Cooperative Overtaking: Overcoming Automated Vehicles’ Obstructed Sensor Range via Driver Help

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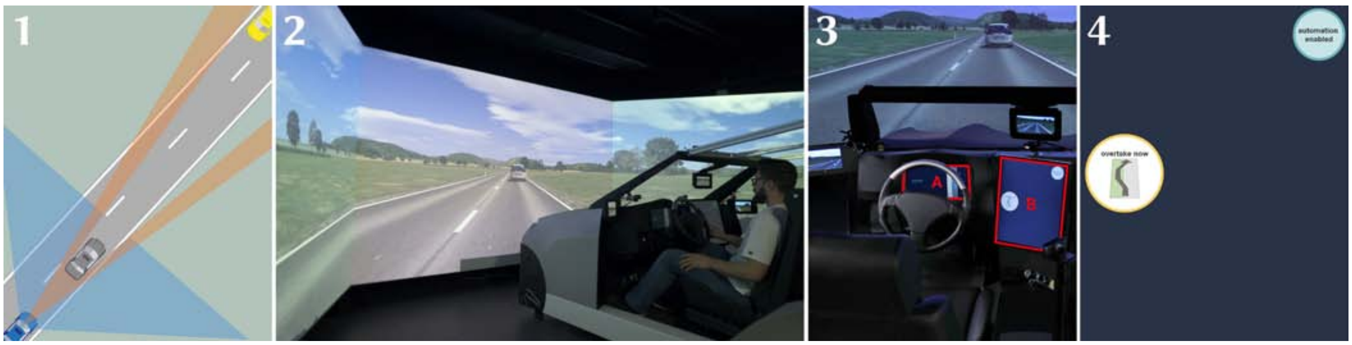

Figure 1: We investigated the feasibility of cooperative overtaking as an alternative to handovers in a lab study (2): drivers were asked to approve maneuvers on a touchscreen (3.B, 4) in case of a slower car preventing the detection of contraflow (1).

ABSTRACT

Automated vehicles will eventually operate safely without the need of human supervision and fallback, nevertheless, scenarios will remain that are managed more efficiently by a human driver. A common approach to overcome such weaknesses is to shift control to the driver. Control transitions are challenging due to human factor issues like post-automation behavior changes. We thus investigated cooperative overtaking wherein driver and vehicle complement each other: drivers support the vehicle to perceive the traffic scene and decide when to execute a maneuver whereas the system steers. We explored two maneuver approval and cancel techniques on touchscreens, and show that cooperative overtaking is feasible, both interaction techniques provide good usability and were preferred over manual maneuver execution. However, participants disregarded rear traffic in more complex situations. Consequently, system weaknesses can be overcome with cooperation, but drivers should be assisted by an adaptive system.

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CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**.

KEYWORDS

automated driving, driver-vehicle cooperation, user study

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1 INTRODUCTION

The technical advances in the domain of automated driving make great progress. Changing road surfaces, extreme weather conditions or interaction with people outside, just to name a few, still remain challenging for automated vehicles (AVs) [34]. Even when highly and fully automated vehicles (SAE Level 4 and 5 [32]) can operate on their own without the need for a human driver as supervisor or fallback in all (Level 5) or at least some (Level 4) driving modes, there will remain scenarios that can be handled by the system only in a less efficient way compared to a human driver. One exemplary scenario is depicted in Figure 1.1: a highly automated vehicle (HAV) is following another traffic participant who is driving significantly slower than the target velocity of the HAV. Depending on the trajectory of the road it is likely that the vehicle ahead obstructs the sensors of the AV and impedes an automated overtaking maneuver. Consequently, the travel time increases and the journey is less efficient.

One approach to deal with system boundaries is to shift the control back to the human driver (see [22, 23, 26] for an overview). Such handovers are a binary approach where only one agent (driver or system) is in charge of the driving task at one time. Manual driving as the solution to overcome system boundaries can be problematic [27], since drivers are likely focused on non-driving-related tasks (NDRTs), consequently pay less attention to the traffic and end up being out-of-the-loop [6]. Saffarian et al. [33] name several human factor issues of automated driving: overreliance, behavioral adaption, erratic mental workload, reduced situation awareness, and an inadequate mental model of automation functioning. Furthermore, the usage of automated driving can decrease the driving skills [10, 29]. Moreover, it has been shown that the usage of automation affects the post-automation driving behavior, for instance unstable lateral control [24] or a decreased headway after platooning [4].

Driver-vehicle cooperation has been suggested as an alternative approach to deal with system boundaries with these human factor issues in mind [39]. The major goal of this approach is to avoid entire shifts of control and to find solutions to overcome system boundaries somewhere in between the poles manual and fully automated driving. This is particular feasible when the system is just lacking some information that can be provided by the driver. For instance, the vehicle can ask the driver to classify situations or objects [40].

Similarly, in the scenario that is depicted in Figure 1.1 the vehicle is lacking some information—is there oncoming traffic? However, the driver is likely to have a better overview, especially on winding or sloping tracks, and is able to decide whether to overtake or not. Preliminary previous work on cooperative overtaking [37, 38] did not consider cancellations of drivers and the system due to overseen oncoming traffic. In contrast, we included such cases in our study to investigate the feasibility of cooperation in more complex and realistic scenarios. In addition, we leveraged eye tracking to gain an objective assessment of how responsible NDRT-engaged drivers act with regards to monitoring traffic when they are asked to approve maneuvers. We implemented a system that asks the driver to approve the maneuver but conducts it autonomously to ensure high execution safety. This has two advantages: it handles the situation more efficient (by reducing travel time) and avoids a potentially problematic handover. Even in case of erroneous approval (oncoming traffic was overlooked), there is no need to switch back to manual control: the vehicle just returns to the original lane when spotting an oncoming vehicle. Any of the two cooperation partners (driver and system) is able to trigger a cancellation of the maneuver if oncoming traffic is perceived due to increasing foresight while the vehicle is transitioning onto the oncoming lane. We explored simple touch interactions to approve and cancel maneuvers. Specifically, we compared holding down a button to approve maneuvers and lifting off the finger to cancel, as opposed to clicking a button once to approve and a second time to cancel.

We conducted a driving simulator study with 32 participants to investigate the feasibility of cooperative maneuver approval in general, approval and cancel behavior, and the usability of touch interactions in this context. We evaluate these factors in light of human weaknesses like the lack of situation awareness of varying severity which we induced through a cognitive-visual-motor NDRT that varied in the level of induced cognitive load. Overall, our findings provide evidence that driver-vehicle cooperation is a feasible concept to overtake a slower vehicle with the help of the driver. Both interaction techniques provided good usability, however, the holding down / lift off approach is advantageous through facilitating faster cancel maneuvers and consequently leads to safer maneuvers. Furthermore, the glance analysis confirms that most participants act responsibly when they are asked to approve a maneuver and monitor the traffic scene. Nevertheless, the glance analysis also shows that more complex situations reduce safety precautions of drivers (i.e. glances in the rear mirror) and highlights the need for adaptive systems that monitor drivers to verify that they check all areas of importance prior to triggering an action.

2 RELATED WORK

Cooperative driver vehicle interaction is an approach to create a driver vehicle system that enables vehicle control adapted to the automation level and allows both agents (driver and vehicle) to work together towards a common goal. This approach is not only relevant in the current transition phase from manual to partial and highly automated driving, but will also play a decisive role in future fully autonomous vehicles [8]. A vast amount of research has been conducted to enable cooperative driver vehicle interaction (e.g. [7, 13, 41]) and equally numerous are the definitions for cooperation and (shared) control in the driver-vehicle context (e.g. [11, 17, 18, 20, 28]). Our cooperation concept extends from the definition by Flemisch et al. [12]: a driver vehicle system is characterized cooperative if the vehicle is used predominantly in collaboration with humans rather than completely autonomously (detached from the driver). The decisive factor here is the integration of the driver and automation into a cooperative unit. In this unit driver and vehicle form intentions based on their perception. These are then translated into cooperative actions. The cooperative actions in the proposed concept are serial. This means that the driver gives the vehicle a command for a maneuver, which the vehicle then executes. This kind of cooperative control is described in more detail in the concept *Conduct-by-Wire* [15]. However, drivers are not requested to stay in the loop continuously opposed to the Conduct-by-Wire approach: the cooperation only takes place in a short time window. Besides the detailed theoretical considerations of driver-vehicle cooperation there already exist successful implementations of task-sharing. For instance, navigation systems support drivers by guiding them, which leads to reduced workload and increased attention to safety critical behavior [35]. These systems generate a selection of route options, show the current location on a map and provide additional information.

With regard to highly automated driving, Banks et al. [2] developed a concept of a cooperative pedestrian warning and detection system based on the hierarchy of levels of automation [9]. But this concept has not been evaluated within a user study so far. The concept of partial automation was also investigated by Gold et al. [16]: while the AV controlled the lateral and longitudinal control, the human had to monitor the situation. This condition was compared to manual control with regard to safe driving in critical situations. Even if the monitoring request was rated positively in comfort and usefulness, it reduced the probability and reaction time of intervention in contrast to manual driving.

Touchscreens are increasingly prevalent in modern cars and are preferred over other devices to interact with AVs [31]. While touch interaction is not that common in academic publications regarding control transition interfaces, it is a very common interaction technique in industry patents [26]. In the case of maneuver approval, it has been shown that touchscreens [1, 19] and touchpads [14] can be used for maneuver approvals in conditional or partial automation and also in HAVs [37, 40]. The approval was performed either via dragging on a touchpad or via clicking a button. Another approach to approve a maneuver is to hold down a button as long as the maneuver is executed [38]. Some manufacturers use the concept of holding down a button for remote controlled parking (e.g. [3]). One advantage of this approach could be that it is easier and faster to cancel maneuvers just by lifting off the finger compared to click on a button, which is under investigation in this work. Moreover, we propose that the interaction technique facilitates mode awareness—as long as drivers are holding down the button they are involved in the control of the vehicle. These features can become very beneficial in highly automated driving due to the out-of-the-loop performance problem [10].

Merat et al. [25] have shown that high cognitive distraction affects the ability of regaining control negatively. Consequently, it is possible that cognitive distraction also affects the ability to interact with an HAV, in particular, to cooperate with it successfully. Therefore, we consider different levels of cognitive engagement in NDRTs in our experiment.

3 SYSTEM DESIGN

We implemented a *blended decision making* [9] maneuver approval system for highly and fully automated vehicles (SAE Level 4 and 5 [32]) to investigate driver-vehicle cooperation in the exemplary scenario overtaking a slower vehicle on a two-lane rural road. These vehicles can offer to overtake a slower vehicle to reduce travel time even if they cannot perceive oncoming traffic due to the limited sensor range towards the front caused by the slower vehicle (see Figure 1.1). When the vehicle approaches a slower vehicle and offers the overtaking maneuver (*generating*) the driver can check the environment and approve the maneuver (*selecting*). Next, the maneuver is executed by the system (*implementing*). As long as the vehicle travels towards the oncoming lane, both agents can cancel the maneuver (*monitoring & selecting*). Nevertheless, the system is always in charge of the lateral and longitudinal control (*implementing*).

The cockpit was equipped with a status display (Figure 1.3.A). This display shows the state of the ego vehicle: mode (automated or manual driving), speed, presence of a vehicle ahead and the progress of the overtaking maneuver. The display contributes to build a common ground between vehicle and driver—a *shared situation representation* that allows them to cooperate successfully [39].

Maneuver Approval & Cancellation

Drivers can approve overtaking maneuvers on a 17" touchscreen in the center console (Figure 1.3.B). Moreover, in case they missed oncoming traffic they can cancel an ongoing maneuver as well via this interface. We implemented two approval techniques using a button on the touchscreen (Figure 1.4: in the CLICK system, the driver clicks the button to approve the maneuver. Next, the button changes to a cancel button which allows to trigger the cancellation of the maneuver with another click in case oncoming traffic was overlooked. The HOLD variant allows to execute the maneuver via holding down the button. In case the finger is lifted off the button before the vehicle finished the lane change to the oncoming lane (signaled via a sound) the maneuver is canceled. The interaction can be characterized as comfortable, the approval button was easy to reach next to the steering wheel as Figure 1.3 shows. A lane change to the oncoming lane lasted 2–3 s, which means participants had to hold down the button (HOLD condition) only for this time.

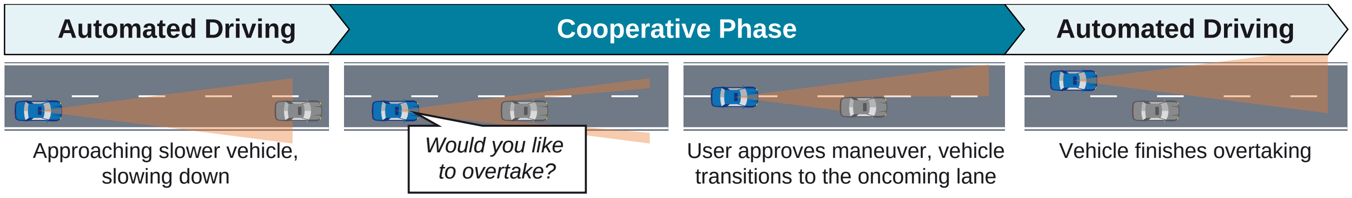

Figure 2: When the vehicle approaches a slower vehicle it asks the driver to approve an overtaking maneuver. As soon as the vehicle is on the oncoming lane, it has free vision again and can finish the maneuver on its own.

Automation Behavior & Cooperative Phase

When the system perceives a slower vehicle ahead (sensor range 200 m) it displays this on the status display. When the ego vehicle approaches the lead vehicle the sensor range towards the front is obstructed and does not allow for an automated overtaking. Consequently, the ego vehicle decreases its speed and asks the driver to approve the overtaking maneuver (*Would you like to overtake?*) and follows the lead vehicle with a headway of 18 m (≈ 1 s at 70 km/h). This quite short headway was chosen purposely to narrow participants' foresight as we wanted to investigate erroneous approvals. When the vehicle asks the driver to approve the maneuver, the cooperative phase begins (see Figure 2). As soon as the driver approves the maneuver, the vehicle signals left (right-hand traffic) and starts the lane change towards the oncoming lane. In this phase, when the vehicle has not yet reached the oncoming lane, both cooperation partners can trigger a cancellation of the maneuver in case they perceive oncoming traffic that was overlooked by the driver as illustrated in Figure 3. The sensor range increases steadily when the vehicle travels towards the oncoming lane. If the system senses contraflow, it is able to cancel instantly, especially when the oncoming traffic is close by. In such a case, it overrides the driver's input, plays a sound, and justifies its behavior (*Cancel, contraflow!*) as suggested by Koo et al. [21]. In contrast, the driver is likely to perceive a distant vehicle prior to the system due to the obstructed sensor range or for example on roads with slight bends it can happen, that the radar is maybe not heading towards the contraflow. In sum, both cooperation partners work towards the same goals: overtaking a slower vehicle, and if necessary, canceling the maneuver and avoiding dangerous situations even if the other partner does not perceive them.

4 EXPERIMENT

We conducted a simulator experiment to investigate the usability of both proposed approval and cancel techniques as well as participants' performance and behavior—in particular their glance behavior—when the vehicle asks them to cooperate after they were engaged in a NDRT. In Part I of

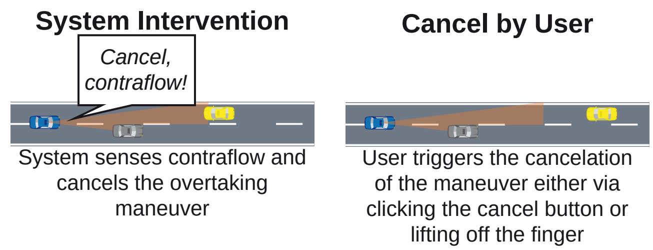

Figure 3: While the vehicle is transitioning to the oncoming lane, system and driver can cancel the maneuver.

the experiment, participants experienced both interaction techniques with two levels (low and high cognitive load) of the NDRT. They had to approve a maneuver in each combination of the levels three times. This results in a 2 (interaction) x 2 (NDRT) x 3 (repetitions) within-subjects experiment.

The scenario contained another vehicle following the ego vehicle. Moreover, there was contraflow present from time to time while the vehicle was driving autonomously and the participants were engaged in the NDRT, however, when the system asks them to approve the maneuver, there was no oncoming traffic. Participants were not informed regarding the omission of contraflow. Consequently, they had to check in both directions, i.e., whether the following vehicle is about to overtake them, or whether there was oncoming traffic. However, it is likely that they got inattentive because they neither experienced that they were overtaken nor that contraflow was present when they were asked to approve the maneuver. In Part II of the experiment we investigated whether the assumption that drivers get untrustworthy and do not check the environment prior the approval holds true: they were challenged with contraflow shortly after the system asks them to approve the maneuver without being briefed. To create the most challenging situation, they had to engage in the more difficult NDRT (2-back task). Each participant had to pass one trial with one of the two interaction techniques in Part II to avoid learning effects (between subject design).

Apparatus. The study was conducted in a fixed-base driving simulator which consisted of a vehicle mockup and three

Figure 4: N-back Task: participants had to click the checkmark button when the displayed letter matched the previous (1-back) or second last (2-back) displayed letter and the button with the red cross otherwise.

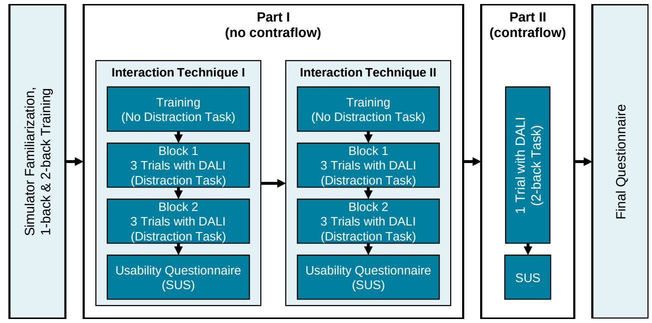

Figure 5: Outline of each session. The order of interaction and NDRT levels was counterbalanced.

large projections (field of view: 190°) as shown in Figure 1.2. The simulator was equipped with a *Smart Eye* eye tracker. The driving scenarios were simulated with the *SILAB* simulation software. The cockpit provided displays as side and rear-view mirrors as well as the previously described touchscreen and status display. Oncoming traffic as well as vehicles behind the ego vehicle were not displayed in the status display, consequently, participants had to glance towards the oncoming lane and the mirrors to perceive the surrounding.

Non-Driving-Related Task (NDRT). It has been shown, that it is very likely that drivers engage in NDRTs when travelling in an AV [6]. Consequently, participants had to engaged in a cognitive-visual-motor NDRT (n-back task) that was displayed on the touchscreen. The usage of this controlled task allowed us to draw the attention away from the road and to manipulate cognitive load of participants targeted. Thus, we were able to investigate drivers' behavior and glances when they are entirely focused on a NDRT and then prompted to make a driving-related decision as a manner of a very realistic scenario. They were challenged with two different cognitive load levels: 1-back task (lower) and 2-back task (higher). Participants saw one stimulus (letter) at a time and had to input whether the current stimulus matches the last (1-back) or second last (2-back) stimulus as shown in Figure 4. Every 2.5 s a new stimulus was displayed for 2 s. The appearance of a new stimulus was accompanied by a sound, additionally in dependence of the input of the participants the system played either a positive (correct input) or negative sound (wrong input). The negative sound was also played when the participants did not make any selection within the 2 s. When the system asks them to approve the overtaking maneuver the NDRT was interrupted and was substituted with the overtaking dialog on the touchscreen.

Questionnaires. Workload was assessed with the driving activity load index (DALI) [30] every time an overtaking maneuver was finished while the vehicle continued driving. The usability of the two interaction techniques was measured via the system usability scale (SUS) [5] (see Figure 5). At the end of the session participants had to fill in a questionnaire regarding their preferences and feedback towards the experienced system variants.

Procedure. After giving informed consent, participants filled in a demographic questionnaire. Next, they were accompanied to the driving simulator. The examiner helped them to adjust the seat to their needs and calibrated the eye tracker. After setting up the simulator, participants had to drive approximately 17 km manually to familiarize themselves with the simulator. They were told to follow traffic rules, in particular the speed limit of 100 km/h and that they should overtake slower vehicles. In the second half of this manual drive they had to overtake three slower vehicles driving with 70 km/h as they were going to do in automated mode in the following trials. Next, automation was activated (target speed 100 km/h) and every time when there was a slower vehicle ahead (70 km/h), the system asked them to approve an overtaking maneuver. Participants were told, that the vehicle cannot pass the slower vehicle automatically, since it blocks the sensor range. When the ego vehicle is on the oncoming lane the sensors are not blocked anymore and it is able to drive on its own again.

Figure 5 shows the outline of each session. Prior to the actual experimental trials, the two levels of the NDRT were explained and participants had to practice each version (58 stimuli in each condition). Next, the first interaction technique (assignment was counterbalanced) was explained and they performed a training drive without the NDRT. After finishing all drives with the first technique they had to answer a usability questionnaire. Then they were introduced to the second technique. After finishing Part I, they were told which technique and NDRT they have to do for the next three drives, but were stopped after the first. They were not briefed regarding Part II of the experiment so it was pretended to be just another round, but they were challenged surprisingly with contraflow. Each session lasted approx. 75 min. To ensure engagement in the NDRT, participants were told that they would be compensated with 8 €, and could gain 2 € extra when they perform well in the NDRT. However, all participants got 10 € regardless of their performance.

Participants. We recruited 15 female and 17 male drivers from the university population with an average age of 23.66 years ($SD = 2.87$). They reported that they own their driving license for averagely 5.97 years ($SD = 2.77$) and spend on average 11.55 hours per month ($SD = 9.98$) behind the wheel.

5 RESULTS

We measured data regarding usability, perceived workload, maneuver approval and cancel behavior, and glances of 32 participants. In particular, the glances are analyzed as indicator for the sense of responsibility (safety precautions of drivers like glances in the rear mirror) and consequently for the feasibility of the approach.

Usability

SUS scores can range from 0 – 100, where higher scores indicate better usability. A Wilcoxon signed-rank test revealed, that participants gave the CLICK system significantly higher usability scores ($Mdn = 90$, $IQR = 81.88 - 95$) than the HOLD system ($Mdn = 85$, $IQR = 74.38 - 92.5$) when there was no oncoming traffic, $p < .05$, $r = -.3$. The ratings after experiencing contraflow were not significantly different (CLICK: $Mdn = 92.5$, $IQR = 83.75 - 100$; HOLD: $Mdn = 88.75$, $IQR = 70 - 95.62$), $W = 635$, $p = .099$, $r = -.29$. The presence of contraflow did neither have a significant effect when using the CLICK system, $p = .789$, $r = -.05$, nor the HOLD system, $p = .122$, $r = -.27$.

Cognitive Workload

Participants' cognitive workload was assessed after each trial via the DALI questionnaire. The scores can range from 1 (low cognitive workload) to 7 (high cognitive workload). Due to the data's nature, we analyzed it regarding effects of NDRT levels, omitting the factor interaction and vice versa. First, the data of the conditions without contraflow was analyzed: a Wilcoxon signed-rank test was conducted as a manipulation check and confirmed that participants reported a significantly higher workload when challenged with the 2-back task ($Mdn = 3.06$, $IQR = 2.38 - 3.63$) compared to the 1-back task ($Mdn = 2.38$, $IQR = 1.89 - 2.81$) as intended, $p < .001$, $r = -.61$. The factor interaction did neither affect the scores when there was no oncoming traffic, $p = .322$, $r = -.12$, nor, as a Wilcoxon rank-sum test indicates, when there was contraflow present, $W = 148$, $p = .461$, $r = -.13$. In the contraflow trial, participants reported a significantly higher workload ($Mdn = 3.42$, $IQR = 2.96 - 3.83$) compared to their ratings using the same technique and being engaged in a 2-back task without contraflow ($Mdn = 2.86$, $IQR = 2.06 - 3.53$), $p < .001$, $r = -.42$.

	CLICK		HOLD	
A	4	(25.00%)	4	(25.00%)
A-S-A	3	(18.75%)	7	(43.75%)
A-S-A-S-A	6	(37.50%)	0	(0.00%)
A-U-A	1	(6.25%)	3	(18.75%)
A-U-A-S-A	2	(12.50%)	1	(6.25%)
A-U-A-S-A-S-A	0	(0.00%)	1	(6.25%)

Table 1: Frequencies of event sequences of approvals (A), cancellations by the user (U), and system interventions (S) when participants were challenged with oncoming traffic. Participants had to approve a new maneuver after a failed attempt.

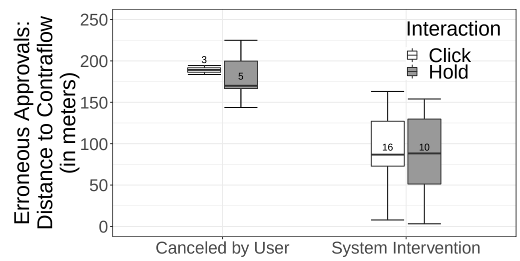

Figure 6: Distance to contraflow at the moment of an erroneous approval. Numbers indicate count of cases, one is missing (S, CLICK) due to logging errors.

Maneuver Approval Time

When there was no oncoming traffic, participants approved the maneuvers on average 2462 ms ($Mdn = 2393\,ms$, $IQR = 1888\,ms - 3005\,ms$) after the system prompted them. This time was neither affected by interaction nor NDRT level. Since, participants had to wait to approve the maneuver when there was oncoming traffic, they approved the maneuver significantly later ($Mdn = 2540\,ms$, $IQR = 1705\,ms - 5125\,ms$), $p < .05$, $r = -.26$. These approvals contain also erroneous approvals that were made too early (before the oncoming traffic passed). These are discussed in the following sections.

Approval Behavior in Case of Oncoming Traffic

When the system prompted the participants in Part II there was an oncoming vehicle driving with a speed of 100 km/h in a distance of on average 246.43 m ($SD = 0.85$) ahead. Table 1 illustrates the occurred event sequences (approvals and cancellations) until participants finally approved a successful overtaking maneuver. In both conditions, four participants waited until the oncoming traffic passed prior to approving the maneuver (A). In the remaining cases there occurred system interventions (S) and cancellations by the users (U)

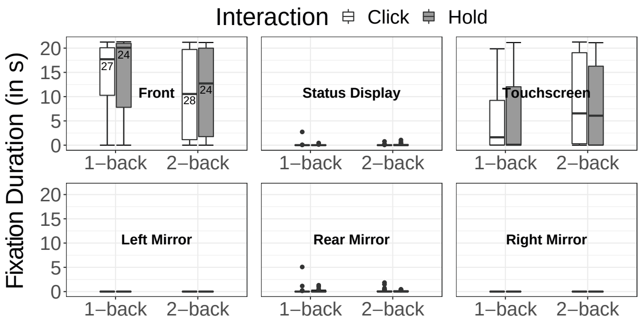

Figure 7: Fixation durations in Phase 1 (no contraflow).

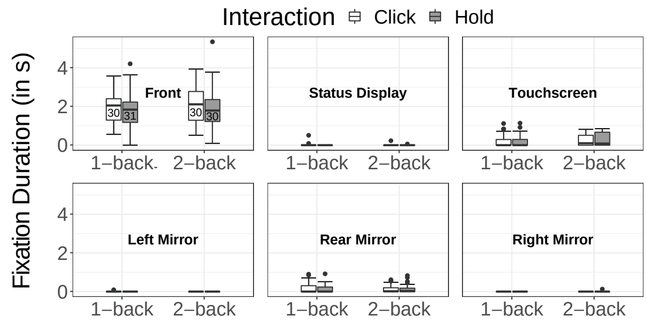

Figure 8: Fixation durations in Phase 2 (no contraflow).

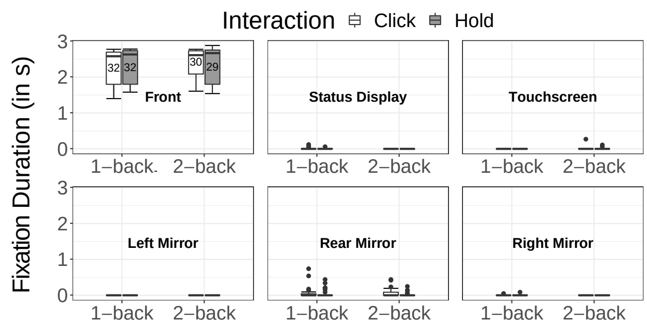

Figure 9: Fixation durations in Phase 3 (no contraflow).

themselves that caused the ego vehicle to move back again to its lane behind the slower vehicle. Next, the maneuver approval dialog appeared again and participants had to approve the maneuver again. In the CLICK condition there were 5 trials and in the HOLD condition 7 where the system did not have to intervene (sequences A and A-U-A). Four of the reported trials in the HOLD condition showed an approval followed by a cancellation of the user after on average 150 ms ($SD = 11.55$) although there was no oncoming vehicle at the moment of approval. These cancellation events were removed from the data since they look very systematic and thus it is very likely that the display did not recognize participants' fingers properly in these cases. A system intervention was necessary in 68.75% of the CLICK trials and 56.25% of trials in the HOLD condition. A Pearson's Chi-squared test does not show a significant association between the interaction technique and the necessity of a system intervention, $\chi^2(1) = 0.53$, $p = .47$.

Erroneous Maneuver Approvals & Cancellations

The boxplot in Figure 6 shows the distance to the oncoming car in the moment an erroneous approval (contraflow present) occurred which led to either a system intervention (S) or a cancellation by the user (U). The vast majority of mistakes that could be recovered by users occurred with a longer distance to the oncoming traffic (CLICK: $Mdn = 189.1\,m$, $IQR = 186.3\,m - 191.7\,m$; HOLD: $Mdn = 170\,m$, $IQR = 166.6\,m - 199.8\,m$) compared to the approvals that led to a system intervention (CLICK: $Mdn = 86.77\,m$, $IQR = 72.85\,m - 127.09\,m$; HOLD: $Mdn = 88.25\,m$, $IQR = 51.25\,m - 129.74\,m$). The distance to the contraflow when the system intervened ranged depending on the moment of approval from 0.47 m to 108.75 m ($M = 74.93\,m$, $SD = 35.53\,m$).

A Wilcoxon rank-sum test shows that participants canceled their approval significantly earlier in the HOLD condition ($Mdn = 120\,ms$, $IQR = 120\,ms - 560\,ms$, $n = 5$) than in the CLICK condition ($Mdn = 2040\,ms$, $IQR = 1820\,ms - 2060\,ms$, $n = 3$), $W = 0$, $p < .05$, $r = -.74$. Accordingly, the distance to the contraflow was significantly larger when participants lifted off their finger (HOLD condition) to cancel ($Mdn = 164.05\,m$, $IQR = 117.2\,m - 193.6\,m$, $n = 5$) compared to the CLICK condition ($Mdn = 91.96\,m$, $IQR = 88.95\,m - 98.46\,m$, $n = 3$), $W = 0$, $p < .05$, $r = -.74$.

Glance Analysis

We analyzed fixations of participants with a duration of at least 100 ms [36] prior and during the maneuver execution to gain insights on how responsible participants act (i.e., checking the traffic scene in front as well as behind via the mirrors) when asked to cooperate. For this purpose, we defined six areas of interest (AOIs): front traffic scene, left mirror, rear mirror, right mirror, status display, and touchscreen. We divided the time span of interest in three phases:

Phase 1 appearance of the slower vehicle on the status display (distance 200 m) ⟶ dialog appearance

Phase 2 dialog appearance ⟶ first input of the user

Phase 3 final approval ⟶ lane change to the oncoming lane is finished

The eye tracker cameras were mounted in the cockpit, rather than head-mounted which created a less invasive user experience but lead to some track loss. Undetected glances that were preceded and followed by glances in the same AOI with a duration below the fixation threshold of 100 ms were labeled as the surrounding AOI. Finally, trials with a track loss of more than 25% in a phase were excluded from the respective analysis. The data from the resulting trials (no oncoming traffic) was averaged for each participant. The track loss analysis removed some participants entirely in some conditions, thus the count of participants who contributed to the analysis is shown in the boxplots in Figure 7 – 9.

Figure 7 shows the total duration of participants' fixations within the AOIs in Phase 1 (no contraflow) during which participants were engaged in the NDRT. Participants focus was to the highest degree on the traffic scene in front followed by the touchscreen where the NDRT was presented. The data is not normally distributed, consequently, the factors NDRT level and interaction were analyzed separately with non-parametric tests. Participants fixated significantly longer the touchscreen when they had to do the 2-back task on this screen ($Mdn = 5970\,ms$, $IQR = 786.67\,ms - 16222.12\,ms$) compared to the 1-back task ($Mdn = 768.33\,ms$, $IQR = 4.17\,ms - 8662.5\,ms$), $p = .001$, $r = -.45$, $n = 26$. Consequently, they fixated significantly shorter on objects in the front AOI when engaged in the 2-back task ($Mdn = 12683.33\,ms$, $IQR = 3263.75\,ms - 19293.5\,ms$) compared to the 1-back task ($Mdn = 18953.33\,ms$, $IQR = 10871.67\,ms - 20253\,ms$), $p < .01$, $r = -.37$, $n = 26$. The interaction technique did neither affect the distribution of fixations during this nor in other phases, nor in trials with oncoming traffic.

When the system asked the participants to approve the overtaking maneuver (Phase 2, no contraflow) their visual focus laid primarily towards the traffic scene in front as shown in Figure 8. The NDRT disappeared and the overtaking dialog appeared instead, nevertheless, the glance behavior was affected of the NDRT levels: participants fixated significantly longer the touchscreen when they were previously engaged in the 2-back task ($Mdn = 136\,ms$, $IQR = 0\,ms - 529\,ms$) than in the 1-back task ($Mdn = 0\,ms$, $IQR = 0\,ms - 382.67\,ms$), $p < .01$, $r = -.33$, $n = 31$.

While the maneuver was conducted by the vehicle (Phase 3, no contraflow) participants looked almost all the time towards the front (see Figure 9). In this phase there were no significant differences between the conditions observable.

Comparing the average fixation duration in each AOI of all trials of a participant when there was no oncoming vehicle with the fixation duration in the last trial with contraflow, we found that there was an significant effect of the presence of traffic on the fixation duration in the rear mirror in Phase 2: participants fixated the rear mirror longer when there was no oncoming traffic ($Mdn = 65\,ms$, $IQR = 0\,ms - 224.33\,ms$, $n = 27$), whereas they fixated the rear mirror rarely, when there was contraflow ($Mdn = 0\,ms$, $IQR = 0\,ms - 0\,ms$, $n = 27$), $p < .05$, $r = -.31$, $n = 27$. Notably, only 6 of 27 participants glanced at all in the rear mirror for 320 ms to 500 ms.

	CLICK		HOLD	
	no contraflow	with contraflow	no contraflow	with contraflow
Yes	31.25%	31.25%	34.38%	31.25%
No	68.75%	68.75%	65.62%	68.75%

Table 2: Participants' votes whether they would have preferred to execute the maneuvers manually.

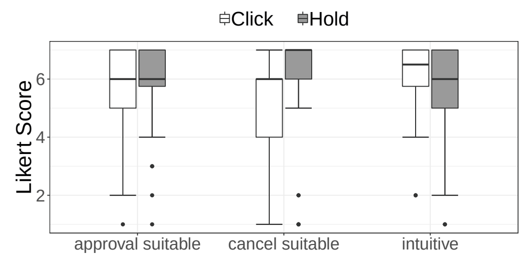

Figure 10: Ratings regarding suitability and intuitiveness.

Taken together, although participants had not to drive manually, they looked to a large amount of time towards the front in all phases, even when the NDRT (Phase 1) was present. A higher cognitive load led to longer fixations on the touchscreen where the NDRT was displayed. When the maneuver was executed (Phase 3) they monitored the traffic scene in front. The side mirrors and the status display were rarely used. Contraflow caused participants to disregard the traffic scene behind prior to the approval (Phase 2).

Participants' Preferences & Opinions[1]

As addition to the usability questionnaire we asked the participants whether they would have preferred to overtake manually. Table 2 shows that approximately two thirds of the participants liked the cooperative approach.

Finally, after all drives, we asked them to rate several statements regarding the suitability and intuitiveness of the both experienced interaction techniques on a 7-point Likert scale that ranged from 1 (*strongly disagree*) to 7 (*strongly agree*). They had to rate for each interaction technique whether they perceived it as intuitive, suitable to approve maneuvers (approval suitable), and suitable to cancel a maneuver (cancel suitable). Overall, the resulting scores were positive as shown in Figure 10. The scores did not differ significantly.

Within the usability questionnaire participants had also the opportunity to give free text feedback regarding usability. However, some participants used this chance to give feedback regarding the automation behavior: a point of criticism stated several times was that the headway to the vehicle in front was quite short and hindered the sight towards the oncoming lane.

[1]The study was conducted in German. The quotes were translated.

They suggested that the system should ask earlier when the distance to the vehicle in front is longer or that the vehicle moves a bit towards the center of the road. We expected this, but decided to configure the system in this way to get the chance to investigate erroneous approvals and resulting cancellations. Interestingly, one participant reported that she tried to use the combination of approval and cancellation to see whether there is oncoming traffic, but she added that the system is not suitable for this since it indicates instantly.

One participant stated that she perceived the HOLD approach *"unpractical"*, another stated that the CLICK system is more *"self-explanatory, however the first [HOLD] system seems better as I had to hold down the overtaking button. This gave me the subjective feeling of higher safety."* One participant described both systems as easy to use and learn. Another reported *"I perceived the first [HOLD] system as better, since I felt safer as I had to pay attention to the system through holding down the button."* One participant felt more control over the system using the HOLD approval and that the higher physical effort should not be relevant when using the system sporadically. *"[The] attention is still needed during the overtaking procedure since one is still active in the task"* was stated by another participant about the HOLD system.

We asked the participants whether and how they experienced a cancellation of the overtaking maneuver in the final questionnaire. Many participants commended the system behavior: they used words like *"appropriate"*, *"somewhat rough, but safe"*, *"good"*, *"tip-top"*, *"quick"*, *"relatively comfortable"*, and *"short response time"*. One participant described the cancel maneuver that was triggered by himself as *"very comfortable and safe. One had control over the vehicle."* In contrast, another participant had mixed feelings regarding the system behavior *"In general, I perceive it uncomfortable to have no control over the vehicle in dangerous situations, however the reaction of the system was satisfying."* One participant who experienced two system interventions perceived them as *"somewhat stressful and hectic"*, he added, *"one clicks too thoughtless on the overtake button"*. One participant was startled from the oncoming vehicle and lifted off his finger reflexively and with this canceled the maneuver (HOLD condition) he supposed that *"another click to cancel the procedure would have come to my mind far too late."* Another participant was also startled, however, she reported that she was able to *"start a new overtaking maneuver calmly"* what she perceived as significantly less stressful than overtaking manually. After experiencing a system intervention one participant stated *"this experience increased my trust in the system substantially."*

6 DISCUSSION

The role of drivers in HAVs changes. As a result, it is likely that they are engaged in NDRTs. In our experiment, participants were challenged with a cognitive-visual-motor NDRT that induced different levels of cognitive load. Even when they reported a higher workload when challenged with the 2-back task they were still able to cooperate with the system. They reported higher workload when challenged with contraflow. This supports our cooperative approach: In more complex situations drivers should be supported rather than being left alone without the assistance of the system (transaction to manual driving) since there remains functionality available that can be used to support the driver [39]. Nevertheless, all workload scores were moderately low.

Two thirds of our participants had not preferred to overtake manually. Both interaction techniques provided good usability. Participants rated the usability of the CLICK system significantly higher when there was no oncoming traffic, maybe due to less physical effort. The scores for both systems did not decrease when participants were challenged with contraflow. This suggests that the approach in general, and both particular interaction implementations provide good usability even when participants made a wrong decision. This is also supported by the free text answers participants gave. Moreover, both systems were rated as intuitive and as suitable to approve and cancel maneuvers. It bears mentioning, that a trend in favor for the HOLD system regarding the suitability to cancel maneuvers was observable.

We classified four of the recorded cancellations as invalid, since in these cases it was very likely that the touchscreen did not work properly. This highlights the importance of robust interaction techniques. It is likely that drivers lift off the finger when driving over an unevenness like a pothole. This could be addressed with tolerance mechanisms that allow short releases. Another solution would be to position the interaction device at places where the arm or hand of the driver is propped up like on the armrest. Maneuver approval can also be done with more robust physical buttons.

Only 25 % of participants managed the contraflow trial without a cancellation or system intervention. System interventions occurred in 68.75 % of trials in the CLICK condition and 56.25 % in the HOLD condition. The high share of erroneous approvals is likely caused by implementing purposely a very short headway. The short headway was bewailed by participants. Moreover, participants may have misused the system: first, it was mentioned that a participant has tried to approve and cancel to get a better sight. Second, knowing that the system prevents collisions, they might have tried to approve the maneuver again and again until the system accepts it. Consequently, we recommend, that such a system should move as far as possible towards the center of the road, keep a long enough headway and ask the driver early to interact to provide best possible viewing conditions. Regarding the potential misuse, it may be beneficial to allow users to activate an aggressive automated driving mode that allows the vehicle to sway periodically across the center of the road which could allow to overtake autonomously or at least increases the foresight of drivers. However, this approach will be uncomfortable when there is oncoming traffic and the vehicle has to cancel and go abruptly back onto its lane—driver and passengers will be tossed about in the vehicle, especially when they do not watch the traffic scene. Considering the frequency of system interventions, we suggest to implement driver monitoring in such systems to decline user input if it is likely that the driver is not able to cooperate reasonably. For instance, eye tracking could be used to monitor whether the driver checked the traffic.

The AOI that was focused longest during all phases was the traffic scene in front, which supports the feasibility of cooperation even if drivers are engaged in NDRTs. The level of induced cognitive load via the NDRT affected the share of fixations between the front and the touchscreen: when participants were challenged to a higher degree their focus laid more on the touchscreen. This phenomenon was still prevalent when the NDRT was interrupted for the purpose of cooperation. Nevertheless, there was a large variance in the proportion of glances towards the front observable. Notably, the participants rarely used the mirrors to gain insights on what is going on behind them. The presence of contraflow reduced the duration of fixations in the rear mirror prior the approval—only 22 % of participants looked at all in the rear mirror when there was contraflow. This shows one more time, that drivers need support from the system when situations become more complex: depending on the system capabilities and the systems' perception of the traffic scene behind, it should ask drivers explicitly to monitor this sector when driver monitoring shows that they disregard it.

Participants canceled faster after an erroneous approval when using the HOLD system, this resulted in a larger distance to the contraflow at the time of cancellation and with this to a safer drive. The erroneous approvals that could be recovered by the user occurred on average at a distance of more than 180 m to the contraflow, whereas approvals that led to a system intervention occurred on average at a distance of less than 94 m. This can also be seen as support for the cooperative approach, since the nearer the contraflow is the faster the vehicle is able to detect it, whereas distant traffic can be perceived earlier by the driver.

Limitations

We gained several insights regarding the feasibility of driver-vehicle cooperation to overtake a slower vehicle and regarding two particular interaction techniques to approve and cancel such a maneuver. Nevertheless, our experiment has its limitations: We conducted a study with a fixed-base simulator. There might be effects on the risk drivers take that a maneuver has to be canceled when they are exposed to vehicle movement. Another limitation is that only young drivers participated. We observed only first use cancel behavior and the analysis is based on a small number of user cancellations.

7 CONCLUSION

We investigated a cooperative approach to overcome weaknesses of HAVs, in particular, to overtake slower vehicles that block the sensor range. We implemented two approval techniques that allowed to approve the overtaking maneuver without falling back to manual driving: clicking and holding down a button on a touchscreen. A simulator experiment was conducted to gain insights on the usability of the approval techniques, how participants deal with oncoming traffic and where they look prior and during the maneuver execution.

Participants liked the concept and the majority did not want to execute maneuvers manually, which is in line with previous work [37, 38, 40]. Both approval techniques provide good usability even when situations become more complex.

In 62.5 % of trials when there was oncoming traffic a system intervention was necessary. Nevertheless, driver and system seem to complement each other in an appropriate way. When the oncoming vehicle was far away at the point of maneuver approval the drivers canceled the maneuver, whereas when the situation was more critical and the oncoming vehicle was not that distant the system intervened. The HOLD system revealed its superiority regarding cancellations: participants reacted quicker when they had to release the button to cancel than when they had to click again on a button. This resulted in safer maneuver cancellations with a significantly longer distance to the contraflow.

The glance analysis supports the feasibility of cooperative maneuver approvals since participants glanced to a large amount of time towards the traffic scene in front. This leads us to suppose that the majority acted responsibly when the system asked them to cooperate. Nevertheless, we recommend to implement driver monitoring in such systems to ensure that drivers behave as the system expects them to do.

In conclusion, the concept of driver-vehicle cooperation in regard to overtaking maneuver approval due to obstructed sensor range is feasible and provides good usability. Due to faster reactions when erroneous decisions were made we recommend to use the holding down approval technique. More research is necessary to investigate in which other scenarios such cooperation is feasible and in which use cases beyond maneuver approval driver and vehicle can become team players and complement each other.

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