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

Nina Kauffmann [a,*], Franz Winkler [a], Frederik Naujoks [a], Mark Vollrath [b]

[a] BMW Group, Landshuterstr. 26, 85710 Munich, Germany
[b] TU Braunschweig, Institute of Engineering and Traffic Psychology, Gaußstr. 23, 38106 Braunschweig, Germany

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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

* Corresponding author.
E-mail addresses: Nina.Kauffmann@bmw.de (N. Kauffmann), Franz.Winkler@bmw.de (F. Winkler), Frederik.Naujoks@bmw.de (F. Naujoks), mark.vollrath@tu-braunschweig.de (M. Vollrath).

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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.