsequently express frustration when, for instance, personalization features fail to work as expected. This tension between data-driven learning and privacy protection likewise becomes evident in the following excerpt from the focus group discussion:

- M2 (moderator): *“As long as the data ...”*
- P2 (professional truck driver): *“... stays in the vehicle.”*
- P1 (professional truck driver): *“Yes, but that’s exactly the point. [...] AI should develop. That means, you need a learning process, this means learning through information, that I [give] as a human in the vehicle.”*

4. Human factors challenges (n=47)

The integration of adaptive HMI solutions introduces several human factors challenges. One concern among ex-

perts and drivers was the loss of skills and vigilance, if an intelligent adaptive system takes over critical tasks:

- *“That could also be a problem if someone has a vehicle that’s fully adaptive and does everything for them. That works fine, until something fails or they have to switch to a vehicle that doesn’t have those features. Then we run into issues. Basically, drivers might become more dependent on the vehicle than they’d like”* (P7, truck/HMI expert).
- *“I think if we start adding systems that range from a high level of self-responsible driving to ‘now I let the vehicle take over,’ [...] the mental demand keeps getting lower, which means you could imagine that fatigue might become an issue. I read something about that before. So basically, drivers need more ways to stay mentally engaged and really alert”* (P1, professional truck driver).

Another challenge lies in the learnability of adaptive HMIs, since they are inherently inconsistent. According to the expert groups, users often show a preference for familiar HMIs and might struggle with changing interfaces. This in turn can cause distraction, especially when the behavior is unpredictable. One aspect was strongly emphasized in every group: Ensuring a high level of controllability to maintain the user’s sense of agency. The experts underline that it *“is important to give users control”* (P1, human factors expert) and that *“one definitely has to prevent the driver from feeling patronized or reprimanded, no matter how the message is delivered”* (P4, truck/HMI expert). The experts assume that otherwise users get frustrated, annoyed, or feel helpless. Claims of the professional drivers confirmed this. P3 (professional truck driver) states that drivers have to think for themselves, and that *“you can’t take everything away from the truck driver. I feel like I’m being patronized.”* Furthermore, transparency can be identified as a key issue. Particularly regarding AI-based systems, processes should be understandable to build trust in the system. This is closely related to what experts described as a low tolerance for errors in technical systems, which can quickly decrease confidence in intelligent systems. In addition, individual preferences regarding adaptivity were mentioned as a central point by drivers and experts. P4 (truck/HMI expert) points out that *“you have to find some kind of balance [...] and that balance is probably different for every user. Everyone has their own sweet spot.”* P3 (human factors expert) expounds that this range is most likely even broader in a professional context, such as commercial freight transport.

4 Discussion

4.1 Adaptive HMI solutions for future trucks

The present focus group study was conducted to identify key challenges in truck drivers' daily work that could be addressed through adaptive features, since research in this domain is limited. Our exploratory study revealed multiple challenges in the daily work routines of truck drivers. The following section discusses these challenges in relation to potential solutions, drawing on relevant literature.

First, drivers reported unfavorable positioning of control elements and poor readability of displays in the context of cabin design. This could be compounded by the high number of functions present in trucks (Schölkopf 2023), as outlined in chapter 1. Potential solutions are tailoring the HMI to the truck type or, for more precise adaptivity, to the specific user. Consequently, fewer functions would need to occupy the top levels of the digital menu. This would allow for functions that were previously removed into less accessible positions to be reintegrated into the menu.

Furthermore, complex driving situations, such as construction sites or urban traffic were highlighted by the expert groups. This aligns with research giving evidence that accidents with trucks are more fatal in urban scenarios (Khorashadi et al. 2005) and could potentially be mitigated through adaptive complexity reduction as suggested. Adaptive information management in trucks has already been identified as a promising approach (Seitz 2013) and warrants further development and empirical investigation. However, these challenges were discussed by the expert groups but were not brought up by the drivers themselves. This points to a difference between attributed task demands and drivers' actual perceived challenges, emphasizing the importance of end user involvement throughout the development process of intelligent systems.

Psychological aspects, such as monotony and loneliness, were mentioned as problems by the expert groups, as well. These have been documented in numerous studies, among other stress factors such as tight schedules (Lemke et al. 2020; Williams et al. 2017). One idea proposed by experts was to mitigate some of these aspects through an intelligent conversational assistant. However, it is questionable whether such a structural problem can be solved through HMI concepts.

Primarily experts mentioned potential dissatisfaction with assistance and warning systems, such as annoyance caused by frequent alerts. In contrast, the aspect accentuated by drivers was the limited configurability of assistance functions. This is another example for the divergence of experts' and professional drivers' assessments and illustrates the importance of involving truck drivers into the analysis and design phases of adaptive system development. The

issue of limited configurability could be counteracted by the solution that received the highest preference rating, namely user-adaptive settings.

Moreover, system errors and failures were mentioned as stress factors, for which adaptive warnings could represent a potential solution strategy. However, such issues should primarily be mitigated by improved system reliability, rather than by relying on adaptive mechanisms as compensatory measures.

Issues related to route planning, infrastructure, and logistics emerged as central topics. In this context, the diverse operational purposes of trucks must be considered. Therefore, adapting the available feature set to the specific truck type was suggested as a way to address the diversity of trucks. Research in the agricultural sector has explored how control elements and displays can adapt to the current use of a tractor (Racs et al. 2022). A similar solution for different truck types or trailers appears conceivable. Furthermore, changes in the traffic situation can represent acute stress factors, particularly when drivers lack real-time traffic information and face truck-specific constraints such as delivery schedules or freight weight. Caspersen et al. (2023), who examined the consequences of capacity reduction on urban main roads, found that truck drivers "had limited options and less flexibility than other road users. The main effects were increased travel time and reduced traffic predictability. Some drivers reported consequences such as more stress and less predictable workdays" (Caspersen et al. 2023). These results underline truck drivers' difficulties related to navigation and logistics and show the potential of smart, adaptive navigation features. These could dynamically adjust route guidance based on up-to-date traffic information, delivery priorities, and personal routines to lower workload. As described in chapter 1, this is supported by research giving evidence for the positive effects of adaptive navigation features in other usage domains (Thompson et al. 2004).

Finally, the complexity of the HMI operation emerged as a focal point. This topic was repeatedly raised and showed the highest mention frequency. It has also been previously discussed in literature (Schölkopf 2023). Through the focus groups, we were able to specify which aspects underlie this broad concept. According to drivers, complexity in this context comprises three dimensions: A nested menu structure, an extensive range of functions, and significant technical demands for operation. This leads to distraction and frustration. As a possible solution, participants expressed a desire for storing personalized settings and for freely assignable favorite buttons to simplify menu structures and prioritize functions. Additionally, tactile switches would reduce technical demands. Adaptive, self-learning personalization was proposed as a more intelligent form of system personalization. Such systems could learn driver routines,

such as frequently used navigation routes, or assistance systems preferred in specific situations, and dynamically adjust the interface based on these recurring patterns. This would reduce manual input requirements. Notably, while drivers tended to favor the adaptable version, experts advocated for the more intelligent, self-learning personalization approach. This may reflect the fact that drivers focused on familiar customization features such as smartphone settings because they have limited experience regarding adaptive system behavior.

4.2 Integration-related concerns

The introduced adaptive HMI solutions entail several challenges regarding their practical implementation. The following section therefore discusses integration-related issues identified in the focus group results. According to the experts, the cost–benefit relation is particularly critical in the truck sector, where financial investments must be clearly justified by operational advantages. As Chen et al. (2024) note, “personalization services [...] are complex industrial products that face numerous challenges when implemented in real-world scenarios”. Among these, high computational demands represent a significant resource cost factor (Chen et al. 2024), which may limit the feasibility of implementing such systems.

This, in turn, raises technical considerations. In this context, system reliability was discussed critically, particularly in relation to the limited availability of interaction data. A lack of sufficient user data can compromise the accuracy and stability of adaptive functions. As stated by Alvarez-Cortes et al. (2007), the key challenge lies in “the number of training cases needed to generate an accurate model of user preferences.” As interaction time is limited, particularly in a driving context, “induction methods that achieve high accuracy from small training sets” (Alvarez-Cortes et al. 2007) are required.

Legal and ethical challenges were also raised, particularly concerning data protection. Participants emphasized that adaptive systems depend on continuous data collection, which can create tensions between data-driven learning and privacy, as outlined in chapter 3.3. This issue becomes especially relevant in the context of personalization, where personal rather than contextual data must be collected. Similar concerns have been highlighted in previous research on personalization in other domains. For instance, Wu and Xu (2023) state that a “higher level of personalization tends to worsen privacy concerns”, attributing this to users’ “anxiety about misuse or abuse of their personal information” (Wu and Xu 2023). Consequently, an introduction of personalized interfaces in the truck sector requires resources to address emerging legal and ethical questions.

These topics are closely related to human factors concerns, which were mentioned most frequently. Learnability can be impaired, since adaptive systems inherently exhibit inconsistency due to their dynamic behavior (Amer-shi et al. 2019) and may thereby increase distraction. This risk could be exacerbated for truck drivers due to their demographic profile. Participants in the present study noted that digitalization tends to be particularly challenging for older drivers (see chapter 3.1). Similar patterns have been observed in the passenger car context, where older drivers showed longer task completion times, slower reactions, and higher cognitive workload when interacting with advanced IVIS (Cooper et al. 2020). The authors concluded that “older drivers stand to benefit the most from advancements in in-vehicle technology, but ironically may struggle the most to use them” (Cooper et al. 2020). According to them, “the results document significant age-related costs in the potential for distraction from IVIS interactions on the road” (Cooper et al. 2020). Furthermore, intelligent functions risk being perceived as paternalistic when decisions are made on behalf of the user (Pätzold 2021), underscoring the importance of maintaining controllability. This concern may carry greater weight for professional truck drivers, who perceive proactive adaptivity as undermining their expertise or professional autonomy (see chapter 3.3).

4.3 Practical and theoretical implications

To summarize, the findings indicate that many of the identified challenges in truck drivers’ work routines are interrelated and tend to reinforce one another. For instance, complex menu structures become particularly problematic in conjunction with frequent vehicle changes, high logistical demands, or complex driving situations. In such situations, difficulties in locating a required function can critically increase cognitive demands and divert attention from the primary driving task. This interconnectedness highlights the potential of adaptive systems, which can simultaneously address multiple issues through responsive adjustments. In particular, personalization emerges as a key principle that aligns system behavior with individual driver needs. Both adaptable and adaptive personalization approaches were discussed. However, contextual factors such as real-time traffic data or changes in daily logistics planning call for a dynamic personalization approach that extends beyond static user adaptation. Combining different adaptive strategies, such as adaptive navigation features and personalized interface adaptivity, could further enhance driver efficiency and satisfaction.

Several challenges have to be addressed when integrating such systems into trucks. Conducting user studies is crucial to prevent additional distraction and to identify ways to mitigate privacy and paternalism concerns. In addition,

sufficient resources must be allocated to ensure technical feasibility and to address the associated legal and ethical issues. If these aspects are adequately considered, adaptive personalization carries the potential to advance truck HMIs toward meeting the dynamic and demanding nature of professional heavy-duty driving.

5 Limitations and future work

This study is subject to certain limitations. First, the sample size was relatively small ($N = 19$) and male-dominated, particularly within the driver group. Although the sample included both long-haul and short-haul drivers, it did not represent foreign drivers. The sample size was based on established recommendations for focus group research (Krueger and Casey 2014) and reflects the gender distribution of truck drivers, with only 2.3% female truckers (Statista 2025). While this approach provides in-depth insights, the generalizability of the findings is limited. Recruitment partly relied on email networks, which may have introduced a sampling bias toward participants who are more open towards innovative topics. Future work should evaluate HMI concepts with a larger and more diverse sample of professional drivers. Furthermore, organizational actors in the transport context, such as dispatchers or fleet management, were not included. Future research should therefore adopt a more holistic socio-technical perspective by integrating additional stakeholder groups.

The focus group discussions were potentially influenced by group dynamics. Hence, the possibility of dominant or one-sided opinions shaping the outcome must be considered in the interpretation of the results. Additionally, participants rated concept ideas through a dot-voting procedure without exposure to actual interface representations. As noted above, drivers may have favored adaptable over self-learning personalization because they cannot yet envision such concepts. These aspects further underline the importance of evaluating the generated ideas in more extensive concept studies. Furthermore, the introductory explanation of adaptive systems prior to the discussions may have caused priming effects. This step was considered necessary to establish a common understanding. Future studies could address this methodical issue by comparing conditions with and without prior conceptual clarification.

Nevertheless, the study provides valuable insights for adaptive truck HMI research, for which results cannot be directly inferred from passenger car research. The focus group study's findings form a foundation for subsequent studies. The next steps should involve evaluating personalized adaptivity in comprehensive simulator or real vehicle studies, allowing drivers to experience personalization. Different adaptive strategies should be combined to examine

whether they can enhance efficiency and comfort while reducing distraction as hypothesized.

6 Conclusion

A research gap exists concerning adaptive HMIs in trucks, despite their potential to address domain-specific challenges. While adaptive systems have proven beneficial in passenger cars, their application in commercial vehicles presents unique opportunities and challenges, since trucks involve distinct operational demands. To the best of our knowledge, no prior study has examined truck drivers' work routines in relation to the integration of adaptive HMIs, nor has research addressed truck-specific challenges associated with such systems. The present focus group study contributes to filling this gap by identifying challenges in truck drivers' work routines that could be mitigated by adaptive features. Participants highlighted several problematic aspects, such as the unfavorable positioning of control elements, limited configurability of assistance systems, issues related to route planning and logistics, and the overall complexity of interaction sequences. In these areas, adaptive personalized HMI solutions could offer meaningful support by reducing the number of required manual inputs and aligning with individual drivers' needs. At the same time, results show concerns about loss of control, perceived patronization, and data privacy, highlighting the need for user-centered design choices. Adaptivity in trucks must balance intelligent assistance with driver autonomy, ensuring transparency and controllability. Future research should explore personalization features for truck-specific functions, such as route planning and logistics.

Supplementary Information The online version of this article (<https://doi.org/10.1007/s41449-026-00522-8>) contains supplementary material, which is available to authorized users.

Acknowledgements Special thanks go to Christiane Wölfel and Jan Haentjes for the valuable input.

Funding This research was funded by the Federal Ministry for Economic Affairs and Energy as part of the SALSA project (19A24002C).

Funding Open Access funding enabled and organized by Projekt DEAL.

Declarations

Conflict of interest A. Eckl, S. Mertens, E. Hillenmeier and K. Bengler declare that they have no competing interests.

Ethical standards The focus group study was approved beforehand by the independent ethical committee for non-medical research at the Technical University of Munich (reference no. 2024-112-NM-BA, October 17, 2024).

Open Access Dieser Artikel wird unter der Creative Commons Namensnennung 4.0 International Lizenz veröffentlicht, welche die Nutzung, Vervielfältigung, Bearbeitung, Verbreitung und Wiedergabe in jeglichem Medium und Format erlaubt, sofern Sie den/die ursprünglichen Autor(en) und die Quelle ordnungsgemäß nennen, einen Link zur Creative Commons Lizenz beifügen und angeben, ob Änderungen vorgenommen wurden. Die in diesem Artikel enthaltenen Bilder und sonstiges Drittmaterial unterliegen ebenfalls der genannten Creative Commons Lizenz, sofern sich aus der Abbildungslegende nichts anderes ergibt. Sofern das betreffende Material nicht unter der genannten Creative Commons Lizenz steht und die betreffende Handlung nicht nach gesetzlichen Vorschriften erlaubt ist, ist für die oben aufgeführten Weiterverwendungen des Materials die Einwilligung des jeweiligen Rechteinhabers einzuholen. Weitere Details zur Lizenz entnehmen Sie bitte der Lizenzinformation auf <http://creativecommons.org/licenses/by/4.0/deed.de>.

References

- Alvarez-Cortes V, Zayas-Perez BE, Zarate-Silva VH, Ramirez Uresti JA (2007) Current trends in adaptive user interfaces: challenges and applications. In: Electronics, Robotics and Automotive Mechanics Conference CERMA 2007, Cuernavaca, 9/25/2007–9/28/2007. Los Alamitos, pp 312–317 <https://doi.org/10.1109/CERMA.2007.4367705>
- Amershi S, Weld D, Vorvoreanu M, Fournay A, Nushi B, Collisson P et al Guidelines for human-AI interaction. In: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems <https://doi.org/10.1145/3290605.3300233>
- Beyea SC, Nicoll LH (2000) Learn more using focus groups. AORN J 71(4):897–900. [https://doi.org/10.1016/s0001-2092\(06\)62276-x](https://doi.org/10.1016/s0001-2092(06)62276-x)
- Bubb H, Bengler K, Grünen RE, Vollrath M (2015) Automobilergonomie. Springer Vieweg, Wiesbaden
- Caspersen E, Ørving T, Tennøy A (2023) Capacity reduction on urban main roads: how truck drivers adapted, and what effects and consequences they experienced. Transport Policy 130:68–83. <https://doi.org/10.1016/j.tranpol.2022.10.016>
- Chen J, Liu Z, Huang X, Wu C, Liu Q, Jiang G et al (2024) When large language models meet personalization: perspectives of challenges and opportunities. World Wide Web 27(4):1–45. <https://doi.org/10.1007/s11280-024-01276-1>
- Condens (2025) All your customer insights in one place. <https://condens.io/>. Accessed 10 Jan 2025
- Cooper JM, Wheatley CL, McCarty MM, Motzkus CJ, Lopes CL, Erickson GG et al (2020) Age-related differences in the cognitive, visual, and temporal demands of in-vehicle information systems. Front Psychol 11:1154. <https://doi.org/10.3389/fpsyg.2020.01154>
- Federal Office for Logistics and Mobility (2025) Gleitende Mittelfristprognose - Winter 2024/2025. https://www.bmv.de/SharedDocs/DE/Anlage/G/gleitende-mittelfristprognose-winter-2024-2025.pdf?__blob=publicationFile. Accessed 10 Nov 2025
- Federal Statistical Office of Germany (2022) Lkw-Verkehr: Ein Drittel aller Berufskraftfahrer und -fahrerinnen ist 55 und älter. https://www.destatis.de/DE/Presse/Pressemitteilungen/2022/05/PD22_N023_13.html. Accessed 10 Nov 2025
- Graefe J, Engelhardt D, Rittger L, Bengler K (2022) How well does the algorithm know me? In: Soares MM, Rosenzweig E, Marcus A (eds) International Conference on Human-Computer Interaction, 1st edn. Springer, Cham, pp 311–336 https://doi.org/10.1007/978-3-031-05906-3_24
- Hajek W, Gaponova I, Fleischer KH, Krems J (2013) Workload-adaptive cruise control—A new generation of advanced driver assistance systems. Transp Res Part F Traffic Psychol Behav 20:108–120. <https://doi.org/10.1016/j.trf.2013.06.001>
- Hartmann M (2009) Challenges in developing user-adaptive intelligent user interfaces. In: 17th Workshop on Adaptivity and User Modeling in Interactive Systems Darmstadt
- Hilgers M (2021) The driver's cab: commercial vehicle technology, 2nd edn. Springer, Berlin
- Hoepke E, Breuer S (eds) (2010) Nutzfahrzeugtechnik: Grundlagen, Systeme, Komponenten, 6th edn. Springer, Wiesbaden
- International Organization for Standardization (2025) ISO/PAS 8235. <https://www.iso.org/standard/83080.html>. Accessed 15 July 2024
- Khorashadi A, Niemeier D, Shankar V, Mannering F (2005) Differences in rural and urban driver-injury severities in accidents involving large-trucks: an exploratory analysis. Accid Anal Prev 37(5):910–921. <https://doi.org/10.1016/j.aap.2005.04.009>
- Kiefer P, Giannopoulos I, Athanasios Anagnostopoulos V, Schöning J, Raubal M (2017) Controllability matters: the user experience of adaptive maps. Geoinformatica 21(3):619–641. <https://doi.org/10.1007/s10707-016-0282-x>
- Köhler L (2019) Adaptives Informationskonzept für beanspruchende urbane Fahrsituationen. Cuvillier, München (Dissertation)
- Krueger RA, Casey MA (2014) Focus groups: a practical guide for applied research, 5th edn. SAGE
- Lemke MK, Apostolopoulos Y, Sönmez S (2020) A novel COVID-19 based truck driver syndemic? Implications for public health, safety, and vital supply chains. Am J Ind Med 63(8):659–662. <https://doi.org/10.1002/ajim.23138>
- Lohre D, Bernecker T, Stock W, Düsseldorf K (2014) ZF-Zukunftsstudie Fernfahrer 2.0. Der Mensch im Transport-und Logistikmarkt.
- Mayring P, Fenzl T (2019) Qualitative Inhaltsanalyse. In: Baur N, Blasius J (eds) Handbuch Methoden der empirischen Sozialforschung, 2nd edn. Springer VS, Wiesbaden, pp 633–648 https://doi.org/10.1007/978-3-658-21308-4_42
- Meixner G, Häcker C, Decker B, Gerlach S, Hess A, Holl K et al (2017) Retrospective and future automotive Infotainment systems—100 years of user interface evolution. In: Meixner G, Müller C (eds) Automotive user interfaces: creating interactive experiences in the car. Springer, Cham, pp 3–53 https://doi.org/10.1007/978-3-319-49448-7_1
- Mercedes-Benz Group (2025) MBUX Multimediasystem. <https://www.mercedes-benz.de/passengercars/technology/mbux.html?srsltid=AfmBOop7dvD979H11V6Yzg5w6Mg-H7ciafUfVrEPtlzygRYIPmrrL-8d>. Accessed 10 Nov 2025
- Muse Group & Contributors (2025) Audacity | Free Audio editor, recorder, music making and more. <https://www.audacityteam.org/>. Accessed 10 Nov 2025
- Pätzold A (2021) Adaptive human machine interfaces in a vehicle cockpit: indication, impacts and implications. Technische Universität Chemnitz (Dissertation)
- Racs M, Kaufmann A, Meiners A, Maier T (2022) aISA 2.0—Adaptive Interfacesysteme in Ackerschleppern 2.0. Leibniz-Institut für Agrartechnik und Bioökonomie e. V., Potsdam, pp 91–101
- Rädiker S, Kuckartz U (2019) Analyse qualitativer Daten mit MAXQDA: Text, Audio und Video. Springer VS, Wiesbaden
- Reinmüller K (2019) Towards the adaptation of warning driver assistance: behavioral effects and implications. Katholische Universität Eichstätt-Ingolstadt (Dissertation)
- Rittger L, Engelhardt D, Schwartz R (2022) Adaptive user experience in the car—levels of Adaptivity and adaptive HMI design. IEEE Trans Intell Transp Syst 23(5):4866–4876. <https://doi.org/10.1109/tits.2021.3124990>
- Schölkopf L (2023) Entwicklung und Evaluation einer adaptiven Mensch-Maschine-Schnittstelle für Nutzfahrzeuge. Technische Universität München (Dissertation)
- Schulz M (2012) Quick and easy!/? Fokusgruppen in der angewandten Sozialwissenschaft. In: Schulz M, Mack B, Renn O (eds) Fokusgruppen in der empirischen Sozialwissenschaft: Von der Konzep-

- tion bis zur Auswertung. Springer VS, Wiesbaden, pp 9–22 https://doi.org/10.1007/978-3-531-19397-7_1
- Seitz M (2013) Informationsmanagement im Nutzfahrzeug. Technische Universität München (Dissertation)
- Statista (2025) Straßengüterverkehr in Deutschland – Statistiken und Fakten. <https://de.statista.com/themen/1171/strassengueterverkehr/#topicOverview>. Accessed 10 Nov 2025
- Thompson CA, Goker MH, Langley P (2004) A personalized system for conversational recommendations. *jair* 21:393–428. <https://doi.org/10.1613/jair.1318>
- VERBI Software (2025) MAXQDA | Die #1 Software für Qualitative & Mixed-Methods-Forschung. <https://www.maxqda.com/de/>. Accessed 10 Jan 2025
- Williams DF, Thomas SP, Liao-Troth S (2017) The truck driver experience: identifying psychological stressors from the voice of the driver. *Transportation Journal* 56(1):54–76. <https://doi.org/10.5325/transportationj.56.1.0054>
- de Winter J, Driessen T, Dodou D, Cannoo A (2024) Exploring the challenges faced by Dutch truck drivers in the era of technological advancement. *Front Public Health*. <https://doi.org/10.3389/fpubh.2024.1352979>
- Wu G, Xu L (2023) Demystifying the privacy-personalization paradox: the mediating role of online trust in websites/apps with personalized ads and attitude towards Online personalized advertising. In: Degen H, Ntoa S, Moallem A (eds) *International Conference on Human-Computer Interaction*, 1st edn. Springer, Cham, pp 480–491 https://doi.org/10.1007/978-3-031-48057-7_30

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.