PUBLIC SUMMARY

Increasing clarity, cooperation and driver experience in lane changes

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About this document

This is **not** the full thesis, but a public summary that holds information about research that has been conducted at the Volkswagen AG’s research and development department between April 2017 and September 2017. The master’s thesis that has been written as a result of this research is marked as confidential until September 2022. Therefore, this document wraps up the information that may be disclosed to the public before the non-disclosure agreement ends. Consequently, much of the information is disclosed and masked by terms like “HMI concept 1” and “HMI concept 2”. Other parts of the thesis had to be omitted altogether.

The research that has been conducted for this thesis is related to the dissertation that is currently being written by Adrian Haar.

Table of Contents

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There are traffic situations that require cooperation between drivers to be solved. A common example is a situation in which a fast car is driving with 130km/h on the fast lane of a highway and approaches a much slower car that is driving 110km/h on the other lane. The driver of the slower car sets the turn signal to communicate the intention to change to the faster lane. Most likely, this creates an uncomfortable feeling in the driver of the fast car and leaves him guessing whether he might have been overlooked. A quick decision has to be made between slowing down to let the other car in and speeding up to quickly escape the ambigious situation. The two drivers have to cooperate by adapting their behavior to each other in order to avoid a collision. Unfortunately, the driver's interpretation of the situation is the only thing upon which the decision can be based. Consequently, it is hard for the drivers to choose the correct behavior because it is unclear what the other driver's intentions are. This lack of certainty presents a dangerous source of misunderstandings, which in turn might lead to accidents.

Sen, Smith and Najm (2003) found that about 9% of all accidents are related to lane chane situations. In general, false assumptions of others' actions have been identified as the cause of 4.5% of all car accidents (National Highway Traffic Safety Administration, 2008). Therefore, false assumptions should be reduced by improving the communication between drivers. This paper proposes two ways in which the communication between drivers could be enhanced. Eventually, if one or both of those approaches turn out to be useful, the resulting findings would be a first step towards safer and more comfortable lane changes.

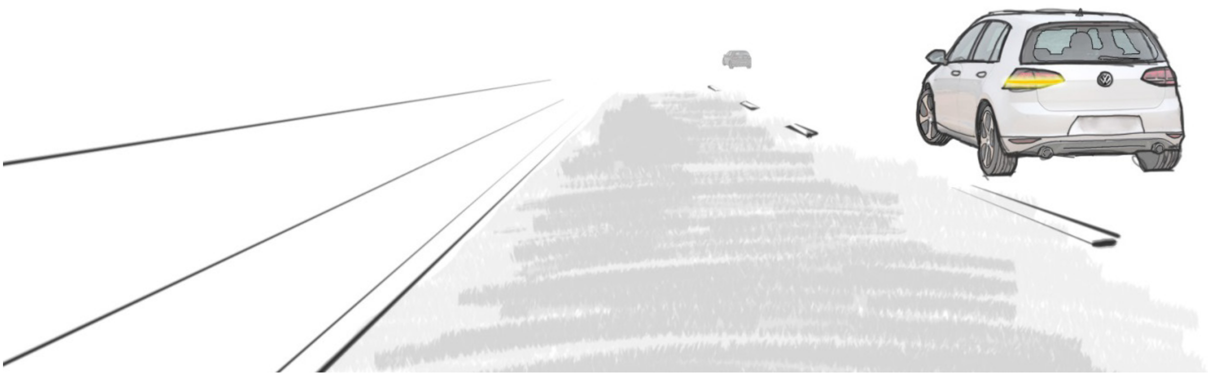

Figure 1. An example of an ambigious lane change situation. It is unclear whether the other driver will immediately change lanes or wanted to communicate that he will change lanes behind the approaching car.

1.1 Cooperation among road users

Most traffic situations embrace multiple road users and often cooperation among them is required to solve a situation. Ellinghaus (1986) conducted a survey among 2000 motorists and identified lane changes as one of the most cooperative situations in traffic. In situations like these, drivers have to adapt their behavior to the behavior of another driver. For instance, the slower driver might use the turn signal to communicate the intention to change lanes. In response, the driver of the fast car might decide to slow down to create a gap for the slower car. Thus, by doing so, the driver of the fast car reacts to the behavior of the slower car's driver. Cooperation is also required in other situations, including intersections where all drivers have equal right of way and where hand gestures are the common way of arranging the order in which the drivers will enter the intersection (Björklund & Åberg, 2005).

Facilitating cooperative behavior in traffic is expected to have multiple positive effects. Benmimoun, Neunzig and Maag (2004) identified comfort and safety as core needs that are of immense importance to road users. Firstly, successful cooperation between drivers promises to increase safety by minimizing the amount of accidents that occur due to misunderstandings. Secondly, it is likely that traffic is perceived as more comfortable when road users cooperate by e.g. opening a gap for a slower car or by changing to a slower lane when a faster car is approaching from behind.

To get a better grasp of the processes that are involved in cooperative situations, several models of cooperative interactions have been proposed. Benminoun et al. (2004) suggested a model to describe the factors that play a role to determine whether or not a road user will cooperate. Their model suggests that the decision whether to engange in cooperation or not depends on the assessment of three factors in a given situation. Firstly, a driver assesses whether it would be safe to cooperate. Secondly, the costs of cooperating are assessed and thirdly, the other driver's need of help is estimated. Consequently, the model suggests that it is likely that drivers behave cooperatively if their safety won't be compromised, if the costs are not too high and if the other driver appears to really be in need of help.

With this in mind, this study will compare today's way of communicating during lane changes with two alternative approaches that promise to enhance communication and thereby benefit the cooperation among drivers. In the next sections a critical look at today's turn signals is taken and the two alternative approaches are introduced.

1.2 The present study

The present study is an attempt to improve the interaction between drivers in cooperative lane changes with two HMI concepts. The two new concepts under investigation are based on the findings of a study by Haar, Kleen, Schmettow and Verwey (in preparation). Their potential of making communication between drivers clearer and less ambigious will be examined. There are three expected outcomes. Firstly, it is expected that the two concepts will have an effect on the amount of cooperative behavior and the perception of cooperation.

> ***Research question 1:*** *In how far does usage of the new HMI concepts affect cooperative behavior and the perception of cooperation?*

Secondly, it is assumed that that using the two HMI concepts will allow the participants to get a better feeling for the exact moment in which another driver is starting a lane change maneuver.

> ***Research question 2:*** *To which degree do the new HMI concepts increase clarity about the exact moment in which another driver starts a lane change maneuver?*

Thirdly, it is expected that the use of the two HMI concepts will lead to less stressful and more pleasant interactions during lane changes.

> ***Research question 3:*** *What is the impact of using the new HMI concepts during a cooperative lane change on the driver experience?*

Method

2.1 Participants

A sample size of n = 48 or more participants was desired to make complete counterbalancing possible as it requires a multiple of 24 when four conditions are used. In order to deal with possible attrition, 55 participants have been invited. After all, n = 53 participants completed the study (M_{age}= 36, 46% female). One participant quit the study prematurely due to simulator sickness. Consequently, that participant has been removed from the sample and a total of n = 52 remains. Participant 24 accidentally quit the survey application which resulted in a failure to save the questionnaire data for one condition. Therefore, the questionnaire data for condition A has not been captured for participant 24. The remaining questionnaire scores of that participant score were included in the analysis. Furthermore, the logging of the driving data failed six times. All of the participants were employees of the Volkswagen AG. The recruitment was done via Volkswagen's Probandenpool (participant pool). Upon completion of the study, the participants received a small gift from the participant pool to compensate for the time that they spent to participate. All participants were German and all questionnaires and instructions were provided in German language. Good vision (with or without correction) and a driver's license were required for participation. On average, the participants drove 18068km (SD = 10910) per year. None of the participants stood in a relation to the experimenter that might have had an influence on the results.

2.2 Apparatus and setting

Material. A traffic simulation software was used to create a scripted highway scenario. It included other road users that were controlled by the computer. When the participant approached those vehicles, a set of pre-defined actions has been executed.

The HMI concepts that were used were the product of a pre-study with two iterations that has been conducted prior to the study.

Experiment. When driving the scenario, the driver was driving on a highway with two lanes. The driver experienced a number of situations in which another car attempted to change to the driver's lane. In those situations, the participant had to choose whether he let the other car in or not by accelerating or decelerating. In total, there were five encounters in which the participant passed by a slower car. In three out of those five encounters, the car set the turn signal to change to the participant's lane. In the other two situations the car did not attempt a lane change. It took the drivers five to six minutes to complete the whole scenario.

Each participant experienced all four conditions (with 5 situations each). The only thing that changed across those conditions was the HMI concept that has been used.

Measures. Subjective as well as objective measurements were done to determine how the participants perceived the lane change situation and how much cooperative behavior the participant showed. The *subjective measurement* consisted of 18 questions that measured the quality of the lane changes in terms of comfort, efficiency, safety and the feelings that were evoked in the participant. Furthermore, the questionnaire included ratings of how clear the intentions and the timing of the other drivers were. Aside from this, the following entities were measured: the participant's feelings during the lane changes, the workload while driving and the degree to which the situation was assessed as being cooperative. Three questions were based on Benmouni et al.'s (2004) findings that identified comfort, efficiency and safety as the core needs that people strive for while driving. The remaining questions were based on a questionnaire that has proven to measure what it purports to measure in a study by Zimmermann et al. (2014). The participants could give their ratings on a 7-point Likert-scale that ranged from *"I fully disagree"* to *"I fully agree"*. In addition, the participants were asked to rate the different concepts on the Van der Laan scale (Van der Laan, Heino & De Waard, 1997). The Van der Laan scale is used widely in usability testing and has been developed for the evaluation of HMI concepts. It consists of 9 items and measures the dimensions of *satisfying* and *usability*. The ratings are done on a 5-point Likert scale. Moreover, participants were invited to write down a more detailed description of how they perceived the lane change if they felt limited by the phrasing of the questions. Furthermore, the Driving Activity Load Index (DALI) was used to assess the workload of the participants during the driving task (Pauzié, 2008). Finally, the participants were asked to rank the four concepts to determine which concepts they liked the most.

The *objective measurement* of cooperative behavior consists of counting the amount of lane changes in which the participant slows down to let the other car in. The more often a participant allowed a lane change, the more cooperative that behavior was regarded.

Setting. The study took place in one of the fixed-base simulators in Volkswagen's Research and Development facility. A lab demonstrator with a real steering wheel, pedals and car seat and a display for the standard driving information has been used. The simulation was projected on three 4x4m canvases in their front and to their sides. To allow for a look in the rear mirror and the side mirrors, three flatscreens were placed behind the simulator to create an immersive experience. Prior to the conduction of the study, the Volkswagen participant pool reviewed the procedures of the experiment with the conclusion that they were ethical.

2.3 Design

This study was designed to allow for both, between-participant and within-participant observations. The independent variables were whether HMI concept 1 was active (*disabled* or *enabled*) and whether HMI concept 2 was applied (*applied* or *not applied*). The dependent variables were the amount of cooperative behaviour, which was measured by looking at whether the participants allowed the slower car to change lanes (objective) and the participants' perception of the situation (subjective). Complete counterbalancing has been used to control for order and learning effects. Hence, the total number of participants had to be a multiple of 24 ('Finer points of design', 2001). Any participants that exceeded this number received their order of trials based on randomized counterbalancing. Thus, a total of 48 participants has been determined as the target sample size. In order to account for potential attrition, 55 participants were invited to take part in the study.

2.4 Procedure

At the start of the experiment, the researcher instructed the participants about the possible side effects that the use of a fixed-base simulator could have and informed them that they were free to cancel the experiment at any time without any further consequences. After doing so, the participants read a short introduction to the experiment and filled in a questionnaire on a tablet in which they had to answer basic questions about their personality and background. After doing so, the researcher guided the participants to the lab simulator, asked them to sit down in the driver's seat and to adjust the seat and mirrors to their preferences. The researcher then started a testdrive and sat down next to the participants in the passenger seat. He invited them to get used to the simulator by accelerating, braking, steering and changing lanes. This allowed them to get comfortable with the feeling of driving in a simulated environment and the simulator and its handling. Completing the testdrive took about four minutes. Subsequently, the researcher asked the participants how they felt and reminded them that they could stop the experiment at any time. Once the participants were all set, the researcher started the first condition. Upon completion of the first condition, the researcher asked the participants to fill in the first questionnaire on the tablet and told them that they could ask questions at any time. Then, the three other conditions were tested in the same manner (driving and then filling in a questionnaire about the drive). After the fourth questionnaire had been filled in, the participants were invited to ask open questions about the study and to leave remarks if desired. Lastly, to compensate for the time and the effort that the participants had invested, the researcher thanked them for their participation and rewarded them with a small gift.

2.5 Data analysis

This section introduces the methods that have been used for the data analysis. Furthermore, it explains why the researchers refrained from using classical p-value testing.

2.5.1 Uncertainty intervals and Bayesian inferences

The data analysis does not rely on p-values for significance testing but on Bayesian uncertainty intervals to quantify uncertainty about the entities in question. The reason is that major concerns have been raised about the way in which p-values have often led to the publication of allegedly meaningful results, which – upon closer investigation of the data – turned out to be meaningless. P-values make it easy to draw conclusions from statistical patterns that a researcher might stumble upon during the data analysis (Gelman & Loken, 2013). This claim is also supported by a suspicious culmination of publications with p-values slightly below the value of .05 (Masicampo & Lalande, 2012). This easily leads to the assumption that there might have been a trend to tinker with the analysis of the collected data until the “magical” p-value treshold of .05 has been reached. The Bayesian approach tries to shift the focus away from the black-and-white of significance values and hypothesis testing to a more explorative approach that delivers information about how (un)certain the researcher can be about a specific value. In line with this, McElreath (2016) points out that uncertainty intervals have the advantage of being easily interpretable and conveying the meaning that is often falsely attributed to *non-Bayesian* or *frequentist* confidence intervals: the probability that a certain value lies between the boundaries of an interval.

2.5.2 Building the model

A Linear Mixed Models (LMMs) was built to predict the questionnaire ratings and the likelihood that a participant will let the other car in (the dependent variables). In general, Linear Mixed Models that have fixed effects and random intercepts assume that each participant has a different intercept. However, they expect that using HMI concept 1 and HMI concept 2 would have the same effect for each participant (the same slope). As a matter of fact, it is not really likely that this is true. We would rather expect that the effect of HMI concept 1 and HMI concept 2 vary for each participant. Some people might like or understand the HMI concepts more than somebody else which would then have an impact on their ratings. To deal with this variance, the model that has been chosen for the data analysis includes random slopes. It has the intercept, HMI concept 1, HMI concept 2 and the interaction of HMI concept 1 and 2 as fixed effects. Furthermore, it has a random intercept and HMI concept 1 and HMI concept 2 as random slopes that are conditional on participant. Model 2 has Situation as an additional fixed effect and as an additional random slope. The formula of the LMM is presented in Figure 2.

$$y_i = \beta_{0i} + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \varepsilon_i$$

$$\beta_0 \sim N\left(\mu_{\beta_0}, \sigma^2_{\beta_0}\right)$$

$$\beta_1 \sim N\left(\mu_{\beta_1}, \sigma^2_{\beta_1}\right)$$

$$\beta_2 \sim N\left(\mu_{\beta_2}, \sigma^2_{\beta_2}\right)$$

β_0: Turn signal β_1: HMI concept 1

β_2: HMI concept 1 β_3: Interaction between HMI concept 1 and 2

Figure 2. The formulas of the Linear Mixed Model. i represents participant.

Summary of the findings

There were three research questions related to the effects of using HMI concept 1 and HMI concept 2 on *cooperation*, *clarity* and the *driver experience*.

The first research question examined the amount of *cooperative behavior* and the perceived degree of cooperation. On the one hand, it could successfully be shown that using a HMI concept 1 stimulates cooperative behavior in the participants. However, it could not be concluded with certainty that HMI concept 2 had an effect on the amount of cooperative behavior. Even though HMI concept 2 had no effect on the amount of cooperative behavior, they had a strong effect on the perception of cooperation. Using HMI concept 2 drastically increased the feeling that lane changes were a cooperation between the two drivers. Similarly, using HMI concept 1 also led to an increased perception of cooperation.

The second research question dealt with the *clarity* of the other driver's actions. The results suggested that using HMI concept 1 strongly increases the clarity during lane changes. Whereas the effect of HMI concept 1 was already strong, HMI concept 2 was able to provide the driver with even more clarity about the other driver's intentions as well as the exact timing of the lane change maneuver.

The third research question considered the effects of HMI concept 1 and HMI concept 2 on *driver experience*. Both concepts successfully increased the degree to which the lane changes were perceived as comfortable, safe and efficient. There was almost no difference in workload measurements when comparing a turn signal to the different concepts. The only exception was that using HMI concept 1 led to a slight reduction in workload.

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