Investigation of Cooperative Driving Behaviour during Lane Change in a Multi-Driver Simulation Environment

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Abstract

Thanks to significant progress in communication technology, advanced driver assistance and automation systems (ADAS) provide the opportunity to exchange information for performing cooperative manoeuvres where each communication partner adjust its behaviour, for example to optimize the energy consumption and the safety of a group of vehicles. One such example is a cooperative lane change assistant (C-LCA) to be developed within the ARTEMIS project “D3CoS” (Designing Dynamic Distributed Cooperative Systems). The C-LCA aims at reducing possible conflicts on motorways between a lane changing vehicle and oncoming vehicles on the target lane by coordinating their behaviour in order to achieve a maximum of safety and a minimum of energy consumption. An essential prerequisite for such a system to be effective is detailed knowledge about cooperation behaviour of drivers during such manoeuvres. In a driving simulator study in a multi-driver simulation environment at DLR, cooperation behaviour of drivers under different situational conditions, such as availability of lanes or criticality of the situation, was investigated. Results indicate that drivers consider other drivers’ available actions when requesting cooperation behaviour, and that the willingness to cooperate depends on the ability to anticipate other drivers’ behaviour. These results will be used to develop an effective C-LCA.

Introduction

In 2009 4.4 % of all accidents in Germany happened in a lane change situation (Vorndran, 2010). If only accidents on a motorway are taken into focus, errors during a lane change manoeuvre are even one of the most frequent causes for accidents.
Lane change manoeuvres are prone to errors because there are often two or more road users involved which can negatively interfere in their actions. A potential for negative interference is especially then given when resources like driving lanes are demanded by more than one road user at the same time, so that this resource is in a conflict state (figure 1). The frequent and rather complex interference makes a lane change one of the most challenging manoeuvres in a motorway scenario (e.g. Ammoun, Nashashibi, & Laugreau, 2007). To successfully perform a lane change

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the involved road users have to manage the interference between them at so far, that no critical situation arises, or in such a way that even the efficiency of the manoeuvre can be maximised with respect to fuel or time consumption. This harmonization of strategies can be achieved through cooperation between the involved road users. According to Hoc (2001) cooperation can always then take place when two or more agents can interfere with other road users on goals, resources, procedures etc. and the involved agents try to manage this interference in such a way to facilitate the achievement of each agent’s goals or the common task goal.

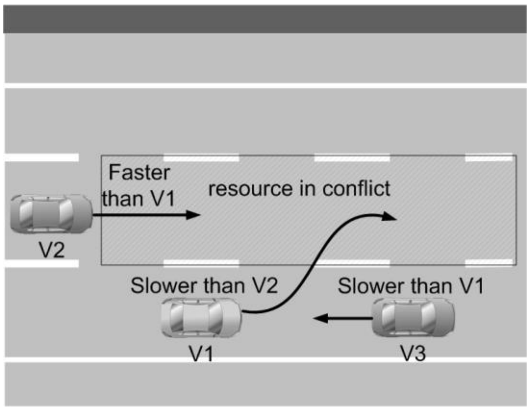

Figure 1: Example of a prototypical lane change situation with a potential resource conflict

A cooperative assistance system for a lane change could influence or facilitate the process of interference management and hence increase the occurrence of cooperative behaviour. Such cooperative assistance systems could be realized on the basis of Car2Car communication, which enables the exchange of information between vehicles respectively the exchange of information between the assistance systems in the vehicles. The question is how a cooperative lane change assistance system should be designed.

Requirements for a good design could be for example that there is a good cooperation not only between the different road users, but also between the assistance system itself and the driver (e.g. Flemisch et al., 2008). It would also be beneficial if the cooperative assistance system could improve the involved drivers' situation awareness (e.g. Endsley, 1997) of the potentially involved agents, or to give directed action suggestions to the driver. As a starting point for interaction design a bottom up approach could deliver first insights into underlying processes and conditions. According to this it is useful to get detailed knowledge how drivers behave in a lane change scenario with conflict potential when there is no assistance system involved. Of special interest in this context are the situational factors that might influence the occurrence of cooperative behaviour. For example, which factors influence the willingness of a driver to cooperate or which factors let a driver decide to perform a lane change in a situation with conflict potential. This bottom up strategy could complement a theory driven design approach. From the knowledge obtained by this approach cooperation strategies for an assistance system could be derived. For a systematic investigation of cooperative processes between two or more road users some methodical implications have to be considered.

First cooperation is a dynamic process with at least two involved agents, hence to get a sufficient and coherent picture of a cooperative process it is necessary to observe cooperative behaviour from the perspectives of all involved agents. for example the behaviour of a road user who requests cooperation and a road user whose cooperation is requested. Secondly a method has to be developed by which a situation can repeatedly be reproduced in which the involved agents can interfere which each other in a lane change situation and where this interference can really cause conflicts. A methodology for the investigation of lane change situations with agent – agent interference was developed, and first knowledge of drivers' behaviour in such situations was gathered.

Method

To investigate the effect of situational factors on the occurrence of cooperative behaviour in a lane change situations an explorative study was conducted at German Aerospace Center (DLR) in Braunschweig.

Aparatus

For the study the DLR multi driver simulation MoSAIC (Modular Scalable Applications Platform for ITS Components) was used. Based on this platform, two or more driving simulators can be integrated into the same framework, so that the drivers of each simulator can interact in the same driving scenario. Each simulator was equipped with 160 degree view, realized by 3 monitors (one for front view and one each for left and right side view, see figure 2). The simulator was also equipped with an 8 inch LCD monitor as a left side mirror. The steering wheel and the pedals were Logitech G27 game wheel/pedals combinations, whereas the steering control unit remained the Logitech unit, but the steering wheel itself was exchanged by an original car steering wheel. The drop arms were also original car manufacturer parts. Each participant had a headset to hear the engine sound and to communicate with the experimenter. In the setting used for this investigation two fixed based driving simulators were integrated in the platform (see figure 2).

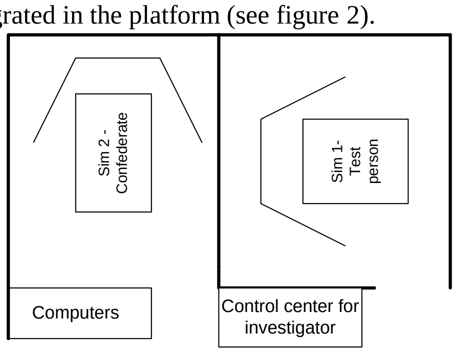

Figure 2: Schematic view on the MoSAIC driving simulation platform as used in the study

Confederate

One reason for using the multi driver simulation was that the test persons should know that they were driving with real human agents in the same scenario. In this study one simulator was driven by a test person and the other simulator was driven by a so called confederate. The confederate was clued-up and instructed to behave in a certain manner, depending on the situation. This way, the same class of situations could repeatedly be experienced by the test persons without being in exactly the same situation as experienced before. The confederate was able to react to possible manifold variability of the participants actions in the lane change situation in a dynamic and non artificial way, so that the situations remain natural. At the same time the confederate could help in the creation of consistent situation classes.

Sample

Twenty participants, 10 male and 10 female with a mean age of 31.4 years (SD = 12.7 years) were invited to the study. All participants were acquired from the DLR test driver pool, which contains about 800 persons. All participants possessed a valid driver’s licence in mean for 13.1 years (SD = 12.1 years)

The basic scenario & construction of comparable situations

To investigate cooperative behaviour a lane change situation in which at least two agents can interfere in their action is necessary. To produce interference a potential conflict state must be generated. Therefore a basic scenario was developed in which one agent can perform a lane change to avoid collision with a slower driving car, but at the same time a faster car is approaching from behind on the neighbour lane.

To reduce the situation complexity a relatively simple and generic lane change scenario was used. In this scenario, three agents were involved: the two human agents (one was the test person and one was the confederate) and one simulated agent. The scenario was a straight 3-lane motorway. The vehicle V1 and V2 were driven by humans and the vehicle V3 was controlled by a simulation (figure 3).

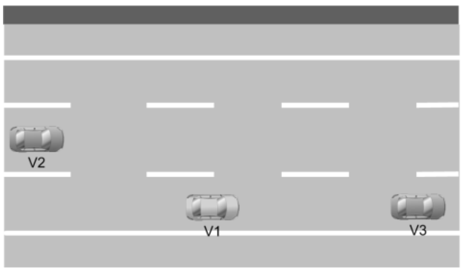

Figure 3: the basic scenario with the three involved agents.

Vehicle V2 always started on the centre lane and had to maintain a velocity of 130 km/h. Vehicle V1 always started on the right lane 300 meters before V2 and had to maintain a velocity of 100 km/h. Vehicle V3 controlled by the simulation started also on the right lane approximately 70 meters before vehicle V1. The velocity of V3 was coupled to the velocity of V1 and the gap of 70 meters was kept continuously (figure 4).

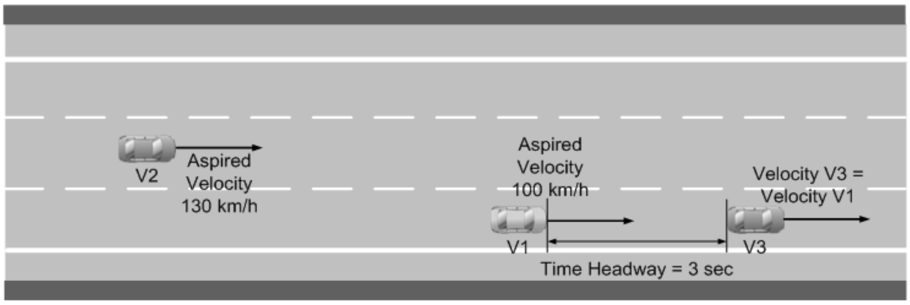

Figure 4: initial positions and velocities of the involved agents

Because of the different instructed velocities of V1 (100 km/h) and V2 (130 km/h), V2 approached V1. When a certain time to collision (TTC) was reached (TTC = 12 sec) this was a trigger for V3 to begin the brake manoeuvre (dependent on the condition either strong or weak – figure 5).

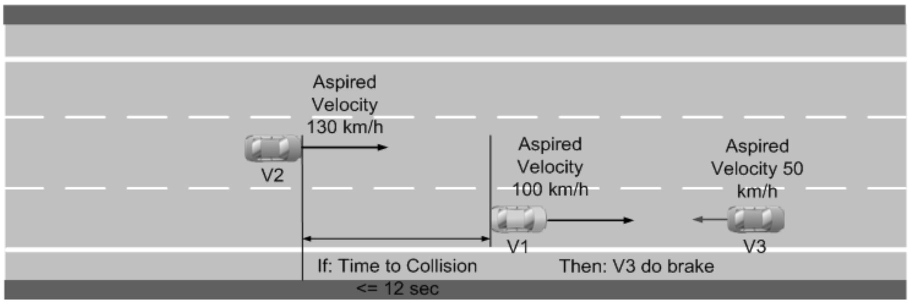

Figure 5: Triggering of a situation in which two agents can interfere

The values for this trigger point and the different velocities were derived from the literature (Baumann, Steenken, Kassner, Weber, & Lüdtke, 2010; Choudhury, Ben-Akiva, Toledo, Lee, & Rao, 2007) and are supposed to resemble the moment in which half of the participants driving V1 decide for merging in front and half of the participants decide for merging behind the approaching car V2. Because V3 got slower, vehicle V1 approached V3 and had to perform a lane change in order to maintain the initially instructed velocity of 100 km/h. At the same time, vehicle V2 on the centre lane interfered with the lane change of V1.

After V2 has passed V3 the conflict scenario was over and the participants were told to stop the vehicle. After that, a new situation started. This way, several comparable situations could have been produced only altered by the variation of the independent variables.

Perspectives

In the chosen scenario there were two human agents involved, each of them with different perspectives (vehicles V1 and V2). Because both perspectives play an important role in the lane change manoeuvre, each test person took both perspectives during the drive. So in some drives they took perspective V1 and in other drives they took perspective V2.

Experimental Design

For each perspective, there were the same independent variables with one exception for the perspective V1. There was one independent variable less than for perspective V2. Therefore, for each perspective a different experimental design is presented.

Table 1. Shows the independent variables for the perspective V2 and the resulting eight conditions

		Availability of left Lane			
		Closed		**Free**	
		Indication V2		**Indication V2**	
		Yes	**No**	**Yes**	**No**
V3 Brake strength	**Low**	20 * 2 drives	20 * 2 drives	20 * 2 drives	20 * 2 drives
	Weak	20 * 2 drives	20 * 2 drives	20 * 2 drives	20 * 2 drives

Table 2: Shows the independent variables for the perspective V1 and the resulting four conditions.

		Availability of left Lane	
		Closed	**Closed**
V3 Brake strength	**Low**	20 * 2 drives	20 * 2 drives
	Weak	20 * 2 drives	20 * 2 drives

It was a within subjects design in which all participants experienced all conditions. Each participant experienced each factor combination in each perspective twice, so this were 2 x 8 situations for the V2 perspective (table 1) and 2 x 4 situations for the V1 perspective (table 2) that means together 24 relevant situations. Additional to these 24 situations 12 "distractor" situations were added, in which the confederate should show behaviour with a broad variety. The distractor situations were introduced to minimize the driver's expectancy that a lane change has to be performed. So in the end, every participant had to drive through 36 situations. The different independent variables were operationalized as depicted in figures 5 to 8.

Operationalization of the independent variables (situations)

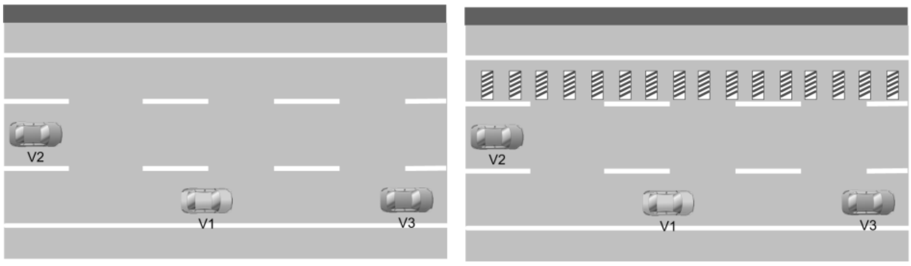

Figure 6: Operationalization of independent variable lane status. Left = free; right = closed.

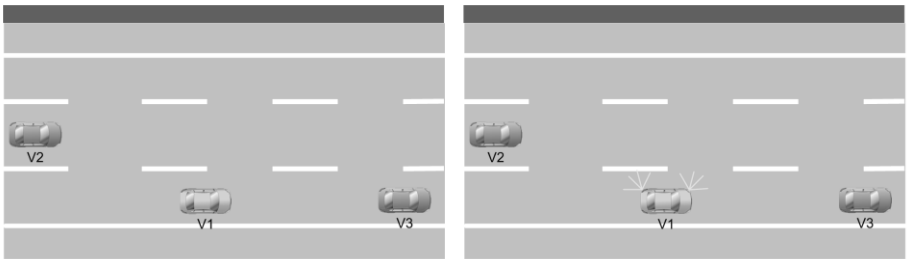

Figure 7: Operationalization of independent variable V2 lane change indication. Left = no indication; right = indication at TTC V2-V1 ≈ 8.5 – 6.6 sec.

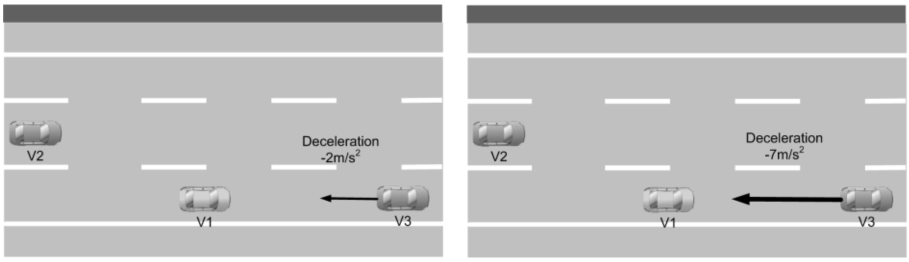

Figure 8: Operationalization of independent variable V3 brake strength. Left = weak deceleration -2m/s^2; right = strong deceleration -7m/s^2.

Because of the variety of different situations, it was not practical to counterbalance the occurrence of the situations between the participants, as a consequence of that the sequence of situations was randomized for every participant.

Procedure

After filling out a consent form and a demographic questionnaire the simulator was shown to the participant (ETC). Here, the participants should explicitly see that they drive together with a real human driver in the scenario. Then the participant could sit down in the simulator and configure the seat so that he/she feels comfortable. After that the simulator was instructed. After a short training, in which the participant should get some experience with the steering of the vehicle, the test drives began.

Depending on the perspective (V1 or V2) the participants started either on the right lane, behind a lead car, or in the centre lane. They were instructed to reach a target velocity of 130 km/h (V2) or 100 km/h. and that they should try to maintain this speed as constant as possible throughout the drive. As previously stated after a certain time the vehicles V1 and V2 reached a defined time to collision and this way the braking of the lead car V3 was triggered and this way a lane change manoeuvre was provoked.

After the lane change manoeuvre, the participant was told to stop the car, and to fill auto a questionnaire. While filling out the questionnaire the vehicles were set to the initial starting position so that the next situation could be experienced. Each drives took approximately 1.5 minutes. After 36 drives the participants had to fill out a final questionnaire and then they were instructed over the real purpose of the study. After that they were paid.

Results

At first, the results of the observation of the drives in the V1 perspective are taken into focus. In the second part of the results chapter, the observations made in the drives of the V2 perspective are analysed. The overall frequencies of observed manoeuvres in each condition are depicted for each perspective. The independent variables were all dichotomous and the dependent variables were dichotomous, too (e.g. braking yes/no acceleration yes/no lane change yes/no etc.). To test for any effect of the independent variables a binominal logistic regression analysis was performed for each class of observed manoeuvres.

Perspective V1

The dependent variables here were the occurrence (yes/no) and the frequency of certain manoeuvres in context of the lane change situation, for example the frequency of setting the indicator, the frequency of acceleration, the frequency of braking / deceleration and the frequencies of either merging before the V2 vehicle or merging after the V2 vehicle. The overall observed frequencies are listed in table 3.

Of special interest in the study of perspective V1 was, under which conditions the drivers would deviate from their goal to maintain a velocity of 100 km/h and wait for the V2 vehicle to overtake (merging behind V2). Or in which situations drivers would merge before V2 and so requesting cooperation from vehicle V2.

Table 3: Frequencies of observed manoeuvres of the V1 vehicle in the different conditions

Factor combination		Indication	Acceleration	Brake	Merging before V2	Merging after V2	∑
Left Lane Closed	Strong Brake V3	36	5	26	10	26	103
	Weak Brake V3	40	29	27	13	27	136
Left Lane Free	Strong Brake V3	39	14	23	16	23	115
	Weak Brake V3	33	22	19	16	19	109
	∑	148	70	95	55	95	463

What can be seen in the frequencies is, that the lane status left lane closed or left lane free has an effect how often drivers decide to merge either before or after a car. The braking behaviour of the V3 vehicle is also closely related to this decision. So if the V2 vehicle approaching from behind has the opportunity to change lanes, more drivers decide to merge in front of this vehicle. To test this, a logistical regression was performed for the manoeuvre merging in front of V2 (see table 4). The Odds Ratio for LaneStatus is 1.777. There was a by trend significant effect of this factor.

Table 4: Logistic regression for manoeuvre V1 merging in front of V2

Dependent Variable	**Estimate**	**Std. Error**	**Z value**	**p**	
LaneStatus	0.575186	0.343857	1.673	0.0944	.
BrakeStrengthV3	-0.20673	0.343256	-0.602	0.5470	

Signif. codes: 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Perspective V2

Regarding the perspective of V2, it was of special interest, under which situational conditions a driver would show cooperative behaviour that means either changing lane to allow the driver of V1 to perform a lane change or by braking or accelerating but without being forced to do so. So in the first step the frequency of lane changes, setting of the turn indicator, acceleration and braking to decelerate was taken into focus in the different conditions (see table 5).

The conditions for V2 were the availability of the left lane (closed/free), the brake strength of the simulated vehicle V3 (strong/weak) and the indication of the V1 vehicle (yes/no)

As it can be seen in table 5 there were more lane changes of V2 when the left lane was available and accordingly more indication of a lane change. Regarding to that, there were less brake actions of V2 when changing a lane. A logistical regression for the lane change of V2 showed a significant effect of the factor lane status on the occurrence of a lane change manoeuvre (odds ratio 591.73). The finding that there are more lane changes in a situation where the left lane is available is somehow trivial. More interesting was a by trend effect of the brake strength of V3 on the lane change frequency (table 6). The Odds Ratio was 1.835. So a lane change was performed more often when the simulated vehicle V3 braked stronger.

Table 5: Frequencies of the manoeuvres of V2 in the different factor combinations

Factor combinations			Lane Change	Indication	Acceleration	Brake	∑
Left Lane Closed	No Indicator V1	Strong Brake V3	0	1	1	16	18
		Weak Brake V3	0	0	4	22	26
	Indicator V1	Strong Brake V3	1	1	3	18	23
		Weak Brake V3	0	0	2	20	22
Left Lane Free	No Indicator V1	Strong Brake V3	32	34	7	2	75
		Weak Brake V3	22	22	6	5	55
	Indicator V1	Strong Brake V3	34	34	9	2	79
		Weak Brake V3	17	27	6	2	52
		∑	106	119	38	87	350

Table: 6: Logistic regression for V2 lane change manoeuvre

Dependent variables	**Estimate**	**Std. Error**	**Z value**	**p**	
LaneStatus	6.38305	0.84247	7.577	< 0.0001	**
Brake Strength V3	1.22624	0.62807	1.952	0.0509	.
Indication V1	0.08866	0.58967	0.150	0.8805	
Signif. codes: ≤ 0.001 ‘**’ <0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1					

Regarding the frequency of brake actions of V2, a significant effect of the V3 brake strength on the frequency of the V2 brake action could have been observed (Table 7). The odds ratio was 0.327.

Table 7: Logistic regression for V2 manoeuvre brake action.

Dependent variable	Estimate	Std. Error	Z value	p	
LaneStatus	-4.0676	0.4551	-8.937	< 0.0001	**
BrakeStrengthV3	-1.1189	0.4533	-2.468	0.0136	*
IndicationV1	-0.1231	0.4300	-0.286	0.7747	
Signif. codes: ≤ 0.001 ‘**’ <0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1					

Because of the significant effect of the V3 brake strength on the brake action of V2, logistical regressions were conducted divided for the lane status, one for the closed lane status and one for the available lane status. The logistical regression for the left lane free status revealed no effect of the brake strength on the brake action of V2 presumably because in this condition most drivers performed a lane change. But in the left lane closed condition there was an effect of the V3 brake strength on the V2 brake action frequency (odds ratio 0.2889).

Table 8: Logistic regression for V2 manoeuvre brake action in the left lane closed condition.

Dependent variable	Estimate	Std. Error	Z value	p	
BrakeStrengthA1	-1.2416	0.6309	-1.968	0.0491	*
IndicationM1	0.2334	0.5818	0.401	0.6883	
Signif. codes: ≤ 0.001 ‘**’ <0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1					

Drivers tend to brake more often when the lead vehicle in front of V1 decelerates strong, so that V1 approaches V3 faster. This way the approach process might be more obvious and so the predictability of a lane change manoeuvre of V1 might be higher.

Discussion

Perspective V1

In this study a significant effect of the brake strength of a lead car on the frequency of cooperative behaviour could not be found. What could be found was a marginal effect of the availability of a left lane on the willingness to engage in cooperation. Results show that drivers on the right lane tend to merge more frequently in front of an approaching car on the neighbour lane, when they see that a third lane is available. Because the driver of V2 was in this case a confederate and had the order to perform lane changes only when the V1 vehicle cuts in and not to indicate such a lane change, there was no information from the V2 vehicle. So it can be concluded that drivers of V1 take the availability of actions of other road users into consideration when deciding for certain manoeuvres, because they based their decision presumably only on the availability of the left lane. So with their own behaviour of merging in front of the V2 vehicle they somehow request the V2 vehicle to behave in a cooperative manner by either decelerating or changing lanes. In the observed case the results indicate that drivers consider other drivers’ available actions when requesting cooperation behaviour.

Regarding the design of an assistance system for cooperative lane changes, highlighting other drivers' available actions could be a strategy to inhibit inadequate lane changes when this way other road users would be forced to perform a manoeuvre for which there is no alternative.

Perspective V2

The results of perspective V2 indicate that the willingness to cooperate on the one side depends on the availability of actions, like the availability of a left lane, but on the other side also depends on the ability to anticipate other drivers' behaviour. So the braking strength of the simulated lead car (V3) and the resulting higher relative speed between V1 and V3 seem to be a cue increasing the predictability of a lane change manoeuvre by V1. Interestingly the indication behaviour (yes/no) of V1 did not had an effect on the cooperative behaviour of V2. A reason for this could be that the indication of a lane change from V1 was too late, so that most participants decided to overtake the V1 vehicle instead of changing lanes. The braking of the V3 vehicle came significantly earlier than the indication of V1, so that this information was more valuable for the drivers in the V2 perspective.

Regarding the design of an assistance system a useful strategy could be to identify approach processes and deduce a certain lane change probability. This probability could be given as a feedback to the driver to increase the predictability of other agents' behaviour. If the predictability is increased, the drivers have more time for decision which would be a prerequisite for cooperation on a voluntary basis.

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