A METHODICAL APPROACH TO EXAMINE CONFLICTS IN CONTEXT OF DRIVER - AUTONOMOUS VEHICLE - INTERACTION

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Summary: Future autonomous vehicles will make their own maneuver decisions whereby situations will occur in which the maneuver performed by the autonomous vehicle contradicts the course of action preferred by the driver. In response, the uninformed driver takes over manual control of the vehicle and performs a potentially inappropriate and safety-critical maneuver due to a lack of information. To prevent such a behavior in future, a methodical paradigm is needed, which is able to create possible driver - autonomous vehicle - conflicts and examine preventive and cooperative solutions in a driving simulator. This study (n = 29) is a successful methodical approach to create possible, authentic and reproducible driver - autonomous vehicle - conflicts. Conflicts were caused by a combination of gradation of visibility by fog (full visibility, 150m, 100m, 50m) and a maneuver performed by the automation (overtaking, following) on a rural road. 83% of the drivers canceled an overtaking maneuver by the automation and took over manual control in the 50m condition compared to 2% in the full visibility condition (z=1.914, p<.00). If the automation performed a following maneuver in the full visibility condition, 95% of the drivers overtook manually, compared to only 6% at 50m visibility (z=2.069, p<.00).

INTRODUCTION

The automotive industry is currently focusing on pushing vehicle technology towards fully automated driving, with technology companies joining these efforts. The aim of vehicle autonomy is to make road traffic safer and more efficient by partially or completely substituting the driver in the driving task (Dokic, Müller, & Meyer, 2015). The transition phase from manually-operated cars to fully automated vehicles is characterized by conditionally and highly automated vehicles that take over parts of the driving task, such as automatically following the road. Since these systems cannot completely manage the driving task, the driver will partially have to support the system or take over control. Therefore, a lot of research is done to implement adequate take-over request strategies (Melcher, Rauh, Diederichs, Widlroither & Bauer, 2015), involving the driver as an additional sensor for example to extend the capabilities of the semi-autonomous vehicles (Walch, Sieber, Hock, Baumann, & Weber, 2016) and to keep the driver in the loop (Lange, Albert, Siedersberger, & Bengler, 2015). However, already existing systems (e.g. emergency stop assistants) and future systems will perform better than humans in more and more sub-areas of the driving task until they finally take over completely. This complex future artificial system, which perceives the environment and makes its own decisions, will be confronted by human beings who are used to making their own decisions and actions in road traffic based on the perceived environment. If these two agents meet, situations will inevitably arise in which the planned action of the automation contradicts the desired action of the driver. Consequently, the driver will wish to override the driving behavior of the automation. This intervention can potentially lead to safety-critical driving behavior such as deterioration of time to collision or lane-keeping (Radlmayr, Gold, Lorenz, Farid, & Bengler, 2014). The driver's behavior is affected by the acceptance and trust in the automation, which is influenced by prior information about the automation as well as experiences in direct interaction with the automation (Beggiato & Krems, 2013). In addition, these systems will make decisions based on information content that is not directly accessible to humans (e.g. based on Car-2-X communication). Therefore, an optimal solution to this conflict is not necessarily allowing the driver to always decide about the next maneuver, but to leave the decision entirely to the system. In order to investigate solution strategies in this context, a methodical paradigm is needed which creates possible human-machine conflicts that can be used to examine these conflicts and possible solution strategies in a laboratory environment or driving simulator.

Our study shows a successful methodical approach to create authentic and reproducible conflicts between automation and driver in a static driving simulator. We made two assumptions about factors that possibly cause a driver-automation conflict. First, a conflict occurs when the vehicle plans a maneuver based on information that is not directly accessible by the driver. Second, a conflict occurs if the vehicle is driving conservatively and the driver considers this unnecessary. We implemented these assumptions by varying the visibility through fog on a rural road and combining it with a car following drive or overtaking maneuvers of the automation. Our leading hypotheses are:
H1: As visibility decreases, the driver will permit an overtaking maneuver less frequently.
H2: As visibility increases, the driver will permit a following drive less frequently.

METHOD

Participants

The sample consisted of 15 female and 14 male participants with an age ranging from 20-53 years of age (*M* = 26.48, *SD* = 8.19). All participants owned a German driver's license for *M* = 8.31 (*SD* = 7.01) years on average with a range of two to 34 years. The participants were compensated monetarily or with course credit.

Driving Simulator

The study was conducted in a static driving simulator consisting of three 1920 x 1200px video projections onto three screens of 3.3 x 2.1m with a 200° viewing angle (see Figure 1). The vehicle mock-up contains the basic car interior elements. The simulation software used was SILAB 5.1.

Human-Machine-Interface

In the center console, a 17"touch display (1024 x 1280px) is located allowing interaction with the automation (see Figure 2). The display contains information about the traffic rules, the distance covered and the amount of delay due to the traffic conditions. In the center of the display, planned and current maneuver (free ride, overtaking or follow the vehicle(s) in front) of the automation is highlighted. In the lower section, the button to enable and disable the automation is located.

Figure 1. Driving Simulator

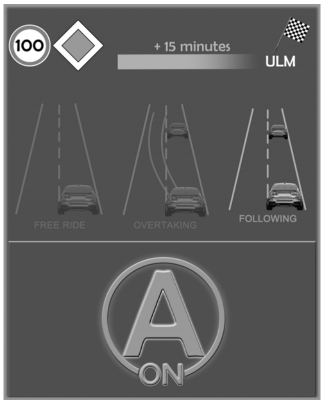

Figure 2. Human-Machine-Interface

Automation

The automation level used in this study corresponds to the SAE-level 4 (SAE International, 2014). The automation was able to recognize road users, (via a simulated radar system) follow the rural road course and pass or follow the vehicles in front. In case of shortcomings of the radar system, the automation always had a fallback strategy to correct the current maneuver. For example, it would brake sharply during overtaking and reeve, when oncoming traffic appears unexpected. When enabled, the automation kept a constant speed of 100km/h (62 mph). The automation was programmed to avoid accidents at all times.

Study Design

This study was conducted in a 4(visibility) x 2(number of cars in front) x 2(maneuver) x 4(randomization group) mixed design. The visibility was operationalized by fog and graded in full visibility, 150m, 100m, and 50m. The fog density was set up in such a way that the participant's vision of the road was fully blocked after 150m, 100m or 50m. The number of cars in front was operationalized by either one or two cars in front of the ego vehicle. All simulated vehicles drove 60km/h (37 mph). The variable "maneuver" was two-tiered. Either the automation overtook or followed the car(s) in front. Moreover, there were four randomization groups to control for order effects. All of them experienced the 16 measurement periods and 4 distractors in the experimental ride in a different order. Participants were assigned randomly to one of four groups. Randomization groups were used because of a technical limitation to randomize all measurement periods and distractors for each participant.

The participants' task was to question the automation's decisions. If for some reason they did not agree with the action of the automation, they should take over control of the vehicle and drive the preferred maneuvers manually. The number of deactivations of automation by the participant constitutes the dependent variable.

Procedure

First, participants signed the informed consent and were informed about the study procedure. Prior to interacting with the driving simulator, they read instructions on how the automated system works, which functions it is able to perform and the possibilities to intervene. It was particularly highlighted that the automation can see through the fog with the help of its sensors. After the participants were familiar with the information about the automation, they were informed about their task in this experiment (see study design). The next step was a training session in order to familiarize with the driving simulator, the automation and the interface. If there were no further questions, the participants were reminded of their task and the experimental course started. At the end of the experiment, the participants filled in questionnaires about demographics, driving experience and system acceptance. Then they were compensated and debriefed. The whole experiment lasted 2 hours.

Course – driving simulator familiarization

This familiarization course consisted of two parts. The first section was driven manually and served to familiarize the participants with the vehicle dynamics of the driving simulator. In the second part, the participants were familiarized with the behavior and interaction with the automation. On this part of the track, the automation performed three overtaking and one car following maneuver successfully while one overtake evoked a fallback strategy caused by a shortcoming of the radar system including harsh braking and abortion of the overtake maneuver.

Course – experimental ride

The experimental ride consisted of a bidirectional rural road with 16 measurement periods and 4 distractors. Each segment of the course was 4540m long. The measurement periods were divided by crossroads, where all simulated vehicles turned off. On the whole course, eight overtaking and eight following maneuvers were performed by the automation. On every section of the route, oncoming traffic was presented. In the segments with car-following maneuvers, oncoming traffic stopped shortly before the maneuver started. In the parts with overtaking maneuvers, the oncoming traffic did not stop and the maneuver was performed in the gap between two cars on the opposite lane. During the distractor drives, no traffic appeared on the lane of the ego vehicle. In total, the participants needed about 65 minutes to complete the course.

Questionnaires

Acceptance of the automated car was measured before and after the interaction with the automation. We adapted a 5-item short version of the English questionnaire by Payre, Cestac and Delhomme (2014) with a reliability of α_{before}=.63 and α_{after}=.69. One sample item of the questionnaire is “The automated driving system would provide me safety compared to manual driving”. Participant’s demographics and driving experience were assessed with single items after the experimental drive.

RESULTS

At the beginning of this section, the results relevant to the research questions are presented descriptively. Subsequently, the results of the corresponding statistical test are shown. Finally, the influence of acceptance of autonomous driving on the behavior of the participants is briefly discussed. A McNemar-test proved that there are no significant differences in the behavior of the test persons with regard to the different number of vehicles driving in front. For this reason, the number of vehicles driving ahead was not taken into account in further calculations.

Figure 3 shows the number of automation-initiated overtaking maneuvers which were canceled by the driver. Over the different visibility conditions, a clear trend in the canceled overtaking maneuvers can be recognized. While 2% of overtaking maneuvers were canceled in clear visibility, 83% of the overtaking maneuvers were canceled in the 50 m visibility condition.

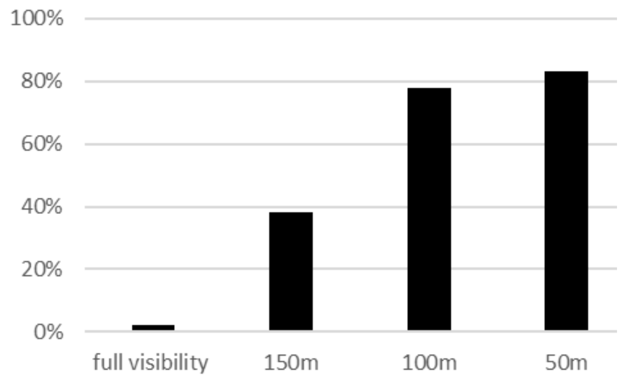

Figure 3. Number of automation-initiated overtaking maneuvers canceled by the driver depending on visibility

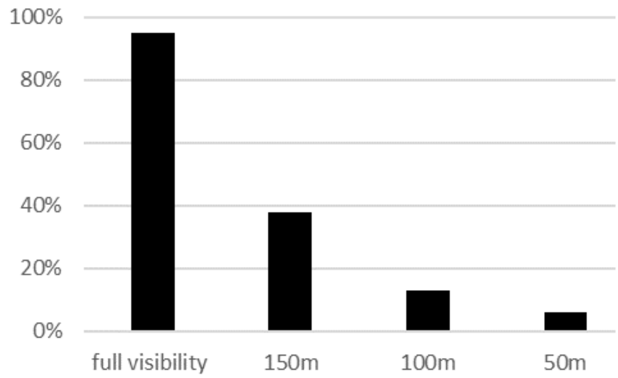

Figure 4. Number of automation-initiated following maneuvers canceled by the driver depending on visibility

Figure 4 shows the number of following maneuvers driven by the automation which were canceled by the driver. The significant number of canceled following maneuvers in the full visibility condition compared to all three limited visibility conditions is of note. In the full visibility condition, 95% of the following maneuvers were canceled by the driver. This means that 5% participants did not turn off the automation and overtook manually. In contrast, 94% of following maneuvers were permitted at a visibility of 50m.

To distinguish the behavior of the participants between the different visibility conditions during an overtaking and a following maneuver a Friedman-Test with a Dunn-Bonferroni post hoc test was used.

Table 1 summarizes the significant differences between the conditions during an overtaking maneuver. In the last column the Pearson's correlation is reported as effect size.

Table 1. Comparing different visibilities regarding canceled overtaking maneuvers

pairwise comparison visibility	test statistic z	significance level p	effect size r
50m vs. 100m	0.121	not significant	-
50m vs. 150m	1.138	.005	.211
50m vs. full visibility	1.914	.000	.355
100m vs. 150m	1.017	.016	.189
100m vs. full visibility	1.793	.000	.333
150m vs. full visibility	0.776	not significant	-

It can be seen that almost all gradations in visibility became significant at an average effect size. Only the gradations [50m vs. 100m] and [150m vs. full visibility] do not differ significantly from each other.

Table 2. Comparing different visibilities regarding canceled following maneuvers

pairwise comparison visibility	test statistic z	significance level p	effect size r
50m vs. 100m	0.190	not significant	-
50m vs. 150m	0.845	not significant	-
50m vs. full visibility	2.069	.000	.384
100m vs. 150m	0.655	not significant	-
100m vs. full visibility	1.879	.000	.349
150m vs. full visibility	1.224	.000	.227

As highlighted in Table 2 only the individual conditions with limited visibility differ from the condition without limited visibility with a medium effect size. The conditions with limited visibility do not differ significantly from each other.

Acceptance

Prior to the experiment, the acceptance of automated vehicles was rated rather positive with an average of $M = 5.03$ ($SD = .98$) on a 7-point Likert scale. Afterwards, the acceptance of automated vehicles decreased $M = 4.52$ ($SD = 1.12$). The difference between prior and post acceptance was tested with a paired t-test. The test revealed that prior and post acceptance differ significantly from each other ($t = 3.30$, $p = .003$, $n = 28$) with a strong effect size ($r = .53$). No significant correlations between the measured acceptance and the behavior of the participants in the different conditions could be detected.

CONCLUSION

Both research questions can be answered in the affirmative. Especially the gradation of visibility in the overtaking condition shows a strong effect regarding the creation of conflicts between automation and driver. Although not all of the gradations differed significantly, the descriptive statistics and the medium effect sizes showed a clear tendency that the disagreement between system and driver is stronger or more frequent with worsening visibility. This finding is in line with our initial assumption that a conflict between driver and vehicle occurs when automation uses information that is not directly accessible to the driver. The second research question, which is based on the assumption that a conflict occurs if the vehicle is driving conservatively and the driver does not consider this as necessary, is supported by the results. Almost all drivers switched off the automation when it had not overtaken the slower traffic ahead in a clear view condition. That the gradations differed only from the clear view and not from any other, can be explained by the fact that the driver may feel less safe in reduced visibility. For this reason, they initiate fewer overtaking maneuvers with reduced visibility. Uncertainty and acceptance are often mentioned in the context of autonomous driving (Beggiato & Krems, 2013). In this study no evidence for a correlation between acceptance and the behavior of the participants in the different situations was found. Nevertheless, before the experiment the acceptance of automated driving was significantly greater than at the end. This result can be explained by the fact that a conflict between the driver and the vehicle was deliberately created. This in turn can affect the measured acceptance.

The aim of the study to establish a methodical approach to create authentic and reproducible conflicts between automation and driver was successfully achieved. This methodical approach should now be used to examine machine-driver conflicts and strategies to avoid the conflicts preventively or to provide collaborative solutions based directly on specific situations. One possible limitation to be addressed in future studies is the lack of distraction in the study paradigm and the influence on driver - autonomous vehicle - conflicts.

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