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"What Makes a Cooperative Driver?" Identifying parameters of implicit and explicit forms of communication in a lane change scenario

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ABSTRACT

An automated vehicle needs to learn how human road users communicate with each other in order to avoid misunderstandings and prevent giving a negative outward image during interactions. The aim of the present work is to develop an autonomous driving system which communicates its intentions to change lanes based on implicit and explicit rules used by human drivers. To reach this goal, we aimed at gaining a deeper understanding of which aspects of lane change behaviour makes them cooperative from the perspective of other drivers. Therefore a vehicle used various lane change announcement strategies by varying combinations of driving parameters in a static driving simulator. (First study: Start indicator signal, Waittime, lane change duration; Second study: Longitudinal acceleration). It's impact on the perception and behaviour of other road users was observed in two studies ($N = 25$ per study). The results showed that the earlier the merging vehicle was indicating its intentions, the more cooperative it was perceived. When turning on the indicator at a later time participants considered it as more cooperative to merge with a slower or faster lane change duration or to wait longer in the lane before starting to move to the other lane. An early longitudinal acceleration when starting to change lanes is perceived more cooperative. These findings can be used to model a lane change strategy based on human behaviour, which will eventually lead to more acceptable and safer interactions between automated and non-automated road users.

1. Theoretical background

1.1. General introduction

The increasing automation level in vehicles will lead to a gradual change in traffic conditions. Manually operated vehicles and vehicles with different levels of autonomation are already coexisting, and the percentage of automated vehicles is steadily growing. Studies show that road users generally have a positive attitude towards autonomous cars (Kyriakidis, Happee, & De Winter, 2015; Neukum, Naujoks, Kappes, & Wey, 2014; Payre, Cestac, & Delhomme, 2014; Rödel, Stadler, Meschtscherjakov, & Tscheligi, 2014). But as Müller, Risto, and Emmenegger (2016) pointed out, there are still many challenges to overcome when it comes to mixed traffic scenarios. Human drivers use explicit and implicit signs to underline

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their own intentions or to interact with other road users (Witzlack, Beggiato, & Krems, 2016) and these signs can be perceived differently. In this context attribution plays an important role. Without using these different forms of communication and understanding the effect on other drivers, an autonomous vehicle might endanger the surrounding traffic and will hardly be accepted (Nees, 2016; Richtel & Dougherty, 2015). Just recently, a field trial of a fully automated shuttle ended in a crash just after the first twenty minutes. A delivery truck driver expected the automated vehicle to cooperate, which it did not. One of the passengers stated: "The shuttle just stayed still. And we thought it's going to hit us, it's going to hit us. And then it really hit us" (Beene & Levin, 2017).

As this incident shows, many researchers focus on developing automated driving systems (Chen, 2010; Patel, Härri, & Bonnet, 2017) but these systems neglect the fact that human drivers use various forms of communication and that those can trigger attribution and emotions thus causing different reactions (Fekete et al., 2015). But the consideration of such phenomena will be necessary to guarantee safe and efficient interactions between automated and human drivers. According to Färber (2015), it is a prerequisite that the intentions of road users must be unambiguously communicated in order to guarantee traffic safety and a collision free interaction. Furthermore, Nees (2016) emphasizes the importance of the acceptance of autonomous vehicles by surrounding road users. Social psychologists have repeatedly demonstrated that attributing characteristics to others based on their behaviour, is one of the fundamental cognitive heuristics that helps us to effectively interact with each other in social situations. This effect is called fundamental attribution error (Krull et al., 1999). In the driving domain, the typical stereotype of an aggressive driver is someone who drives too close to another vehicle. On the other hand, certain behavioural characteristics tend to lead other road users to be cooperative, assigning positive attributes to the driver exhibiting such behaviour. Thus it is important to include what we define as the "outward image", when developing a driving strategy for automated vehicles. "Outward image" means how the driving behaviour of a vehicle is perceived by the other road users. In this paper, we examine which aspects of driving behaviour during lane changes are perceived by human drivers as unambiguous as well as positive when it comes to interact with other road users. In a second step we can transfer these findings to autonomous vehicles.

1.2. Scope of the study

It is well known that cooperative driving creates positive feelings among the involved road users (Maag, 2004; Mcknight, Carter, & Thatcher, 2011; Zimmermann et al., 2015). A situation that requires a high degree of coordination and communication is a lane change in a slow and dense traffic such as traffic jams on highways. Additionally according to Bie, Roelofsen, Jin, and Van Arem (2013), a lane change maneuver to the left in a dense traffic situation has a high crash and accident potential. Thus there is a big demand in strategies for automated vehicles to deal with such situations (Bie et al., 2013). Therefore this use case is the focus of the current study. The aim of the current study is to learn more about human communication behaviour and its outward image to derive recommendations for an automated vehicle when interacting with a human driver.

We focused on the behaviour of the merging vehicle and its implicit and explicit forms of communication prior to and during a lane change on the subsequent driver in the target lane (the so-called "ego driver") in a dense traffic situation. We assumed that when the ego driver decides whether he/she should allow another vehicle to merge, she/he uses implicit cues (of the driving behaviour) in his/her assessment of the situation. We assume that, depending on the degree to which these cues are present or absent, the other road user will be perceived in an either positive or negative manner, i.e. being cooperative or non-cooperative.

The contribution of this paper is twofold: First, as few research efforts have been devoted to examining the interaction behaviour of human drivers and the implicit cues that guide the interaction process, the current study aims at providing a more detailed understanding of the preparation and execution phase of lane changing and its communication to other road users. Second it is enriching the existing literature. Third, the findings can be used to model an autonomous lane change strategy in order to gain more acceptance.

1.3. Human factors of cooperative driving behaviour for automated lane changes

The aim of our research effort is to identify human factors that are perceived as cooperative by human road users and that work successfully in cooperative driving situations. These should serve as a basis for the development of automated driving strategies, making them safe and efficient. As a starting point, influencing factors on how to design cooperative driving strategies are derived from a literature review on perceived willingness to cooperate in traffic research.

Several authors have examined cooperative driving behaviour in manual driving contexts. According to Maag (2004) driving behaviour can be classified as either cooperative or reckless driving. According to the author this is an adaption to deal with situational traffic requirements. Using a general definition, cooperation is defined as working together on a common aim (Hoc, Young, & Blosseville, 2009; Khamis, Kamel, & Salichs, 2006; Radlmayr & Bengler, 2015). In a more technical sense, it can be considered as a balance of cost and benefit (Giraldeau & Caraco, 2000; Kollock, 1998). Referring to traffic situations each driver is, at a given moment, evaluating different options available to her/him and choosing the subjectively optimal result. Hence, if there is no personal or subjective advantage, a cooperative action will not be triggered, even if the general traffic flow could be increased. Thus, it can be expected that automated driving strategies that force human drivers to perform subjectively non-optimal driving behaviours (such as slowing down, staying in a slow lane, needing to speed up unnecessarily) will be perceived negatively. Ellinghaus (1986) emphasizes this aspect by saying that a driver has to renounce his right in favor of the other driver.

Using the extended definition of cooperation introduced by Benmimoun et al. (2004), cooperation describes a mixture of proficiency and fairness in driving situations, which is the definition used in the study described here. Thus, it is not the pure benefit but a sense of fairness that could lead drivers to perceive the behaviour of an automated vehicle to be cooperative. Even when cooperation results in perceived costs (such as prolonged travel time), it might be tolerated to some extent. An example for cooperative behaviour is when drivers are allowed to take their time to make a decision and aren 't forced into a decision, which would cause reactance (Brehm, 1966). For this reason, we varied several behavioural aspects of the lane-changing vehicle prior to and during the lane change, such as the time between the starting of the indicator signal and the start of the lane change or the duration of the lane change, which could influence the perceived level of cooperation as they have consequences for the costs of cooperation of the (human) ego driver. For example, the combination of a late signaling and a quick lane change might force drivers to brake, while an earlier signaling might not require a drastic slowing-down of the ego driver's car.

In this paper, we focus especially on driving behaviour, a factor which can arouse attributions and emotions of the surrounding traffic (Ellinghaus, 1986). Thus, it is an important tool to influence the behaviour of others. In this context the actor-observer effect (Jones & Nisbett, 1972) plays a major role. Transferring the effect to the driving context, this means that when interacting with another vehicle and perceiving a certain behaviour such as driving too close to one's own vehicle, it can be taken personally which increases the possibility of reacting in an emotional way. According to Mcknight, Carter, Thatcher, and Clay (2011) positive feelings such as trust and a sense of confidence are linked to cooperative behaviour. Zimmermann et al. (2015) found out that a successful lane change, which means that the lane change was executed, was perceived more positively than an unsuccessful one. Moreover, his results indicated that cooperative behaviour is highly correlated with a feeling of satisfaction, relaxation and peace of mind. Therefore, we also assessed how drivers felt about cooperative lane changes by self-reporting measures.

To sum up, several studies point out the importance of driving behaviour for perceived willingness to cooperate. To study perceived willingness to cooperate, a situation has to be created in which the human participants will have to interact with other drivers, deciding whether or not to let them merge to their lane. Based on the theory of reactance (Brehm, 1966) we expect that participants will evaluate those situations as non-cooperative that bring subjective costs with them such as the feeling of being forced into the decision for the benefit of the other vehicle, but also that they may be willing to do so to a certain extent. Although many studies investigate cooperative driving (Bengler, Zimmermann, Bortot, Kienle, & Damböck, 2012; Kollock, 1998; Zimmermann et al., 2015), the outward image of the vehicle on the surrounding traffic is rarely in the focus of interest. When it comes to automated driving, we believe that this is an important aspect, since an autonomous vehicle cannot afford to be perceived as aggressive when it comes to acceptance by the surrounding traffic.

As stated above, we expect the behaviour of the automated vehicle to be interpretated as cooperative or not. From a standpoint of cognitive information processing, we propose that the behaviour of the automated vehicle serves as a cue to its intentions. Apart from the question which aspects of driving behaviour will be interpreted as cooperative or not, it is also important to determine how strongly a behavioural cue needs to be present in order to be noticed by the human road users (e.g., accelerating, indicating, etc.). The detection and perception of signals in traffic scenarios can be explained by the signal detection theory (Green & Swets, 1966). Their work is based on the assumption that a signal needs to be located against a constant background of noise. An absolute threshold to separate a signal from noise does not exist thus inferring a decision process upon or against the existence of a stimulus. The perception of the signal is influenced by many factors. Detecting motion in front of the vehicle is easier than in the surrounding traffic on the periphery (Green, 1983). Another factor is the expectancy of the signal (Green, 2000) as well as the importance of the current situation perceived and factors concerning the person such as age, workload (Alm & Nilsson, 1995) and the intensity of the signal (Arbuthnott, 1980).

In summary, various explanations have been provided to explain whether cues in the road environment will be noticed and accurately interpreted or not. In order to be effective, behavioural cues provided by automated vehicles that are designed to convey their attention to other road users have to be strong enough to be interpreted as "cooperative" against the background noise by the receivers of information. Therefore, we included the examination of whether a driving behaviour can be interpreted unambiguously into the study.

2. Study I part 1

The first part of the study examined how different lane change announcement behaviours are perceived by the ego driver on the target lane. To investigate this, participants were put in the position of reacting to cutting-in vehicles in dense traffic in a driving simulator. The cutting-in vehicles announced their intentions to the participants by several behavioural indicators. The impact of these behaviours on the perceived willingness to cooperate were the focus of the study.

2.1. Method

2.1.1. Participants

A total of 25 participants took part in the study (14 females). Their age was between 21 and 73 years (M = 36 years; SD = 15.7 years), owning a driver's license on average for 18.6 years (SD = 14.5 years). The mean annual mileage driven was 10.700 km (SD = 115.98 km). The licensed drivers were recruited from a participant panel of the Würzburg Institute for Traffic Sciences (WIVW). All participants were trained beforehand in the driving simulator to ensure that they were familiar with driving in the simulator and to reduce motion sickness (Hoffmann & Buld, 2006). The training consisted in different situations and maneuvers for example lane changing, braking or car following and was designed to improve handling the simulated vehicle and to reduce motion sickness.

2.1.2. Study design

A $3 \times 3 \times 3$ repeated measures design was used with Start indicator signal (12 m, 16 m, 20 m), Waittime (1 s, 2 s, 3 s) and Lane change duration (4 s, 6 s, 8 s). The order of the lane change announcements was randomized.

2.1.2.1. Description of independent variables. Simulated vehicles announced their intention to change lanes with a combination of parameters which are listed in Table 1. Two selection criteria were used to select the main factors: Firstly, factors were used that are indicators for lane change, such as the turn signal or longitudinal acceleration (Henning, 2010; Olsen, Lee, & Wierwille, 2002; Toledo & Zohar, 2007). Secondly, factors were examined which are likely to trigger attributions. For example, a driver who only indicates and waits until a gap is large enough is interpreted as an inexperienced driver (Ellinghaus, 1986). Therefore, the "Start of the indicator signal", "Waittime" and "Lane change duration" of the simulated merging vehicle were chosen as independent variables of the experiment. The values were derived from pretests and the literature (Henning, Georgeon, & Krems, 2007; Hetrick, 1997; Olsen, 2003) and chosen according to the MAX – KON – MIN principle (Kerlinger & Pehazur, 1973). Table 1 offers a detailed description of these factors.

The procedure of an experimental trial was as follows: The simulated vehicle (M) first flashes at a defined distance to the ego driver (P) (Start indicator signal). In the next phase, the vehicle remains on its own track for a certain time period (Waittime). And finally, after the waiting period, a longitudinal acceleration was applied to reach the speed in the target lane and the vehicle changed lanes with different lane change durations (see Fig. 1).

The combination of these three factors resulted in 27 situation which were presented to the participants in a randomized order in a within-subjects design.

2.1.2.2. Description of dependent variables. Subjective ratings of perceived willingness to cooperate and criticality (Neukum & Krüger, 2003) were collected after each situation (see Table 2). Perceived willingness to cooperate was rated using a 15-point scale that also uses verbal labels as anchoring points based on the category-subdivision scale by Heller (1985). The rating was given in a two-step procedure: First, one of the verbal labels was selected (e.g., "very cooperative"). In the second step, a numerical rating was given. The criticality scale is an uni-dimensional scale that uses verbal labels as anchoring points (e.g., "imperceptible", "uncontrollable"), ranging from 0 to 10.

Table 1
Overview of independent variables.

Factors	Factor levels	Unit	Description of variable
Start indicator signal	12, 16, 20	[m]	The turn signal is set at different distances relative to the ego driver on the target lane
Waittime	1, 2, 3	[s]	Time period from indicator set until the car begins to change the lane
Lane change duration	4, 6, 8	[s]	Duration of the time period when the center of gravity of the vehicle has moved from the center of the current lane to the center of the target lane

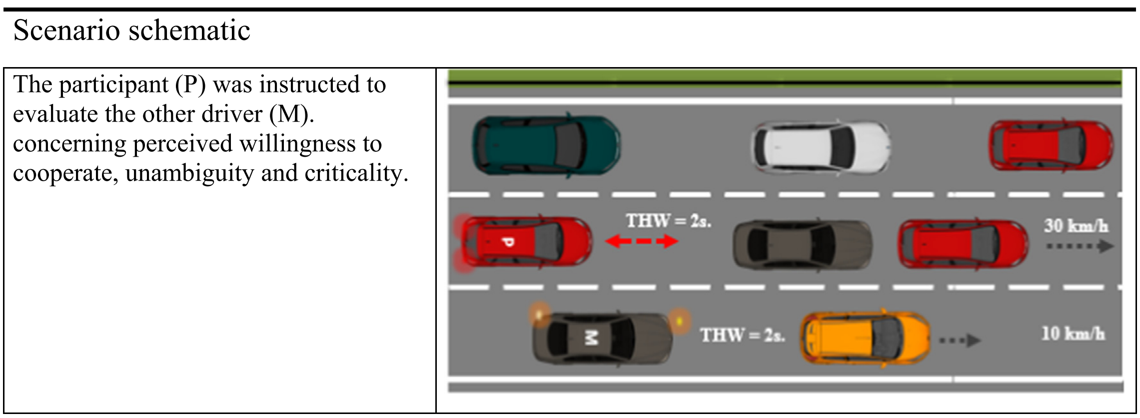

Fig. 1. Subjective, dependent measures employed in a simulator study.

Table 2
Subjective, dependent measures employed in the simulator study.

Parameter Description

Scale for perceived willingness to cooperate of the merging vehicle
How cooperative was the driver on the right lane?

Not at all	Very little cooperative			Little cooperative			Intermediate cooperative			cooperative			Very cooperative		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Scale for perceived unambiguity of the merging vehicle
How clearly did the driver show his intention to merge?

Not at all	Very little unambiguous			Little unambiguous			Intermediate unambiguous			unambiguous			Very unambiguous		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Scale for perceived criticality of the merging vehicle (Neukum & Krüger, 2003).
How critical was the situation?

2.1.3. Driving simulator

The study was conducted in a fixed-based driving simulator at the WIVW (Würzburg Institute for Traffic Science). The simulator uses an automatic gearbox and the driver sits in a driver's seat using a steering wheel with force feedback, accelerator and brake pedals. The virtual scenery is projected on five screens (front, left, right, left behind, right behind) in order to simulate a driver's 300° field of vision (see Fig. 2). The scenario was created by using the driving simulation software SILAB (Krueger, Grein, Kaussner, & Mark, 2005).

2.1.4. Test environment

The test track was a three-lane highway with congested traffic conditions. Convoys of vehicles were driving on the left and right lane with a time headway (THW) of 2 s between them, while the study's participant was driving on the middle lane and faced the 27 scenarios described above. The task of the driver was to keep driving on the lane and to evaluate the merging car on the right. In order to keep expectations low that something will happen, six additional scenarios were inserted between the above in a randomised order. In these situations, the vehicle on the right lane was only indicating, but not changing the lane.

2.1.5. Procedure

At the beginning of the experiment the participants were informed about the goal of the study, the examination of the outward image of lane change announcements, as well as the procedure of the study before signing a consent form. Afterwards, the participants completed a practice drive to become familiar with the vehicle and the driving task. This training was followed by the test drive. The drivers were instructed to follow a lead vehicle at a distance of two seconds THW = 2 s in order to make the situations comparable. This was supported by an enhanced reality strip that was superimposed on the roadway (Frey, 2016). When the strip turned yellow, the distance was too large whereas it turned purple when the distance was to small. No colour indicated that the distance of 2 s was kept. When the car at the right turned on the signal the participants were instructed to behave in a cooperative way and let the other vehicle merge in front of them and to evaluate the cut in vehicle afterwards, while following the lead vehicle in front of them.

Fig. 2. The fixed based driving simulator of the WIVW.

After each scenario the single item questions, listed in Table 2 (dependent variables), were presented to the participant while driving and he/she was instructed to answer these questions concerning the perceived lane change strategy verbally. After the experiment the participants received an expense allowance of 25 Euros and were thanked for their participation. The overall duration of the trial was approximately 90 min.

2.2. Results and discussion

A 3 × 3 × 3 factorial ANOVA with repeated measures as well as Bonferroni corrected post hoc t-tests were used to investigate the influence on the dependent variables. Perceived willingness to cooperate, Unambiguity and Criticality, respectively. A significance level of < .05 was adopted for all statistical tests. If necessary, Greenhouse Geisser (GG) correction was used when correcting against violations of sphericity. η^2 is given as a measure of effect size.

2.2.1. Perceived willingness to cooperate

Table 3 summarizes the effects with regard to perceived willingness to cooperate. Concerning the start of the flashing signal, a significant main effect was found, indicating that drivers considered an earlier start of the flashing signal of 20 m as more cooperative (M = 10.1, SD = 0.6) than a later start of 12 m (M = 8.0, SD = 0.5). As shown in Fig. 3, this main effect was influenced by the lane change duration (interaction effect start indicator signal * lane change duration). The decreased perceived willingness to cooperate by a late signaling can be altered by the duration of the lane change, as road users that turn their indicator signal delayed by a distance of 12 m were interpreted more cooperatively when changing lanes either slowly (8 s; M = 8.7 s, SD = 0.6) or more rapidly (4 s; M = 8.4 s, SD = 0.6) compared to the intermediate condition (6 s; M = 7.1 s, SD = 0.6) . In the first case, drivers had already passed the cutting-in vehicle, while in the latter case, still enough space to cut in before them remained. However, in the intermediate condition (6 s), the participants had to brake to let the cutting-in vehicle in. When the cutting-in vehicle started flashing at a greater distance (20 m), the participants considered the shortest lane change duration as most cooperative (4 s; M = 10.5, SD = 0.6; see Fig. 3).

There was also a significant interaction between the start of the start indicator signal and Waittime (see Table 3, Fig. 4). Bonferroni corrected post hoc t-tests indicated that when flashing was late (12 m) a long Waittime was perceived as more cooperative than a short Waittime. This difference disappeared for the medium and early start of the turn signal. Due to this interaction, the main effect of Waittime cannot be interpreted although it is significant.

2.2.2. Perceived unambiguity

Concerning Unambiguity a significant main effect of the start of the indicator signal and a significant interaction effect of the start of the indicator signal and lane change duration were found (see Table 4). As Fig. 5 shows, signaling the lane change

Table 3
Results of the effects of perceived willingness to cooperate on the ego driver.

Parameter description	F	df	p	η^2
Start indicator signal (m)	6.9	2	*.002*	*.224*
Waittime (s) (GG)	4.3	1.54	*.030*	*.151*
Lane change duration (s)	2.3	2	*.113*	*.087*
Start indicator signal*Waittime	2.9	4	*.024*	*.110*
Start indicator signal*lane change duration	2.8	4	*.032*	.103
Waittime* Lane change duration (GG)	1.3	2.61	.294	*.050*
Start indicator signal*Waittime* Lane change duration (GG)	1.7	4.24	.163	.064

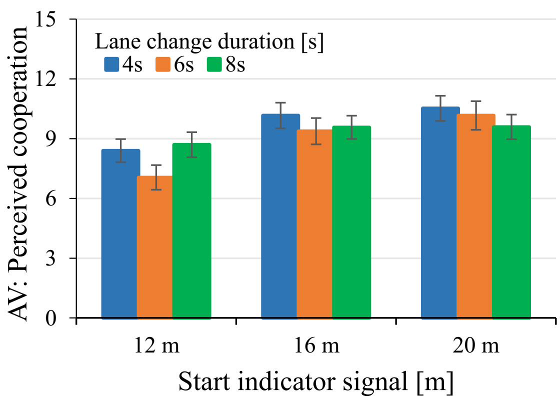

Fig. 3. Interaction between Start indicator signal and lane change duration. Mean and standard errors are depicted.

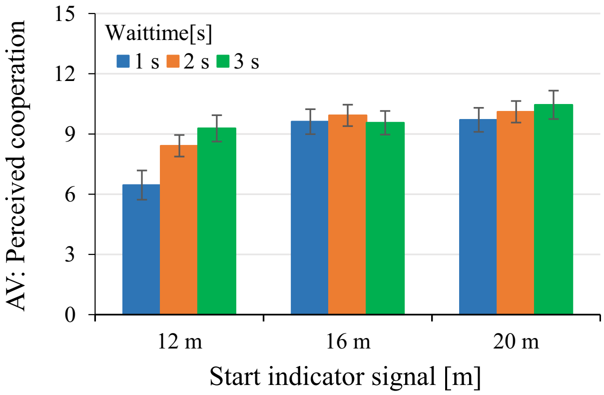

Fig. 4. Interaction between Start indicator signal and Waittime. Mean and standard errors are depicted.

Table 4
Results of the effects of perceived unambiguity.

Parameter description	F	df	*p*	η^2
Start indicator signal (m)	7.9	2	*.001*	*.249*
Waittime (s)	2.3	2	*.114*	*.087*
Lane change duration (s)	0.7	2	*.521*	*.027*
Start indicator signal*Waittime (GG)	1.2	3.01	*.334*	*.046*
Start indicator signal*lane change duration (GG)	5.2	2.81	*.003*	.177
Waittime* Lane change duration	2.2	4	.069	*.086*
Start indicator signal*Waittime* Lane change duration	0.6	8	.735	.026

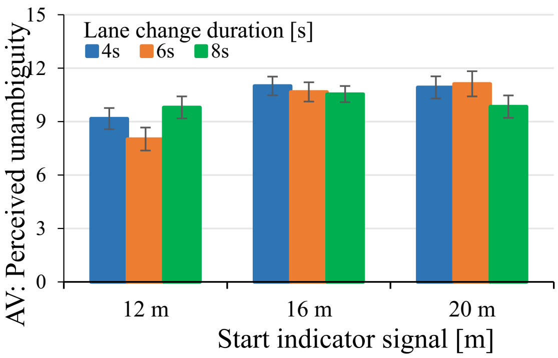

Fig. 5. Interaction between Start indicator signal and lane change duration. Mean and standard errors are depicted.

early at 16 m (*M* = 10.7; *SD* = 0.5) or 20 m (*M* = 10.6; *SD* = 0.5) was perceived most unambiguous, compared to the 12 m condition (*M* = 9.0; *SD* = 0.5) where it was perceived as less unambigous. With regard to the interaction, when indicating early (20 m) a faster lane change duration (4 s; *M* = 10.9; *SD* = .6 and 6 s; *M* = 11.1, *SD* = 0.5) was considered more unambiguous compared to the slowest condition (8 s; *M* = 9.8, *SD* = 0.6). When indicating late (12 m) drivers were considered as more unambiguous the slower they changed lanes (4 s; *M* = 9.2, *SD* = 0.6; 6 s; *M* = 8.0, *SD* = 0.5; 8 s; *M* = 9.8, *SD* = 0.6).

2.2.3. Perceived criticality

For Perceived Criticality there was a significant main effect of the start of the indicator signal (see Table 5). None of the other effects or interactions was significant. As Fig. 6 shows, the later a merging vehicle starts flashing, the more critical it is perceived (12 m; *M* = 2.8, *SD* = 0.3; 16 m; *M* = 2.3, *SD* = 0.3; 20 m; *M* = 1.8, *SD* = 0.2). However, the values are still in the category of "harmless".

3. Study 1 part 2

The results of the first study indicated that a delayed start of the turn signal was considered as being less cooperative than an early turn signal (20 m). It is quite possible that under these circumstances the automated vehicle could still be interpreted as being cooperative provided it makes up for the late signaling by an earlier acceleration, which would reduce

Table 5
Results of the effects of perceived criticality.

Parameter description	F	df	*p*	η^2
Start indicator signal (m)	6.7	2	*.003*	*.218*
Waittime (s) (GG)	1.8	1.54	*.186*	*.070*
Lane change duration (s) (GG)	0.6	1.66	*.504*	*.026*
Start indicator signal*Waittime (GG)	0.6	2.75	*.623*	*.023*
Start indicator signal*lane change duration (GG)	0.5	3.12	.655	.023
Waittime* Lane change duration	1.3	4	.271	*.052*
Start indicator signal*Waittime* Lane change duration (GG)	0.6	4.27	.628	.027

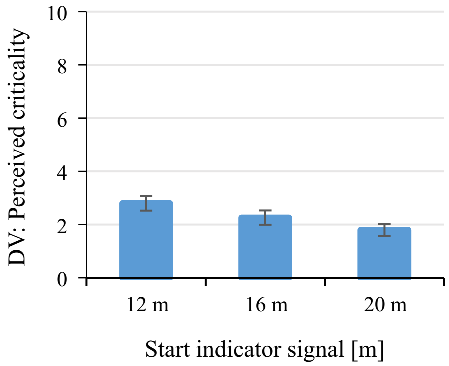

Fig. 6. Means and standard errors of the perceived criticality.

the need for the driver on the target lane to decelerate. The second study focused, therefore, on the question whether the start of the longitudinal acceleration of the merging vehicle had a positive influence on the outward image of the merging vehicle.

3.1. Method

3.1.1. Sample, driving simulator, test environment and procedure

Part 2 is a continuation of the first study meaning that the test environment, the procedure as well as the participants were in accordance with the previously conducted study.

3.1.2. Experimental design

In this study, the scenario was identical with the first part. However, the start of the indicator signal was fixed at 12 m (i.e., the simulated vehicles always started signaling when the participants were 12 m away from them). The first independent variable was the "Waittime" with the same three levels as in the first part (1 s, 2 s, 3 s). This factor was combined with the new factor "start longitudinal acceleration" (after 60% or 80% of the Waittime). Lane change duration was varied as in the first part with 4 s, 6 s and 8 s. An overview is given in Table 6. Again, these factors were combined resulting in 18 scenarios which were presented in random order in a within-subjects design. The same dependent variables were measured as in the first part.

3.2. Results

3.2.1. Perceived cooperation

Three-way ANOVAs with repeated measures were used to investigate the influence on the dependent variables. With regard to Perceived Cooperation, two significant main effects, "start longitudinal acceleration" and "lane change duration", were found. None of the interactions was significant (see Table 7). As Fig. 7 shows, an earlier start of longitudinal acceleration

Table 6
Overview of independent variables.

Factors	Factor levels	Unit	Description of variable
Waittime	1, 2, 3	[s]	Time period from indicator set until car begins to change the lane
Longitudinal acceleration	60, 80	[%]	Percentage of Waittime until vehicle accelerates
Lane change duration	4, 6, 8	[s]	Time span when the center of gravity of the vehicle has moved from the center of the lane to the center of the target lane

Table 7
Results of the effects of perceived cooperation.

Parameter description	F	df	*p*	*η2*
Waittime (s)	0.49	2	.613	.020
Start longitudinal acceleration (%)	12.29	1	.002	.339
Lane change duration (s)	7.49	2	.001	.238
Waittime* Start long.acceleration	0.86	2	.428	.035
Start longitudinal acceleration *lane change duration	0.13	2	.882	.005
Waittime* Lane change duration (GG)	1.50	2.72	.225	.059
Waittime* Start longitudinal acceleration*Lane change duration (GG)	0.18	2.46	.879	.007

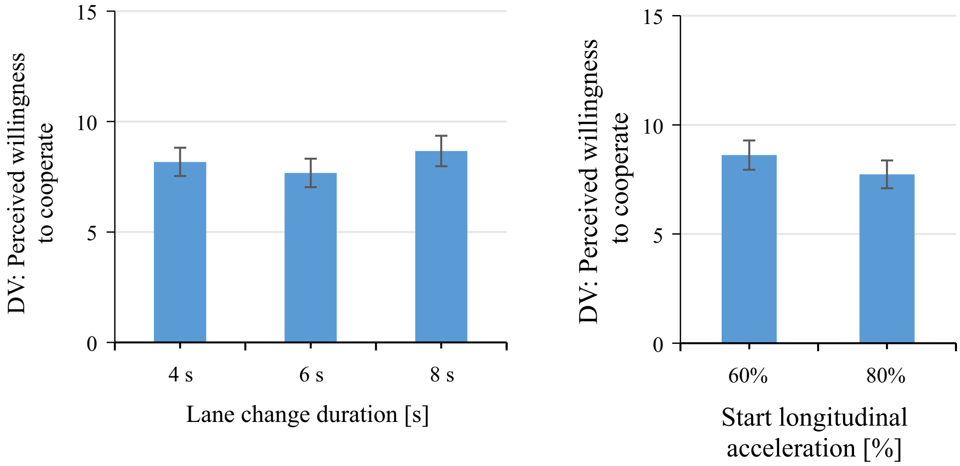

Fig. 7. Means and standard deviations of the perceived cooperation.

(60% ; *M* = 8.6, *SD* = 0.7) was considered more cooperative than a delayed start (80% ; *M* = 7.7, *SD* = 0.6). This result is in line with the assumption that the perception of a late start of indicator signal can be compensated by an early longitudinal acceleration. Concerning lane change duration 8 s (*M* = 8.7, *SD* = 0.7) and 4 s (*M* = 8.2, *SD* = 0.7) was interpretated as being more cooperative than 6 s (*M* = 7.7, *SD* = 0.6). This result reflects the findings of the first study, indicating that in the intermediate condition (6 s), the participants had to brake to let the cutting-in vehicle in and, therefore, viewing the merging vehicle as less cooperative than in the other conditions.

3.2.2. Perceived unambiguity and criticality

As seen in Table 8 no significant effect was found concerning Unambiguity. The result shows that longitudinal acceleration does not generate any significant added value in terms of the Unambiguity of the situation.

Concerning Criticality only one significant effect was observed: A delayed longitudinal acceleration (80%; *M* = 2.2, *SD* = 0.4) led to significantly higher values of self-reported Criticality than an earlier acceleration (60%; *M* = 1.6, *SD* = 0.3), demonstrating the importance of this lane change parameter for traffic safety (see Table 8). Nevertheless, it must be emphasized, as pointed out in Study 1, that despite the significant difference both values are categorized as "harmless".

Table 8
Results of the effects of perceived unambiguity and criticality.

Parameter description	Perceived unambiguity					Perceived criticality			
	F	df	*p*	*η2*		F	df	*p*	*η2*
Waittime (s)	1.53	2	.227	.060		1.70	2	.193	.066
Start longitudinal acceleration (%) (GG)	2.17	1	.154	.083		6.12	1	.021	.203
Lane change duration (s)	2.00	2	.146	.077		0.85	2	.433	.034
Waittime* Start longitudinal acceleration	2.03	2	.142	.078	GG	2.61	1.57	.098	.098
Start longitudinal acceleration *lane change duration	2.04	2	.770	.011		0.91	2	.408	.037
Waittime* Lane change duration (GG)	0.33	2.68	.779	.014	GG	0.69	2.64	.541	.028
Waittime* Start longitudinal acceleration*lane change duration	0.76	3.12	.526	.031		1.41	4	.244	.055

4. Discussion

In order to enhance the potential benefits of automated driving, it is necessary to cope with upcoming challenges of mixed-traffic scenarios. In this paper, we argue that the intentions of automated vehicles must be understood by surrounding traffic. We also suggest that implicit and explicit communication ans its outward image play an important role for guaranteeing traffic safety. As a first approach human communication behaviour needs to be analyzed to derive decision making rules for autonomous cars. The aim of the two studies presented in this paper was to gain a deeper understanding of how the outward image of other drivers is influenced by their behaviour in a lane change situation in dense traffic (start flashing signal, Waittime, lane change duration, longitudinal acceleration), in an attempt to identify a cooperative driver behaviour. The main findings can be summarized as follows:

Study 1 demonstrated that it is considered more cooperative and unambiguous as well as less critical when signaling one's lane change intention early (20 m). However, in real life it is often not possible to start flashing so early, either because of the need for quick decisions or because an early flashing can be misunderstood by other road users. Thus, the question arises whether there is a possibility to create cooperative driving experiences even when there is only a short timeframe for the ego driver to react to the request of the cutting-in vehicle. The study results show that when indicating at a later point in time (12 m), it is interpreted as more cooperative to change the lane either slowly (8 s) or fast (4 s), or to wait longer before starting to change lanes (3 s). A possible explanation regarding the results may be the fact, that when people have more time to decide whether or not to let the other driver merge they feel less reactance, because he/she is not confronted with fait accompli. This means that they don‘t feel forced into a decision. However, when the cutting-in vehicle started flashing at a greater distance, there was no influence of the waittime on perceived cooperation anymore. This result is in line with the theory of reactance (Brehm, 1966), because the following driver has more time left to make a decision and therefore additional time isn‘t necessary. In addition, **Study 2** confirmed the results of Study 1 concerning the factor lane change duration and indicated that an earlier longitudinal acceleration (60%) is considered less critical and can contribute to a positive outward image.

The results of the study add additional value to the available literature in several aspects: First, current literature, focusing on modeling lane change behaviour in dense traffic based on human behaviour (Ahmed, 1999; Choudhury, Rao, Lee, Ben-Akiva, & Toledo, 2007; Hidas, 2002) neglect the aspect of the outward image of the vehicle. This is an essential aspect when it comes to modeling a lane change strategy for autonomous vehicles to be understood and accepted by surrounding traffic (Richtel & Dougherty, 2015). Second, literature concerning interaction between human drivers can scarcely be found (Ellinghaus, 1986; Risser, 1987). Third, the findings enrich literature on cooperative driving (Bengler et al., 2012; Zimmermann et al., 2015) in so far as they go into detail on what is meant by cooperative driving at parameter level.

At this point some limitations need to be addressed: Further research is required especially regarding the transfer of the results to actual driving behaviour. This has several reasons: First the relatively short test times spent in the simulated environment could limit the generalizability of the results. The actual extent of the behavioural adaptation effects in daily driving behaviour (e.g., speed change, tracking distance and attention) must be examined. Second, the study was conducted in an artificial environment, a fixed-based driving simulator. In a real-life environment the driver is exposed to a variety of factors, which may lead to more complex decisions. Third, concerning the dependent variables the generalizability of the results of perceived criticality is limited and requires further attention due to the artificial environment and the knowledge of the procedure of the study (Hoffman, Lee, Brown, & McGehee, 2002). To sum up, the comparison of our results with a real traffic situation is of great importance and merits further research.

The number of independent variables may also be a limitation for generalization of the study. These were considered as most relevant in the decision making process of the driver who intends to change lanes (Henning, 2010; Rehder, Muenst, Louis, & Schramm, 2016). For the development of an algorithm for dense traffic on the highway, however, additional parameters need to be taken into account such as distance to the lead vehicle (Haar, Kleen, Albrecht, Schmettow, & Verwey, 2016; Marczak, Daamen, & Buisson, 2013). Finally it is necessary to explore if human drivers prefer an automated vehicle to drive like a cooperative human driver. For future work, we recommend therefore to not only include different background conditions for static obstacles such as a construction site and involve more independent variables such as time headway towards the lead vehicle or intra-personal factors (for example urgency or aggressiveness), but as a second step explore the expectations of human drivers how an automated vehicle should behave.

5. Conclusion

Despite these limitations, the study provides overall indications on how an automated system could be designed in order to be perceived positively and unambiguously by the surrounding traffic. From these studies, driving parameters could be identified that are relevant for autonomous lane changing. These should be included and tested in autonomous lane change algorithms. Additionally, this paper provides a new approach on how to deal with mixed traffic problems, not only for improving acceptance but also in order to increase traffic safety.

References

Ahmed, K. I. (1999). Modeling Drivers' Acceleration and Lane Changing Behavior. Massachusetts Institute of Technology. Retrieved from http://web.mit.edu/its/papers/DRIVIN.PDF.

Alm, H., & Nilsson, L. (1995). The effects of a mobile telephone task on driver behaviour in a car following situation. *Accident Analysis & Prevention, 27*(5), 707–715. https://doi.org/10.1016/0001-4575(95)00026-V.

Arbuthnott, D. (1980). Effects of noise and perceptual style on reaction to a simulated driving emergency. *Canadian Journal of Behavioural Science/Revue, 12* (1), 78–86 https://doi.org/https://doi.org/10.1037/h0081050.

Beene, R., & Levin, A. (2017). A Truck Backed Up and This New Self-Driving Shuttle Froze. Retrieved November 27, 2017, from https://www.bloomberg.com/news/articles/2017-11-10/vegas-fender-bender-highlights-risks-of-sharing-road-with-robots.

Bengler, K., Zimmermann, M., Bortot, D., Kienle, M., & Damböck, D. (2012). Interaction principles for cooperative human-machine systems. *It - Information Technology, 54*(4), 157–164. https://doi.org/10.1524/itit.2012.0680.

Benmimoun, A., Neunzig, D., & Maag, C. (2004). Effizienzsteigerung durch professionelles/partnerschaftliches Verhalten im Straßenverkehr. In FAT-Schriftenreihe 181. Frankfurt am Main: Forschungsvereinigung Automobiltechnik e.V. Retrieved from http://trid.trb.org/view.aspx?id=967153.

Bie, J., Roelofsen, M., Jin, L., & Van Arem, B. (2013). Lane change and overtaking collisions: Causes and avoidance techniques. In Wireless Vehicular Networks for Car Collision Avoidance (Vol. 9781441995, pp. 143–187). https://doi.org/10.1007/978-1-4419-9563-6_6.

Brehm, J. W. (1966). A theory of psychological reactance. *New York*. https://doi.org/10.1002/hrdq.20027.

Chen, J. (2010). *Fahrerassistenzsystem zum autonomen Spurwechsel*. RWTH Aachen.

Choudhury, C., Rao, A., Lee, G., Ben-Akiva, M., & Toledo, T. (2007). Modeling cooperative lane changing and forced merging behavior. In 86th Annual Meeting of the Transportation Research Board. Washington, DC.

Ellinghaus, D. (1986). Rücksichtslosigkeit und Partnerschaft. Eine sozialpsychologische Untersuchung über den Umgang unter Kraftfahrern im Straßenverkehr. (Uniroyal V). Köln: IFAPLAN.

Färber, B. (2015). Kommunikationsprobleme zwischen autonomen Fahrzeugen und menschlichen Fahrern. In Autonomes Fahren (pp. 127–146). Berlin, Heidelberg: Springer, Berlin Heidelberg. https://doi.org/10.1007/978-3-662-45854-9_7.

Fekete, S., Vollrath, M., Huemer, A., & Salchow, C. (2015). Interaktionen im Straßenverkehr : Kooperation und Konflikt. In 8. VDI-Tagung Der Fahrer im 21. Jahrhundert, Fahrer, Fahrerunterstützung und Bedienbarkeit, VDI-Gesellschaft Fahrzeug- und Verkehrstechnik, Braunschweig, DE, 10. - 11. Nov, 2015 (pp. 325–338). Düsseldorf: VDI Verlag GmbH.

Frey, A. (2016). Statischer und dynamischer Fahrsimulator im Vergleich – Wahrnehmung von Abstand und Geschwindigkeit (BASt-Beric). In C. S. V. GmbH (Ed.). Bergisch Gladbach.

Giraldeau, L.-A., & Caraco, T. (2000). *Social foraging theory*. Princeton University Press.

Green, M. (1983). Contrast detection and direction discrimination of drifting gratings. *Vision Research, 23*(3), 281–289. https://doi.org/10.1016/0042-6989(83)90117-7.

Green, M. (2000). "How Long Does It Take to Stop?" Methodological analysis of driver perception-brake times. *Transportation Human Factors, 2*(3), 195–216. https://doi.org/10.1207/STHF0203_1.

Green, D., & Swets, J. (1966). *Signal detection theory and psychophysics, 4054*. https://doi.org/10.1901/jeab.1969.12-475.

Haar, A. , Kleen, A. , Albrecht, L., Schmettow, M., & Verwey, W. B. (2016). Intentionen wahrnehmen und Umfeld verstehen: Kognitive. Prozesse in der Interaktion mit anderen Verkehrsteilnehmern. In 32. VDI/VW-Gemeinschaftstagung Fahrerassistenzsysteme und automatisiertes Fahren,. Wolfsburg.

Heller, O. (1985). Hörfeldaudiometrie mit dem Verfahren der Kategorienunterteilung (KU). *Psychologische Beiträge, 27*, 478–493.

Henning, M., Georgeon, O., & Krems, J. F. (2007). The quality of behavioral and environmental indicators used to infer the intention to change lanes Retrieved from. *Proceedins of the 4th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, 231–237.

Henning, M. J. (2010). Preparation for lane change manoeuvres : Behavioural indicators and underlying cognitive processes. TU Chemnitz.

Hetrick, S. (1997). Examination of Driver Lane Change Behavior and the Potential Effectiveness of Warning Onset Rules for Lane Change or "Side" Crash Avoidance Systems. Virginia Polytechnic Institute and State University. Retrieved from http://scholar.lib.vt.edu/theses/available/etd-382915749731261/unrestricted/etd.pdf.

Hidas, P. (2002). Modelling lange changing and merging in microscopic traffic simulation. *Transportation Research C, 10*(5–6), 351–371.

Hoc, J.-M., Young, M. S., & Blosseville, J.-M. (2009). Cooperation between drivers and automation: Implications for safety. *Theoretical Issues in Ergonomics Science, 10*(2), 135–160. https://doi.org/10.1080/14639220802368856.

Hoffman, J., Lee, J., Brown, T., & McGehee, D. (2002). Comparison of driver braking responses in a high-fidelity simulator and on a test track. *Transportation Research Record, 1803*(1), 59–65. https://doi.org/10.3141/1803-09.

Hoffmann, S. ., & Buld, S. (2006). Darstellung und Evaluation eines Trainings zum Fahren in der Fahrsimulation. In V. D. I. Verlag (Ed.). VDI Wissensforum (Ed.), Integrierte Sicherheit und Fahrerassistenzsysteme (pp. 113–132). Düsseldorf.

Jones, E. E., & Nisbett, R. E. (1972). The actor and the observer: Divergent perceptions of the causes of behavior. *Perceiving the Causes of Behavior Attribution*. https://doi.org/10.1037//0022-3514.71.2.375.

Kerlinger, F. N., & Pehazur, E. J. (1973). Multiple regression in behavioral research. In Rinehart & Winston (Eds.). New York: Holt.

Khamis, A. M., Kamel, M. S., & Salichs, M. A. (2006). Cooperation: Concepts and general typology. *Conference Proceedings – IEEE International Conference on Systems, Man and Cybernetics, 2*, 1499–1505. https://doi.org/10.1109/ICSMC.2006.384929.

Kollock, P. (1998). Social Dilemmas: The Anatomy of Cooperation. *Annual Review of Sociology, 24*, 183–214.

Krueger, H., Grein, M., Kaussner, A., & Mark, C. (2005). SILAB – A Task Oriented Driving Simulation. In Proceedings of the driving simulator conference (DSC) (pp. 323–331). Iowa City: University of Iowa, USA.

Krull, D. S., Loy, M. H.-M., Lin, J., Wang, C.-F., Chen, S., & Zhao, X. (1999). The fundamental fundamental attribution error: Correspondence bias in individualist and collectivist cultures. *Personality and Social Psychology Bulletin, 25*(10), 1208–1219. https://doi.org/10.1177/0146167299258003.

Kyriakidis, M., Happee, R., & De Winter, J. C. F. (2015). Public opinion on automated driving: Results of an international questionnaire among 5000 respondents. *Transportation Research Part F: Traffic Psychology and Behaviour, 32*(July), 127–140. https://doi.org/10.1016/j.trf.2015.04.014.

Maag, C. (2004). Fahrer und Verkehrsklima : eine verkehrswissenschaftliche Untersuchung zu den Ursachen und Folgen von Emotionen im Strassenverkehr. Fortschritt-Berichte VDI. Reihe 22, Mensch-Maschine-Systeme, Nr. 18. VDI-Verlag, Düsseldorf.

Marczak, F., Daamen, W., & Buisson, C. (2013). Key variables of merging behaviour: Empirical comparison between two sites and assessment of gap acceptance theory. *Procedia – Social and Behavioral Sciences, 80*, 678–697. https://doi.org/10.1016/j.sbspro.2013.05.036.

Mcknight, D. H., Carter, M., & Thatcher, J. B. (2011a). Trust in a specific technology: An investigation of its components and measures trust in a specific technology: An inves- tigation of its components and measures. *ACM Transactions on Management Information System, 2*(25). https://doi.org/10.1145/1985347.1985353.

Mcknight, D. H., Carter, M., Thatcher, J. B., & Clay, P. F. (2011b). Trust in a specific technology: An investigation in its components and measures. *ACM Transactions on Management Information Systems, 2*(2), 1–12. https://doi.org/10.1145/1985347.1985353.

Müller, L., Risto, M., & Emmenegger, C. (2016). The social behavior of autonomous vehicles. *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing Adjunct - UbiComp, 16*, 686–689. https://doi.org/10.1145/2968219.2968561.

Nees, M. A. (2016). Acceptance of self-driving cars: An examination of idealized versus realistic portrayals with a self- driving car acceptance scale. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 60*(1), 1449–1453. https://doi.org/10.1177/1541931213601332.

Neukum, A., & Krüger, H. (2003). Fahrerreaktionen bei Lenksystemstörungen–Untersuchungsmethodik und Bewertungskriterien. In VDI-Berichte 1791 (pp. 297–318). Düsseldorf: VDI Verlag. Retrieved from http://www.psychologie.uni-wuerzburg.de/izvw/texte/2003_neukum_krueger_fahrerreaktionen.pdf.

Neukum, A., Naujoks, F., Kappes, S., & Wey, T. (2014). Kontrollierbarkeit unerwarteter Eingriffe eines Bremsassistenzsystems aus Perspektive des Folgeverkehrs. In 9. Workshop Fahrassistenzsysteme (pp. 115–125). Darmstadt: Uni-DAS e.V.

Olsen, E., Lee, S., & Wierwille, W. W. (2002). Analysis of Distribution, Frequency, and Duration of Naturalistic Lane Changes. In Proceedings of the Human Factors and Ergonomics Society : 46th Annual Meeting (pp. 295–297). Baltimore, Maryland, USA.

Olsen, E. C. B. (2003). Modeling slow lead vehicle lane changing. Ph.D. Thesis. Virginia Polytechnic Institute and State University. Retrieved from http://scholar.lib.vt.edu/theses/available/etd-12032003-152916/.

Patel, R. H., Härri, J., & Bonnet, C. (2017). Braking Strategy for an Autonomous Vehicle in a Mixed Traffic Scenario. *Proceedings of the 3rd International Conference on Vehicle Technology and Intelligent Transport Systems*, 268–275. https://doi.org/10.5220/0006307702680275.

Payre, W., Cestac, J., & Delhomme, P. (2014). Intention to use a fully automated car: Attitudes and a priori acceptability. *Transportation Research Part F: Traffic Psychology and Behaviour, 27*(Part B), 252–263. https://doi.org/10.1016/j.trf.2014.04.009.

Radlmayr, J., & Bengler, K. (2015). Literaturanalyse und Methodenauswahl zur Gestaltung von Systemen zum hochautomatisierten Fahren. *FAT-Schriftenreihe, 276*, 1–57. https://doi.org/10.13140/RG.2.1.2222.4401.

Rehder, T., Muenst, W., Louis, L., & Schramm, D. (2016). Learning lane change intentions through lane contentedness estimation from demonstrated driving. *Proceedings of IEEE Conference on Intelligent Transportation Systems, ITSC*, 893–898. https://doi.org/10.1109/ITSC.2016.7795661.

Richtel, M., & Dougherty, C. (2015). Google's Driverless Cars Run Into Problem: Cars With Drivers - The New York Times. New York Times. Retrieved from http://www.nytimes.com/2015/09/02/technology/personaltech/google-says-its-not-the-driverless-cars-fault-its-other-drivers.html?smid=nytcore-ipad-share&smprod=nytcore-ipad&_r=1.

Risser, R. (1987). Kommunikation und Kultur des Straßenverkehrs. Literas Retrieved from. *Wien: Literas Ges.m.b.H., Universitäts-, Buch- und Zeitschriftenverlag*.

Rödel, C., Stadler, S., Meschtscherjakov, A., & Tscheligi, M. (2014). Towards Autonomous Cars: The Effect of Autonomy Levels on Acceptance and User Experience. In Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 1–8). Seattle, WA, USA. https://doi.org/10.1145/2667317.2667330.

Toledo, T., & Zohar, D. (2007). Modeling duration of lane changes. *Transportation Research Record, 1999*(1), 71–78. https://doi.org/10.3141/1999-08.

Witzlack, C., Beggiato, M., & Krems, J. (2016). Interaktionssequenzen zwischen Fahrzeugen und Fußgängern im Parkplatzszenario als Grundlage für kooperativ interagierende Automatisierung. Fahrerassistenz Und Automatisiertes Fahren. VDI-Berichte 2288, 2288(Fahrerassistenz und automatisiertes Fahren), 323–336

Zimmermann, M., Fahrmeier, L., & Bengler, K. J. (2015). A Roland for an Oliver? Subjective perception of cooperation during conditionally automated driving. In 2015 International Conference on Collaboration Technologies and Systems, CTS 2015 (pp. 57–63). Atlanta, GA, USA. https://doi.org/10.1109/CTS.2015.7210400.