Development and qualitative evaluation of new concepts to promote level-compliant driver behavior in automated driving.

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Abstract. Within the BMWK [1]-funded project KARLI, an HMI system for automated driving is developed to ensure level-compliant driver behavior considering SAE Levels 0 - 4 [2]. The goal of KARLI is to develop a new, holistic system that ensures safe driving by the user-centered, iterative development process. Design Thinking methods were used to develop ideas and concepts for the holistic promotion of level-compliant driver behavior. The ideas were elaborated into concepts (e.g. learning systems, gamification, trust calibration) and presented as low-fidelity prototypes in the form of user narratives. These are text-based scenarios in which the concepts are made tangible for the user. The aim of the qualitative study is to evaluate the concepts developed to promote level-compliant driver behavior in terms of acceptance and potential for further development. By the user narratives the concepts were evaluated in a user study. Twelve guided individual interviews (*M* = 74 minutes) were conducted. The sample covers different groups of people with their specific needs. The analysis was based on the qualitative content analysis [3]. The results show, among other things, mixed preferences. Based on the results, a combined system of a learning system with gamification/classic intervention or trust calibration/classic intervention and an emergency stop is recommended. This paper provides insights into the user-centered approach of the KARLI research project and reports on the key findings of the qualitative evaluation study. Based on the key findings, a recommendation and an outlook for ongoing user-centered development will be provided.

Keywords: automated driving, level-compliant driver behavior, User-Centered Development

1 Introduction

This article describes the procedure and outcome of the user-centered development process, with the goal of encouraging level-compliant driver behavior in automated vehicles. The findings include recommendations for the future development of the concepts and provide insights into the ongoing user-centered research process.

1.1 Research Project KARLI

This contribution stems from the publicly funded collaborative project KARLI (Artificial Intelligence for Adaptive, Responsive and Level-Compliant Interaction in the vehicles of the future), which is supported by the Federal Ministry for Economic Affairs and Climate Action (BMWK) [1]. In KARLI, customer-relevant AI functions are developed to detect driver states and shape interactions for different levels of automation. KARLI assumes that vehicles capable of multiple SAE levels of automation [2] will not be market-ready unless the level-specific requirements for occupants and drivers are explicitly represented in the HMI (Human-Machine Interactions). The resulting goal is to "define, recognize, and promote level-compliant driver behavior," explicitly considering multiple available automation levels from SAE 0-4 [2]. At the end of the project, the KARLI applications will be demonstrated in four vehicles.

The project involves several partners, including Continental Automotive GmbH, Ford-Werke GmbH, Audi AG, paragon semvox GmbH, TWT GmbH Science & Innovation, INVENSITY GmbH, studio-kurbos GmbH, Allround Team GmbH, Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., the University of Stuttgart, and the Stuttgart Media University.

1.2 Scientific Background

Level-compliant driver behavior means that the driver behaves according to the SAE [2] rules for that level. Each level has different requirements. Misuse can be divided into two groups. Intentional and unintentional misuse. Intentional misuse is defined as the intentional, improper, and potentially unsafe use of the automated system [4]. Intentional misuse of automated systems includes both violations of regulatory requirements and the deliberate use of automated systems beyond the manufacturer's intended purpose. There are several reasons for intentional misuse. Studies investigating misuse from level zero to level two have identified various personality traits and demographic groups [5 - 7] that are associated with misuse. One example would be young male drivers who misjudge the risk of non-level compliant driver behavior [8]. Another cause of automation misuse is considered to be overtrust (e.g. tesla accident, [9].

Unintentional misuse is an unconscious inappropriate and potentially unsafe use of the automated system. Such as the confusion of different automated systems [10]. Non-intentional misuse can be caused by a lack of knowledge, for example due to incorrect mental models. Mental models are individual ideas (cognitive structures) that generally represent systems and how they work. They are unstable, incomplete, inaccurate, and influenced by the subjective background (e.g. level of education, cultural background) of each individual [11].

There are different approaches to counteract intentional and unintentional misuse. In the case of a commercial driving system based on prohibitions or punitive behavior, rejection may lead to a reaction with contrary behavior (reactance) [12]. In the case of unintentional misuse, the driver may not understand what he or she has done wrong. As an alternative intervention measure against misuse, motivational measures in the form of gamification, have already been successfully applied in manual vehicles [6]. Concepts have been developed in which intrinsic motivation is specifically promoted by involving different types of players [13]. While extrinsic motivation attempts to motivate through external incentives, i.e. the consequences of behavior (e.g. monetary benefits), intrinsic motivation is achieved through incentives in the activity itself (promoting enjoyment of the action) [14]. To reduce the risk of abuse among particularly vulnerable groups, one could start directly with the needs (e.g. high need for stimulation, susceptibility to boredom) [6]. Another approach could be a strategy against overtrust. To prevent the driver from abusing the system due to overtrust, the system could report the system limitations to the driver [15]. Individual feedback on driving behavior based on driver-monitoring could be used. This strategy is recommended for preventive avoidance of speeding [16].

To avoid unintentional misuse, a learning system approach could be helpful. Users could be taught the system limits before they start driving, for example in the form of a tutorial system [10].

1.3 User-centered development process

The Stuttgart Media University (HdM) pursued a user-centered development process, following DIN EN ISO 9241-210:2020-03 [17] (see Fig. 1). The process consists of several phases, which are explained in detail below.

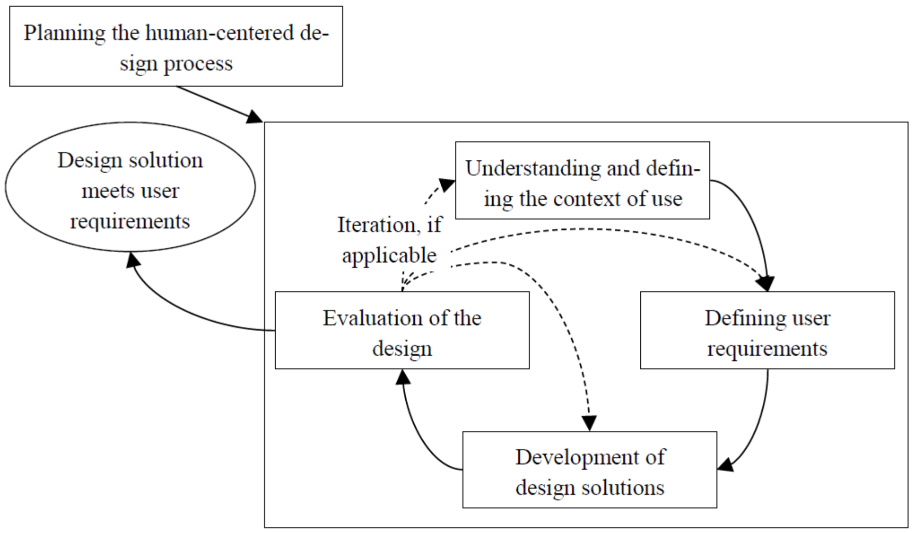

Fig. 1. User-centered development process of DIN EN ISO 9241-210:2020-03 [17]

Based on the planning phase (*Planning the human-centered design process*), in which the project objective and the procedure were designed, the requirements and needs for automated driving in the SAE levels were empirically investigated from the user's perspective in the phase, *Understanding and defining the context of use*. The HdM conducted a literature review. To verify one of the findings, the authors conducted a study in a driving simulator. In the next phase, *Defining user requirements*, the project consortium firstly compiled all findings on user requirements, then extracted key learnings, and derived opportunity areas (challenges identified as relevant for User Experience) with the help of a synthesis workshop. The opportunity areas derived and described in detail were system trust, learning phases, motivation, comprehensibility, transparency and individualization. In the subsequent phase, *Development of design solutions*, the authors generated ideas and initial prototypes for promoting level-compliant driver behavior based on the opportunity areas identified. This was done in a Design Thinking workshop where various alternative concept ideas were developed and concretized in the form of simple low-fidelity prototypes[1]. Using this opportunity areas, the authors created three user narratives[2]. In the current phase, *Evaluation of the design*, the user narratives were evaluated in an initial iteration with users (first evaluation in the iterative user centered process). The purpose of this early evaluation is to – before investing a lot of ressouces into the development of solutions - obtain a first user feedback on innovation ideas and concept concretizations, and to identify design tips for their further development.

1.4 Subject of the evaluation

The subject of the evaluation are the three user narratives that were created with a total of 40 integrated innovative ideas from the user-centered development process. The user narratives describe an example journey in an automated vehicle. Each user narrative follows the same story: two colleagues, Lisa and Matthias, are driving home from a conference in an automated car (ranging from level zero to level four). The car belongs to Matthias and Lisa tests it in levels two to four, despite never having driven an automated car before. Later, Matthias takes over driving. In the course of the story, Matthias does not behave in compliance with his level when he drops from level three to two. The most important concepts are described below.

User Narrative 1 includes a *tutorial for the first use*. During this tutorial, the driver is given a practice drive to learn about all the functions of the automated vehicle and their respective role as a driver. The levels are unlocked after the driver confirms their understanding. Following this, there is a *trust calibration* to inform the driver about the susceptibility of the automated system to errors. The car indicates the traffic conditions it detects and how it evaluates them ("It's raining, I can no longer guarantee the distance due to poor visibility, and you as the driver must focus your attention on the traffic").

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[1] Low-fidelity prototypes are concrete representations of ideas or concepts using simple means to enhance their comprehensibility and ease of experience. These prototypes can take the form of user narratives, sketches, or cardboard models.

[2] User narratives are a type of text-based scenario that describe innovative concepts in story form, depicting the use of a product or system as an action episode from the user's perspective.

Additionally, the driver can create a *user profile* to record their preferences and restrictions.

User Narrative 2 describes an *integrated learning system* that can be activated or deactivated as needed. The system provides explanations of all functions during normal driving and reduces the amount of information provided as the driver gains experience. In addition, the car features a *gamification concept* that rewards level-compliant driver behavior tailored to the driver. The vehicle's artificial intelligence communicates through a graphically implemented *avatar*, which can be configured by the driver.

User Narrative 3 includes the *classical intervention*, which warns the driver of non level-compliant driver behaviour and ultimately performs an emergency stop if necessary.

The aim of the qualitative study is to evaluate the concepts developed to promote level-compliant driver behavior in terms of acceptance and potential for further development.

2 Methods

2.1 Procedure of the qualitative interviews

The interviews for the evaluation of the concepts in the user narratives were conducted by an interviewer and a note-taker. During the interviews, the concepts presented as three different user narratives were qualitatively evaluated regarding user experience, promotion of level-compliant driver behavior and social implications of autonomous driving. The interviews were conducted in the following steps:

1. Thematic introduction: The SAE levels of automated driving [1] were provided to establish a common understanding.
2. Individual reading: The participants read one of the user narratives.
3. Open discussion: The interviewer asked for feedback on the user narrative without guiding the discussion in a specific direction (e.g., "What are your thoughts about the concept presented in the story and its functions?").
4. Idea-related discussion: The interviewer actively addressed innovation ideas contained in the user narrative but not yet discussed (e.g., "You didn't mention anything about element XY so far. How did you experience this? And why?").
5. Theory-related discussion: Participants were asked about their overall experience of the described automated vehicle rather than individual innovation ideas. The discussion was structured according to the six facets of User Experience [18]. The conversation was guided by prompting questions onvarious relevant aspects (e.g., learnability: "What do you find more understandable about operating the vehicle described in the story, and what is less clear? And why?")
6. Expected effectiveness: Reference was made to level-compliant driver behavior, and participants were specifically asked how effective they thought the measures described in the story were in promoting level-compliant driver behavior ("How do you assess the effectiveness of these measures in promoting safety-conscious behavior by drivers?").

7. Expected social implications: Participants were asked about the social implications they expected from automated driving vehicles ("Imagine that such an automated driving system has become widespread and established in the market. What do you think will be the impacts on society and different societal groups?").

2.2 Data processing

The interviews had an average length of 74 minutes, (*SD* = 25, range 60 to 100 minutes). The protocol of the note-taker was checked against the audio recordings. Missing partswere added and mistakes were corrected. The protocols were then analyzed according to Mayring [3] by summarizing user feedback oneach idea. Irrelevant statements and duplicates were removed. For each user narrative, all general statements on the user experience in the UX facets [18] were collected and summarized. Seven overarching ideas that could not be categorized were collected separately. Statements regarding social implications were also collected separately and have been reported elsewhere [19]. Ideas that were considered relevant for further development were adapted based on user feedback and incorporated into the concepts under development. The further developed concepts were visualized using a PC simulation (see heading 5.).

2.3 Participants of the interviews

The interviews were conducted with potential users (N = 12). Four different groups of participants were involved (all of whom had a valid driver's license):

a. Three young individuals (18-25) with an interest in cars and technology
b. Three heavy commuters (minimum 20,000 kilometers per year) with level 2 experience
c. Three Individuals aged 65 or older
d. Three individuals with children and who are responsible for childcare

The inclusion criteria were collected in a pre-survey. The study was conducted from March 24, 2023, to June 26, 2023. Feedback on each of the three user narratives was obtained from one representative of each demographic group, resulting in four interviews per user narrative. The interviews were conducted online using Zoom.

In total, seven female and five male individuals participated in the study. The age range was from 20 to 70 years. For each user narrative, one person from each of the four demographic groups described in Table 1 was interviewed. Table 1 depicts the user groups, evaluated user narrative, age, gender, and employment status of the interviewed individuals.

Table 1. Participants

User group	User narrative	Age	Gender	Employement status

a. Young individuals (18-25) with an intrest in cars and technology	1 2 3	22 20 21	W M W	student student student
b. Heavy commuters (min. 20.000 kilometers per year) with level 2 experience	1 2 3	29 59 36	W M M	employee employee employee
c. Individuals aged 65 or older	1 2 3	70 70 70	M M W	retired retired retired
d. Individuals with childred who are responsible for childcare	1 2 3	42 45 45	W W W	parent parent parent

Each user group includes at least one woman, no men are in the group responsible for childcare. The widest age range is found in the group of heavy commuters (29-59 years). Parents in the fourth group were not asked about their employment status.

3 Results

The authors evaluated 40 innovative ideas from the users'. Table 2 presents selected concept ideas that may be insightful and relevant for further work. An example of user feedback illustrates each idea.

Table 2. Results of the interview study on the concept ideas

Concept ideas	Description	Exemplary user feedback
Motivation for level-compliant driver behavior		
Trust calibration (UN1* C1**)	C1**: The system communicates it's own likelihood of making mistakes ("I recognize nine out of ten pedestrians")	With greater familiarity with the system, you are no longer permanently attentive, so it is interesting and good that susceptibility to errors is displayed (TS31***)
Trust calibration (UN1 C2)	C2: Vehicle shows what it can see/estimate	Promotes trust in the system (TS01)
Trust calibration (UN1 C3)	C3: Feedback from the system in the event of driver misconduct (what is permitted/what misconduct was detected)	A feeling of fear/ insecurity is triggered. To counteract this, the system should warn more penetratingly/ persistently, not just "inform" (TS01)
Gamification (UN2 C1)	C1: Individual gamification concept for every type of driver	Danger that it will not be taken seriously, especially by people who feel superior to the system (TS02)

Gamification (UN2 C2)	C2: Adjustable personality of the game or subtle mechanisms for gamification	Could increase safety, as users thus tend to keep to the rules (TS02)
Gamification (UN2 C3)	C3: Reward for LCB with gamification	Reward through an avatar is completely unimportant; if it is about rewarding level-compliant behavior, an avatar would be nothing serious; even off-putting and test-subject would feel kidded. Better, if the car showed more serious warning signals (TS12)
Classical intervention (UN3 C1)	C1: Reprimand for non-level-compliant driver behavior	Very sensible, independent from the driver's experience, was not perceived as disturbing, as it is a safety notice → happy about information (TS33)
Classical intervention (UN3 C2)	C2: Persistent inattentiveness despite request leads to an emergency stop	Important that the emergency stop is a safe one instead of an immediate one on the highway" (TS23)
Support learning phases		
Tutorial first use (UN1 B1)	B1: Training drive prior to the first driving attempt	Gradual introduction reduces inhibitions (TS21)
Integrated learning system (UN2 B1)	B1: Explanation of the levels during use	Personal responsibility of the driver should be emphasized more to avoid overtrust (TS02)
Individualization		
User profile (UN1 E1)	E1: Creation of an individual user profile	Recognition of individual preferences increases trust in the automated system (TS01)
Avatar (UN2 E6)	E6: Communication with the user is conducted through an avatar	Communication with the avatar is better than a voice 'out of nowhere'.The avatar should first appear and then make an announcement after a short period of time, so that one can prepare for a message (TS22)

Note. * = user narrative, ** = idea, *** = test subjects

The following results are derived from the study on the three concepts of trust calibration, gamification and classical intervention as well as the tutorial during first use, the integrated learning system, user profile and avatar.

Regarding the concept of *trust calibration*, most participants expressed, among other things, that it is important and can increase trust in the system, and encourage personal learning. Two participants, a young individual and a heavy commuter, expressed concerns about the communicated error susceptibility. They said that it would trigger fear and a feeling of being unsafe. The heavy commuter found the error indication to be too burdensome and thought that it was not motivating. Instead, he found the analysis after the drive to be more valuable. In order to make the situation of danger apparent more quickly, the young individual suggested that additional information could be provided via voice output. The heavy commuter suggested different colored lights and vibrations in the steering wheel to attract the driver 's attention. Furthermore, two participants suggested that additional beeping noises might be useful.

The young individual expressed that an individualized *gamification concept* could potentially enhance motivation to behave level-compliant. The individual with childcare emphasized that gamification could support the development of a relationship with the car or avatar, if they could identify with them. The young and the individual with childcare viewed the customizable gamification as a useful and sensible evolution of preestablished reward systems. However, the young individual and the heavy commuter feared that it might not be taken seriously, especially by individuals who perceive themselves to be superior to the system. These two participants suggested that the vehicle should talk to the driver and that serious/subtle signals would be more effective. The heavy commuter expressed that perceived rewards from the avatar were unimportant or even off-putting. This participant suggested combining the gamification concept with a ranking system in order to incentivize the improvement of level-compliant driving behavior.

The *classic intervention* system for non-compliant driver behavior and the threat of an emergency stop were considered very important and meaningful by all participants. The heavy commuter said that it would be fatal if this feature didn’t exist. The individuals with childcare emphasized that it was independent of the driver’s experience and would not be considered disturbing as it was a safety notice. The elderly and the individual with childcare were glad to receive the information and viewed it as a safety feature. Concerns were expressed regarding fear and the feeling of being unsafe that could be triggered by a sudden emergency stop in the middle of the road.

Regarding the *tutorial at first use*, three participants reported that the idea of a training drive at the beginning would give a feeling of safety and a better feeling for the car. The heavy commuter perceived an introductory test or a mandatory training drive as good and sensible. The elderly individual reported that he was initially hesitant to use the assistance systems, stating that it was something new to him, and therefore, he welcomed the gradual introduction. The heavy commuter stressed that the introduction should be tailored based on the individual's past experiences.

Regarding the *integrated learning system*, most participants expressed that the explanation of each level during use makes sense and is important, as it provided asense of security. It was perceived as helpful and the individual with childcare emphasized, that it is espacially important during the first drive. The heavy commuter suggested introducing more variation into the explanations and using individual messages in order to draw attention to theissue. The individual with childcare was of the opinion that if a driver confirms that they have experience with another automated system, it should be possible to bypass the tutorial.

The *user profile* was considered positive and useful by all participants. It was pointed out that the configuration of the user profile should not take up too much time.

Regarding the *avatar*, mixed opinions were reported. Two participants liked the idea, especially if the avatar matched their preferences. The individual adjustments were rated positively. They emphasized that communication with an avatar is better than when the car talks "out of nowhere". The young individual and the heavy commuter expressed that there is too much intimacy with an avatar and that such closeness is only desired in interpersonal relationships, not with an artifical intelligence.

4 Discussion and next steps

The results of the qualitative survey on the concepts reveal a lot of outcomes. The trust calibration receives positive feedback but also expressions of uncertainty. This seems to be a promising approach to prevent overtrust and to ensure level-compliant driver behaviour. However, to avoid individuals developing excessive fear and fundamentally rejecting the system, it is recommended to carefully consider the formulation of the auditory cue. Alternatively, the current recognition reliability, as implemented by the Stuttgart Media University (Fig. 2), could be presented graphically, accompanied by an additional auditory cue.

Fig. 2. Visualization of the trust calibration[3]. In the visualization, a schematic representation of the traffic situation is presented to the driver, with the aim of conveying the information in a transparent way. The authors developed a variant that indicates reliability and another that indicates the probability of an accident.

Gamification also represents a promising approach to promote level-compliant driver behavior. Through playful incentives, drivers may feel motivated to adhere to the rules. However, it is questionable whether individuals are equally motivated by this approach. Depending on personality and affinity for gaming, this approach could promote level-compliant behavior to varying degrees. The heavy commuter, in particular, showed a clear aversion. Therefore, differentiated considerations should be made for the design of gamification, possibly incorporating various variants. The gamification

[3] The authors would like to thank Marvin Chen for creating the visualization.

could look like the design of the Stuttgart Media University (Fig. 3), accompanied by an additional auditory cue.

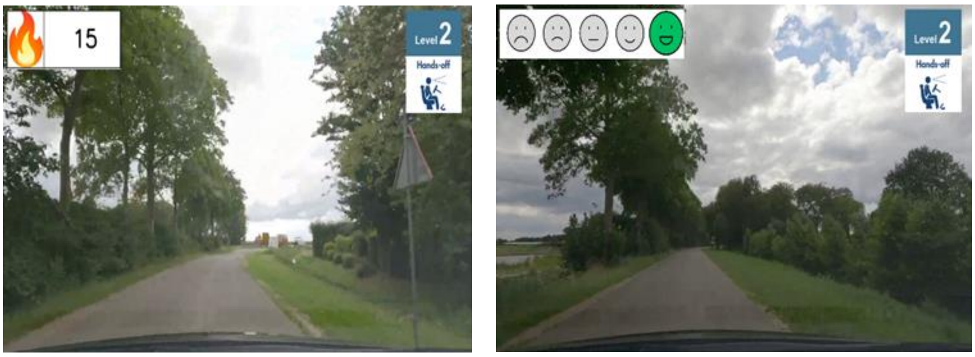

Fig. 3. Visualization of the gamification concept[4]. The authors developed two different feedback systems: one in which credit points could be accumulated, where the points drop to zero at the first miss use and another in which a positive smiley was displayed for correct behaviour, but which was gradually downgraded for nom-level compliant behaviour.

In summary, it can be said that the classical intervention received generally positive feedback from the participants, contrary to the assumption of reactance [12]. As a result of this, participants do not seem to feel demotivated to behave in a level-compliant manner. The integration of an emergency stop as a safety-related function is feasible. It would be advisable to provide a clear announcement of an emergency stop, especially if there is sufficient time for the driver to avoid it by making appropriate behavioral adjustments.

In essence, all systems, whether gamification or trust calibration, should incorporate an audible warning and an announced system shutdown/emergency stop.

In order to provide support, an integrated learning system for beginners is recommended, which should help the driver become familiar with the system. Experienced users could be identified, and a training ride could be suggested only for beginners. This could usefully support the different technical experience of different user groups, such as young and old. They should be offered a training ride adapted to their level of knowledge. An adaptable user profile should be presented. This could support the formation of helpful mental models [10] that match the capabilities of the automation system. Opinions on the avatar presented in the study aremixed. Both the young individual and the middle-aged heavy commuters rejected the avatar.

In summary, the interviews suggest that during the conception, a clear distinction should be made between human and AI. Whether an avatar actually promotes trust would have to be clarified in further studies.

From a methodologicalpoint of view, the low-fidelity evaluation helps to identify relevant aspects for the success of supporting level-compliant behavior in automated

[4] The authors would like to thank Marvin Chen for creating the visualization.

driving. The effort required to conduct interviews varies and can be quite high depending on the research questions and targetgroup, but it remains far below the effort required to design and implementa simulation prototype that may be suboptimal from the user's perspective. Recruiting diverse target groups with specific requirements also involves effort, but is indispensable for the quality of the results to draw conclusions from individual persons to as representative a user group as possible. The results are purely qualitative and require further quantitative validation in the subsequent development process, for example, through a simulation environment developed based on the derived concept. However, it provides only limited insights into which of the concepts best promotes level-compliant driver behavior under real conditions. The research base for the gamification concept is also based on studies of vehicles up to level two. The transferability to higher levels of automation has not been empirically proven.

The results of the interviews provide insights into user's perceptions of the concept ideas developed. The feedback played a crucial role in the early identification of the overall strengths and weaknesses of the concepts, helping to steer the development effort away from potentially inappropriate directions. Several concepts have proved their advantages in the development phase by effectively incorporating ideas with significant potential from a user perspective. Trust calibration, gamification, and the classical ntervenation all showed potential and promise. In order to prevent both intentional and non-intentional misuse of automated vehicles, a combination of different concepts is likely to be the most effective. For instance, a learning system could prevent non-intentional misuse due to the lack of awareness, while a combination of classical/gamification or trust/classical could prevent intentional misuse. As a similar classic intervention is already used in the market in, future work will focus on the other two concept ideas. Further research is needed to determine which of the concepts developed is the most promising.

The concepts presented (Fig. 2 and 3) are tested and further developed as part of the user-centered development process. A future study using VR simulations and a field study in a car will also provide more information. Additional findings from the interview study will be further investigated by other project partners.

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