Towards Cooperative Driving: Involving the Driver in an Autonomous Vehicle's Decision Making

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ABSTRACT
Although there are already fully autonomous vehicles on the roads for testing purposes, a rollout is far away. Autonomous vehicles are still not able to handle everyday driving and remain reliant on the driver when they reach their system limitations. One suggested approach to this problem is handing over the control entirely to the driver, which might become annoying when such situations occur frequently. In contrast, we suggest the usage of cooperative interfaces to avoid full handovers in situations in which the system needs the driver, for instance to approve or monitor a specific maneuver. A driving simulator study with 32 participants revealed that they felt comfortable choosing how the system should handle a situation. They reportedly assessed the situations first instead of relying blindly on the system and were able to handle every situation safely. We report lessons learned regarding cooperative interaction and interfaces, and their in-lab evaluation.

ACM Classification Keywords
H.1.2 User/Machine Systems: Human factors; H.5.2 User Interfaces: Evaluation/methodology, Graphical user interfaces (GUI), Prototyping, Voice I/O

Author Keywords
Automated driving; human factors; human-machine cooperation; multimodal interface; user study.

INTRODUCTION
The future of traveling on roads will be automated to a great extent like it is already the case in aviation. A lot of research, both in academia and industry, is going on to enable autonomous driving (see [14] for an overview). It has already been shown that the technology is at a point where prototypes can drive autonomously on public roads (e.g. [1, 8, 17]). Nevertheless, todays' autonomous vehicles like trucks that are equipped with a Highway Pilot[1] reach their system limitations from time to time, e.g. when they have to leave the highway, pass roadworks or when maneuvers like overtaking or lane changes should be performed. Thus, autonomous driving, where drivers are not involved occasionally during the journey — meaning that they merely give the system the destination — is far away. In contrast to the technological advances that enable autonomous driving like the planning of a trajectory, there are a lot of open questions regarding human-vehicle interaction in autonomous driving.

Recent research has focused on handing the control back to the driver when a system boundary is reached (e.g. [4, 11, 15]). If an autonomous vehicle asks the driver to take over control every time a system uncertainty or boundary occurs the driver might become annoyed. Moreover, it is likely that drivers are out of the loop [10] and engaged in other tasks [16] than monitoring the vehicle's behavior and the traffic scene, thus the frequency of handovers should be minimized as much as possible for both convenience and safety. In many situations handing over control is gratuitous, for instance when a vehicle in autonomous mode reaches a standing car out of town on its lane. But what to do next? For a human driver such a situation is easy to assess — Is it an accident, a breakdown or is someone parking inappropriately? The driver is able to decide whether to stop for instance to act as a first responder or to go past and continue the journey. In contrast, the vehicle senses only a non-moving object blocking its lane. In other words, the context model of the system is lacking information to handle the situation appropriately. At this point the driver comes into play: systems can simply cooperate with drivers and ask them to perform a specific task. This task could be to extend the context model or to decide what to do next. For instance, the vehicle can list propositions like *"stop behind the vehicle"* or *"pass the vehicle"* and the driver can choose one. As a result, the vehicle can continue the journey autonomously without handing over the control entirely. Another task the vehicle can assign to the driver is for instance to monitor the traffic scene for a reasonable amount of time and to approve maneuvers. In the given example this could be necessary if the

[1] Daimler. The auto pilot for trucks Highway Pilot. https://www.daimler.com/innovation/autonomous-driving/special/technology-trucks.html (accessed 05/2016)

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driver decides that the vehicle should pass the obstacle but the sensors of the vehicle are not capable to sense the oncoming traffic (e.g. hilly or serpentine road, signal blocking). Another reason for a necessary approval by the driver could be a violation of traffic regulations, for instance violating the speed limit slightly to adapt to the traffic flow. In conclusion, the vehicle can cooperate with the driver to maintain the automated driving functionality.

The paper is structured as follows: first, related work on cooperative driving is discussed. Second, we propose a generic procedure for involving the driver to avoid handovers. We describe the design and implementation of a cooperative assistant that implements the proposed scheme. Next, we report the evaluation of the prototype. Finally, we conclude with a discussion and lessons learned for future cooperative assistants and evaluations of these.

RELATED WORK

The driving task can be divided in four subtasks: navigation, maneuver guidance, trajectory guidance, and control [2]. When there is *no automation* (level 0[2]) all these tasks have to be performed by the human driver. With increasing levels more and more of the driving task is passed to the automation. Beginning with level 3 (*conditional automation*) the guidance and control tasks are conducted by the system entirely. Since the technical advances are not progressed towards *full automation* (level 5), the human driver has to be available to take over the driving task shortly as fallback (level 3) or when the requirements of the system are not met (e.g. not on a highway) (level 3 and 4). One strategy to overcome system boundaries is to hand over control to the driver [3]. Another less black-and-white approach is cooperative driving. Both parties — driver and autonomous system — become a team and perform the driving task together rather than only one party at a time.

There are different perspectives on cooperative driving. In the context of intelligent transport systems (ITS) cooperative ITS (C-ITS) could be regarded as cooperation between different actors (e.g. vehicles or infrastructure) via vehicle-to-vehicle and vehicle-to-infrastructure communication [9]. According to Zimmermann and Bengler [18] this is cooperation in the area of *traffic control*. On the other hand, they specify *vehicle interaction* as interaction between human and assistance system in a vehicle they control together. Moreover, they propose an interface prototype for a cooperative lane change that combines traffic control and vehicle interaction, since two vehicles and their respective drivers are involved.

Flemisch et al. [2] present two concepts for cooperative guidance of highly automated vehicles: first, *Conduct-By-Wire*: a concept where drivers (in the loop) can select maneuvers like lane changing their automated vehicles have to perform. Second, *H-Mode*: a concept that uses a haptic interface to allow switching of the automation levels.

[2]We use SAE levels [13] in this work to specify the level of automation. See [9] for a comparison of classifications by different institutions.

We address the Human-Machine Cooperation (HMC) [6] scope of cooperative driving, namely the cooperative interaction between driver and the driver's vehicle. In contrast to the cooperative concepts discussed, the cooperation occurs only at system limits or uncertainties rather than almost continuously on the guidance level.

QUESTION-ANSWER INTERACTION AT SYSTEM LIMITS

We propose the usage of cooperative interfaces to overcome system limitations and uncertainties. As a result, handovers could be avoided with a short interaction. To accomplish this, we assume an automation that can detect its system limitations or uncertainties. Therefore, drivers do not have to monitor the system in autonomous mode and can engage in other tasks. Taken together, *conditional* (level 3) to *high automation* (level 4) is assumed with a system that can sense its boundaries and can find propositions in cases of uncertainty, however it needs the driver to select a proposition and to assess whether it is safe to accomplish it.

Figure 1 shows how such an interaction could be implemented. Beginning with the detection of a system limitation or uncertainty the system alerts the driver, who is likely out of the loop and informs them about the limitation or uncertainty. The system is searching for a solution it can propose to the driver. If it does not find a suitable solution it asks the driver to take over. On the other hand, when the system finds solutions it proposes these to the driver. If the driver cooperates with the vehicle and selects a proposition autonomous driving can stay enabled. When no proposition is accepted, either because the driver declines them or does not react at all, the driver will be asked to take over. When the driver is prompted with a take-over request they can take over and start driving manually. If there is still no reaction of the driver, the system has to de-escalate on its own, for instance with an emergency stop. The handover and de-escalation behavior is in line with the handover process proposed in previous research [15]. In particular, this process could be applied in situations like the previously discussed example of a blocked lane: the system could propose to pass the vehicle or for instance if possible to take an alternative route — it is up to the driver to decide whether it is safe to pass the obstacle, to take an alternative route or to take over for being in control and for instance to help as a first responder. The proposed concept can also be applied in cases the vehicle is uncertain if a maneuver is in the interest of the driver, e.g. taking a shortcut on an inconvenient bumpy road or a substantial longer alternative route to avoid a traffic jam. Another use case are bad weather conditions: the system can ask the driver whether it should drive at a lower speed autonomously or if they want to take over.

DESIGN OF A COOPERATIVE ASSISTANT

We implemented the proposed concept as a cooperative assistant that asks drivers how to deal with a broken-down car on their lane. It has been shown that multimodal alerts are superior to unimodal cues [12]. Displaying messages visually in a head-up display directs the attention towards the front, but also occludes parts of the traffic scene. On the other hand, when such messages are displayed in the dashboard or the center console they guide the attention away from the traffic

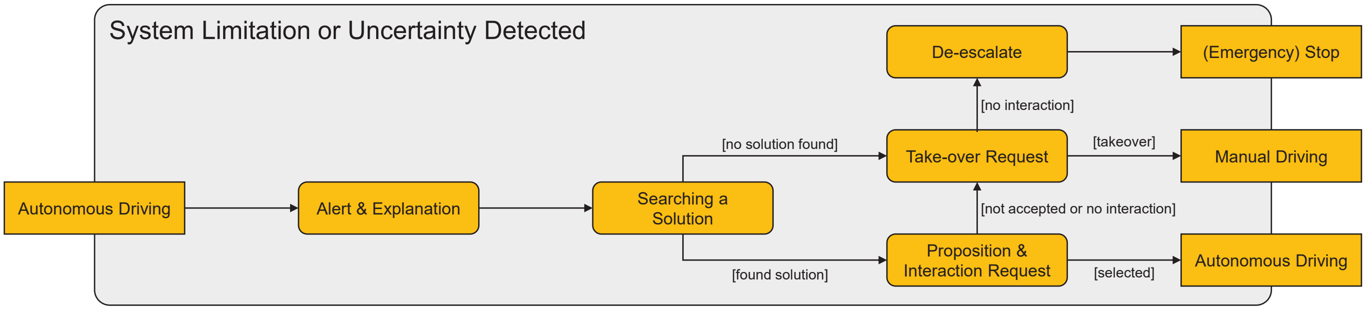
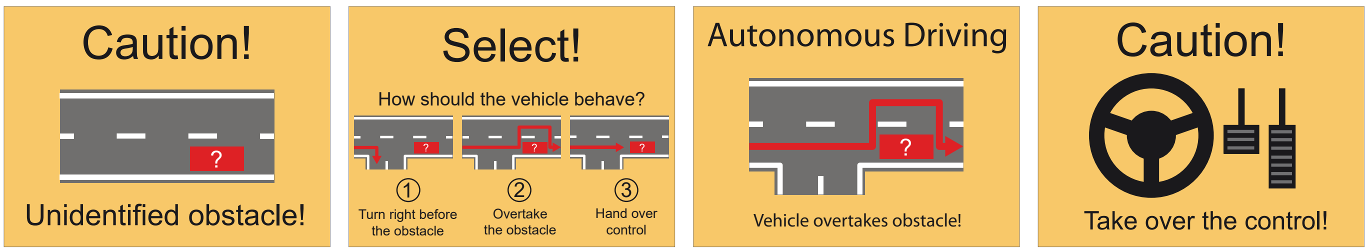


Figure 1: System limitation / uncertainty detected: the system alerts and informs the driver before presenting propositions the driver can choose between to keep automation enabled.



(a) Alert and explanation (b) Interaction request (c) Proposition accepted (d) Take-over request

Figure 2: Cooperative assistant: it first alerts and informs the driver (2a) before asking the driver what to do (2b). The assistant gives feedback when the driver selects an autonomous driving proposition (2c) or a take-over request otherwise (2d).

scene. Nevertheless, drivers can read a textual message on their own speed and multiple times if necessary. Graphical elements can be used to illustrate complex facts.

Auditory cues free the field of view of the driver and can guide the visual attention as well when they are presented from a specific direction [5], but are played at a predefined speed. Moreover, if drivers do not understand parts of the message there has to be a mechanism how they can be replayed which is more complicated than rereading a displayed text and consumes valuable time. The tactile channel can be used to alert drivers as well, but is not suitable to express such complex information as it is necessary in the discussed use case.

In conclusion, both modalities (visual and auditory) have advantages and disadvantages, however, we decided to combine both so that the advantages outweigh the disadvantages. The visual messages can be displayed in the head-up display area, in the dashboard and on a touch screen in the center console to interrupt other tasks [10] that could be performed with the help of the display (e.g. browsing or watching videos). Another positive effect of the display is the ability for selection of propositions via touch as an alternative to speech input.

The visual part of the assistant is depicted in Figure 2. At the top there is always a headline which is used to catch the attention of the driver, to display the system state or to show what the drivers have to do. In the center there are graphical representations to explain quickly the situation, the vehicle's future behavior or propositions. Below these illustrations there is a descriptive text. The yellow background color is chosen with the traffic lights metaphor in mind: the situation is not critical but a reaction is necessary since it will switch to red. The appearance of the visual interface is accompanied by a spoken message that reads the displayed text given in the visual message and a deceleration of the vehicle.

According to the process in Figure 1, first there is a message that alerts the driver and explains the situation (see Figure 2a) since it is important for the driver to know why something is going to happen [7]. The alert is followed by the actual interaction request, that presents the system's propositions and asks the driver to select one. Figure 2b shows an exemplary interaction request that shows three propositions. The propositions are numbered consecutively so that they can be chosen via voice by telling the according number as alternative to selection via the touch screen in the center console. If there are not several propositions, the system can also ask simpler yes-no questions. For the interaction requests the proposition explanations below the images are not read out to shorten the auditory cues. After selecting a proposition, the system shows the proposition accepted message (Figure 2c) to give positive feedback and to illustrate the system behavior to ensure the trust in the system. Otherwise, the system asks the driver to take over with a take-over request as depicted in Figure 2d. Both messages, proposition accepted and take-over request, again are companied by an auditory message that reads out the text displayed visually.

STUDY

A within-subject driving simulator study with 32 participants was conducted to evaluate the proposed concept. We adapted

Figure 3: The driving simulator in which the study was conducted. The participant is watching a video while automation is activated.

Figure 4: Complex situation: in addition to the broken-down vehicle (simple situation) there is a police car behind it and another car on the side of the opposite lane.

the cooperative assistant (displayed only in center console, separated input modalities) and implemented it as an interactive UI mockup to evaluate interaction via touch and speech as well as to gain insights about the user's acceptance, preferences, performance, trust in automation and their way to deal with a cooperative assistant.

Apparatus

The study was conducted in a driving simulator that is composed of three 40-inch screens in front of a gaming seat. It is equipped with a Logitech G27 Racing Wheel and pedals. In addition, a 7-inch android tablet was mounted right next to the steering wheel as a user interface in the center console (see Figure 3). The tablet was used to display videos (distraction task) as well as interaction and take-over requests and for touch input. The simulation was developed using Unity 3D.

Participants

We recruited 32 participants (10 women) with an average age of 25.16 years ($SD = 3.47$) via social networks, mailing lists, and notices at the university. Requirement for participation was a valid driving license and an age of at least 18 years. The participants reported that they owned their driving licenses from 0.16 to 15.8 years ($M = 7.21$, $SD = 3.48$). Moreover, they reported to drive 50 to 55,000 km ($M = 8,289.06$, $SD = 11,043.27$) per year. 26 participants were students, 16 of them had a computer science background.

Procedure

Each session began with an explanation of the research objectives of the study and the takeover avoidance concept; specifically, the interaction between autonomous system and driver as well as the different input techniques (touch and speech). Moreover, the participants were informed that they and the autonomous system have to follow the traffic regulations, but that it is possible that some propositions of the system violate these. Finally, the participants had to sign a consent form.

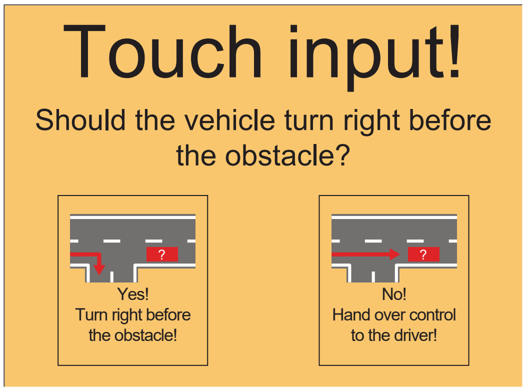
After the introduction, the participants got introduced to the driving simulator and performed a test drive for at least 5 minutes but as long as they needed to feel confident of handling the simulated vehicle safely. Subsequently, they performed a test scenario (without distraction task) where every step was explained to them. After this hands-on introduction they had to complete 12 trials.

In each trial the participants were challenged with a broken-down car that stands on the road on the right lane (right-hand traffic), right after a turnoff to the right. There were two levels of complexity: in the *simple* situation there was the broken-down car and additionally a right of way sign before the turnoff. In contrast, as Figure 4 shows, in the *complex* situations there was a police car behind the broken-down vehicle and another vehicle on the side of the opposite lane.

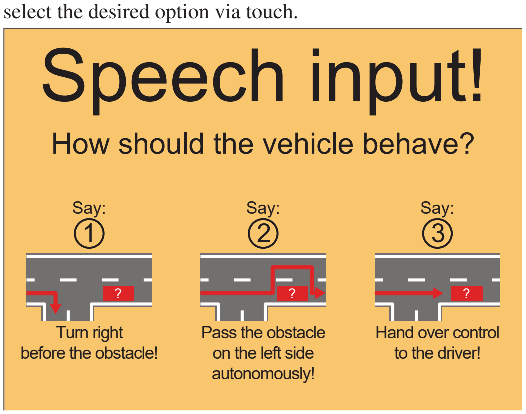
In some situations, the propositions of the vehicle violated traffic regulations. The right of way sign was substituted with a *no entry for vehicular traffic* sign (no. 267) with the addition *"crossing closed"* to create situations where the propositions of the system were not executable. In these situations, participants would have to decelerate and turn the vehicle manually.

All system messages were displayed visually in the center console and as spoken text (see previous section). There were two kinds of propositions: with 2 and 3 options. The question with 2 options was formulated as follows: *"Should the vehicle turn right before the obstacle?"*. The 2 propositions were: *"Yes! Turn right before the obstacle!"* and *"No! Hand over control to the driver!"*. In the other condition, the system asked the driver *"How should the vehicle behave?"*. The 3 propositions were: *"Turn right before the obstacle!"*, *"Pass the obstacle on the left side autonomously!"*, and *"Hand over control to the driver!"*. In half of the cases, participants had to select via touch, otherwise via saying the corresponding number of the desired proposition or *"yes"* / *"no"* (the speech recognition was done by the experimenter as Wizard of Oz). Thus, the input modality was displayed in the headline. In the touch condition the options were displayed as buttons. In the speech condition there was a *"say"* with the according number (3 options) or *"yes"* / *"no"* (2 options) above the icons. Figure 5 shows the interaction requests.

Each trial started with a phase of autonomous driving at a speed of 80 km/h on a rural road. The autonomous driving phase ended after 2 – 4 minutes and varied between trials to avoid habituation. According to the previously described assistant, 200 meters before reaching an accident, the alert and explanation (*"Caution! Unidentified obstacle!"*) was



(a) Interaction request with 2 options. The participant has to select the desired option via touch.



(b) Interaction request with 3 options. Participants select the desired option via saying the according number.

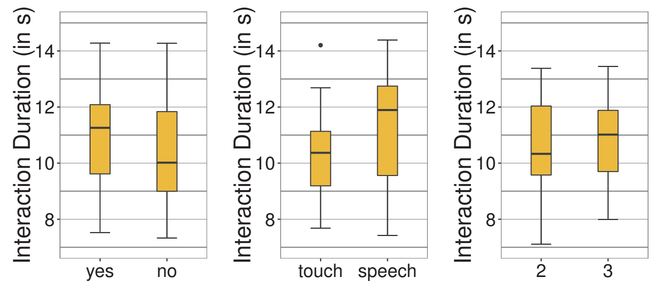
Figure 5: Screenshots of the interaction requests on the tablet in the center console. The input modality was displayed on the top of the screen.

displayed for 4 seconds and the vehicle started to decelerate to 40 km/h. The deceleration resulted in a time budget of 18 seconds. The broken-down vehicle became visible about 300 meters before the system first notified the driver. Next, the system's propositions were presented (interaction request) as long as it took until the participants selected an option. In case, the participant opted for a proposition that avoids a handover, the system executed this plan autonomously and gave feedback as discussed earlier. If they selected to hand over control a take-over request was displayed and the participants had to solve the situation manually. The trial ended after the situation was mastered or when the vehicle stopped autonomously behind the obstacle when there was no input. After completing the 12 trials, the participants had to fill a questionnaire on their impression of the assistant and the interaction techniques as well as a demographic questionnaire. At the end of each session the experimenter thanked the participants and compensated them with 10 Euros. A session took 60 – 75 minutes in total.

Participants were distracted as long as the vehicle drove autonomously by watching videos on a screen in the center console (cf. [15]). The video was interrupted to display the assistant's notifications. After each trial, participants had to

Options	Complexity	Interaction	Executability
2 options	simple	speech	yes
3 options	complex	touch	no

Table 1: The evaluated situational conditions and parameters.



(a) Executability (b) Interaction modality (c) Options

Figure 6: Interaction Duration.

answer four questions regarding the seen videos. Walch et al. [15] reported that the videos they used from public service broadcast were not interesting for all their participants, thus we selected trailers of movies that were to be released after the period of time in which the study took place, so they were likely new and interesting to the participants. Since the autonomous driving phase lasted between 2 – 4 minutes in some cases there were two subsequent trailers. This distraction task was chosen because it is very likely to be a usual activity of a future driver of an autonomous vehicle. To further increase engagement with the distraction task participants were informed that the count of the correct answers was coupled to the reward system. Additionally, they were told that there were also other performance measures coupled to the reward: count of traffic violations and interaction time. The two participants who performed best gained each a 10 Euro amazon voucher.

Taken together, we conducted a 2 (options) x 2 (complexity) x 2 (interaction) x 2 (executability) within-subject driving simulator study (see Table 1 for the levels of the independent variables). Each participant had only to pass 4 out of the 8 possible trials in which the propositions violated the traffic regulations to reduce the strain. In conclusion, each participant had to pass 12 trials (rather than 16). We measured the interaction time, the selected proposition of the participant, and whether the participants choose a executable proposition. Moreover, the participants had to report their perceived comfort, distraction and trust in the system.

Results

With the help of the study qualitative and quantitative data was collected; its analysis is reported in the following.

Interaction Duration

The time between the appearance of the interaction request and the input via touch or speech is called interaction duration. The analysis in the following was performed with a single value per participant (mean) in each condition. Since the data is not normally distributed, Wilcoxon signed-rank

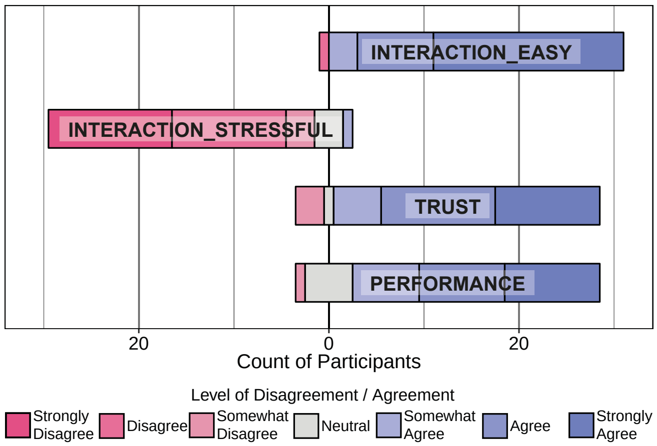


Figure 7: (Dis-) agreement of the participants on 7-point Likert scales to statements regarding the ease of interaction, the trust in automation and the perceived performance

tests were used to analyze it. The analysis revealed that the modeled complexity in which the interactions took place did not have any effect on the interaction duration ($p = .761$). The participants needed significantly more time to interact when the suggested propositions did not violate the traffic regulations ($Mdn = 11.26$s, $M = 10.87$s, $SD = 1.70$, 95% CI $[10.26, 11.48]$) than when the propositions were not executable ($Mdn = 10.02$s, $M = 10.45$s, $SD = 1.83$, 95% CI $[9.79, 11.12]$) as shown in Figure 6a, $p = .048$, $r = -.25$. Furthermore, as Figure 6b shows participants needed longer to select a proposition via speech (Wizard of Oz) ($Mdn = 11.89$s, $M = 11.21$s, $SD = 1.97$, 95% CI $[10.50, 11.92]$) rather than with touch ($Mdn = 10.37$s, $M = 10.25$, $SD = 1.53$, 95% CI $[9.70, 10.80]$), $p < .001$, $r = -.49$. Moreover, the count of options the participants had to choose from had a significant effect on the duration of the interaction (see Figure 6c): the participants needed more time to select an option when there were three alternatives ($Mdn = 11.09$s, $M = 10.96$s, $SD = 1.75$, 95% CI $[10.32, 11.59]$) compared to two propositions ($Mdn = 10.33$s, $M = 10.52$s, $SD = 1.68$, 95% CI $[9.92, 11.13]$), $p = .025$, $r = -.28$.

Ease of Interaction

At the end of each session, we asked the participants how easy (INTERACTION_EASY) or stressful (INTERACTION_STRESSFUL) they perceived the interaction with the autonomous system. Figure 7 shows that the majority of participants agreed that the interaction was easy, on average they rated the according statement with 6.41 ($SD = 1.04$) on a 7-point Likert scale from *strongly disagree* (1) to *strongly agree* (7). Their rating whether they perceived the interaction stressful is in line with the previous finding: The participants did not rate the interaction as stressful ($M = 1.97$, $SD = 1.09$).

Input Modality

Twelve participants (37.5%) preferred touch to select the propositions. Three participants named input speed as a reason, for instance *"I could interact faster with touch and would have more time for the interaction[;] with speech [input] I always waited for the end of the message."* Another reason for the preference of touch was its reliability and the mistrust against the reliability of speech recognition (in total 6 participants): *"Touch, feels more reliable although speech input functioned every time."*, *"[I prefer] [t]ouch, because speech could be easily misunderstood from the system."* Another participant preferred touch because one already glances at the screen.

Speech was preferred by 17 participants (53.13%). Four of them reported that this is because they can keep their eyes on the street. Another participant said that speech input is clearly less distracting. Another reason for three participants was that they have the hands free or already on the steering wheel in case of an emergency. Other named reasons for speech were speed (3 participants), its directness (1 participants) and easiness (2 participant) and that one has not to move oneself (1 participant). One participant reported to prefer speech, but liked touch as a fallback option. A point of criticism of the speech input implementation named twice was that the participants had to say a number to select an option rather naming the action or in contrast to just selecting via touch.

One participant differentiated between situations: *"[I would] rather [prefer] [t]ouch when one shares the car with several people and wants to chat, speech preferably when one is alone and lazy."* The remaining two participants' answers were too vague to be interpreted.

Participants' Preferences: Proposition vs. Takeover

In total, participants completed 384 situations. In 257 situations (66.93%) participants selected one of the vehicle's proposition. In 128 situations none of the system's propositions was executable; nevertheless, 10 participants have chosen a non-executable proposition rather taking over in total in 19 trials (14.84%). On the other hand, they selected 238 propositions (92.61%) in 256 trials where the propositions were feasible.

After finishing all trials, participants had to answer whether they preferred to handle the situations in which they were asked to interact manually or if they preferred to choose a proposition and why they did so. The subjective answers were in line with the quantitative data. The vast majority (26 participants) reported that they preferred to let the system execute propositions. A common reason was convenience (8 participants). Nevertheless, 14 participants reported that they evaluated the situations and propositions and selected them *"as long as the vehicle provided a good solution [...]"* or when there were *"[...] non-dangerous [...]"* or *"[...] easy situations [...]"*. *"When I was not sure, I preferred to take over. When the situation was clear I could let the car do it in good faith."* One participant took over *"[o]nly when the propositions violated the traffic regulations [...]"*. Only one participant preferred to handle situations manually in anticipation of exceptional occurrences. One participant reported that he took over when there were 3 options to choose between as it was too much to read — in cases with 2 options he let the vehicle proceed.

Trust in Automation

Participants had to report their trust in the automated system. Again, they had to express their level of (dis-) agreement (*"I trusted the self-driving vehicle entirely."*) on a 7-point Likert scale (see TRUST in Figure 7). The average rating was 5.84 ($SD = 1.22$), what indicates that the participants trusted the system.

Perceived Performance

Finally, we asked the participants whether they were able to manage every situation safely (PERFORMANCE). On average, they rated their performance with 5.69 ($SD = 1.18$) which suggests that the participants thought that they acted safely. The distribution of the levels of (dis-)agreement is plotted in Figure 7.

DISCUSSION & LESSONS LEARNED

In the following we discuss the insights we gained through the study. At the end of each paragraph we formulate lessons learned and recommendations (bold type), first for cooperative assistants and then for future driving simulator studies. Due to the limitations of a driving simulator study with 32 participants these lessons learned and recommendations should be understood as starting points for future research and validation.

The acceptance rate of system propositions to avoid a handover of control was very high (92.61%). This finding is in line with the reported preferences of the participants. However, it is remarkable that while participants rated their trust in the automation highly, by their own account they acted responsibly when the car asked them for their input by first evaluating the situation, and then checking the propositions before selecting one. The tenor of many participants was that they selected one of the system's propositions only in clear situations they thought the automation was capable of handling. In consequence, it can be assumed that drivers prefer to take over in complex and unclear situations. **Cooperating with the driver to make decisions seems promising, since drivers self-reportedly act responsibly when selecting a plan to be executed by the autonomous system.**

In contrast, in 15% of the situations, participants opted for a proposition even though it violated the traffic regulations. This could be fatal in real traffic or at least result in expensive fines. However, in the study scenario it was not critical. One reason for the wrong decisions might be a misinterpretation of the *"crossing closed"* sign: 3 of the 10 participants (5 trials) who decided wrongly reported problems interpreting the sign in the post-study questionnaire and thought that turning right was allowed. **When the system asks for support, it should help drivers to perceive and assess the traffic situation, for instance by highlighting road signs.**

Overall, the interaction with the cooperative assistant was rated as easy and not stressful. Interaction via speech took a little bit longer than via touch. It should be kept in mind that the speech recognition was done by the Wizard of Oz, thus the reaction time of the experimenter is also included, but potential errors of real speech recognition requiring a repetition of the command are excluded. Nevertheless, more than half of participants preferred speech input. Free text answers indicated great mistrust against the reliability of speech recognition, even though during the study the recognition rate was 100%. There was criticism regarding our implementation (naming numbers). It was also reported that the preference for an interaction modality depends on the in-vehicle situation (alone vs. with passengers). **Many drivers tend to mistrust speech recognition systems, thus such a system has to be robust to convince them of its reliability; this could be supported by natural dialogs and alternative unobtrusive interaction modalities like touch that could be used as fallback options as well.**

The study has shown that the participants needed more time for the interaction when there were 3 rather than 2 options to choose from. In both cases, one option was to take over control — since a takeover should always be possible in a real implementation, it may not be necessary to list it as an option. It was used in the study setting to determine the interaction duration. Future research is necessary to investigate if drivers always go for a presented option or if they also would initiate a takeover on their own when that is the better alternative. **The interaction should be kept as straightforward as possible, for instance by keeping the option count small and by using implicit interaction (e.g. taking over implies that the user declines all propositions).**

The study was conducted in a driving simulator under laboratory conditions. Consequently, the participants did not have monetary or physical risk. The scenarios we challenged the participants with were not critical and did not appear suddenly, thus even in a real world setting there would not have been a high risk. In consequence, we assume that the lack of realism should not impact the findings greatly. A realistic distraction task (watching movie trailers) was chosen. We ensured engagement in the distraction task and conformance to traffic regulations through the reward system that encouraged participants to engage fully, and try to follow regulations. Another issue of the study design and in-lab nature was that a relatively simple situation was repeated often as a tradeoff between participant strain and data acquisition. Moreover, not all consequences of the participants' decisions were covered by the reward system (e.g. increased travel time when making the turn). **We suggest that driving simulator studies in autonomous driving should use a reward system that ensures that participants engage in given tasks and that they take the driving tasks seriously rather than as a game. In particular, decisions the drivers make should have consequences for them.**

CONCLUSION & FUTURE WORK

We proposed the use of cooperative interaction between an autonomous vehicle and its driver to overcome system limitations or uncertainties, thus avoiding complete handovers. In particular, we suggested that the system can ask the driver to enhance the system's context model or to perform tasks like monitoring or approving maneuvers. For this purpose, we presented a generic interaction concept for situations in which a vehicle cannot decide between several alternative plans. Moreover, we implemented this concept for a specific situation where a standing vehicle is blocking the lane. We used this implementation to conduct a driving simulator study.

Our study revealed that participants liked the concept of making decisions for the autonomous system by choosing a proposition rather than taking over. The participants' answers indicate that they chose propositions responsibly by assessing the traffic situation first. Moreover, the findings show that voice input is a good interaction modality for such systems, but there are challenges like mistrust towards speech recognition.

The findings highlight that the proposed concept is promising and should be investigated further. For instance, a cooperative assistant should adapt to individual users (e.g. more detailed explanations for novices or different modalities) and should learn preferences of drivers and how they solve problematic situations manually to reduce the frequency of interaction and take-over requests. More research is necessary to determine in which situations such a cooperative approach is feasible and under which circumstances (e.g. numerous alternatives may lead to long decision making) a full handover is a more suitable method. Moreover, it should be investigated if drivers become too reliant on such a system in long term usage.

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