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Does surrounding traffic benefit from an assisted driver with traffic light assistance system?

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ABSTRACT

Traffic light assistance systems enable drivers more energy and time efficient driving behavior at signalized intersections. However, most vehicles will not be equipped with such systems in the next years. These unequipped vehicles' drivers (UVDs) may benefit from assisted drivers, if they would adapt their behavior. This paper outlines how UVDs ($N = 60$) interpreted and reacted to a driver with traffic light assistance system. We used a multi-driver simulator with three drivers driving in a car-following scenario. The lead driver was not a participant, but a confederate who was followed by two UVDs. The confederate was apparently equipped either with or without a traffic light assistance system. The traffic light assistance system consisted of two functionalities: a Green Light Optimal Speed Advisory and a start-up assistance system with two different parametrizations. These functionalities aimed at preventing unnecessary changes in speed and reducing the start-up lost time after signal change. The results showed that UVDs benefited from the driving behavior of the confederate with traffic light assistance system. However, the assisted driving behavior was hardly understood and partly rated as aversive by the UVDs. We discuss how to enhance behavioral adaptation of UVDs. We also outline which negative consequences may result from encounters of driver with systems and UVDs. We assume that how UVDs react towards drivers with systems may be one factor contributing to a successful launch of such systems.

1. Introduction

Cooperative Intelligent Transport Systems (C-ITS) are considered among the most promising innovations in present automobile industry. Based on sensor or Vehicle-to-X-communication, vehicles with C-ITS are enabled to exchange information with other vehicles or infrastructure in real-time (Bossom et al., 2009). A traffic light assistance system is an umbrella term for different C-ITS applications supporting drivers at signalized intersections. Vehicles equipped with traffic light assistance systems receive and exchange information with traffic lights. Via appropriate human-machine interfaces (HMI), drivers with such systems are provided with information about the current and upcoming traffic light signals. Based on this information, drivers may adapt their driving behavior in anticipation of the upcoming traffic situation. For example, they may be informed that they will not able to cross the stop line within the green signal phase. Based on this information, they may decelerate or coast when approaching traffic lights. In contrast, drivers without such systems would simply keep up the speed until the traffic light switches its signal to red. This may lead to situations where these drivers may have to decelerate heavily to avoid

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running the red light. Such driving patterns (i.e., strong decelerations and accelerations) and a high variability of driving speed respectively, are associated with a higher degree of environmental impact (Frey et al., 2003; Rakha, Van Aerde, Ahn, & Trani, 2000). Traffic light assistance systems may provide drivers with recommendations to prevent such driving patterns and enable more energy efficient driving (Draskoczy, Carsten, & Kulmala, 1998; Kulmala, Rämä, & Sihvola, 2008; Staubach, Schebitz, Köster, & Kuck, 2014). More energy efficient driving may lead to a reduction of environmental impact and fuel consumption (Asadi & Vahidi, 2011; Katsaros, 2011; Tielert et al., 2010; Widodo, Hasegawa, & Tsugawa, 2000). Traffic light assistance systems may also support drivers while start-up maneuvers to optimize traffic flow. Usually, drivers need approximately two seconds to react to signal changes from red to green (Koonce, Rodergerdts, & Lee, 2008). This so-called start-up lost time may be reduced by informing drivers about the upcoming signal switch. Thus, early start-up maneuvers of assisted drivers are enabled. As a consequence, more vehicles may pass the signalized intersection within the green signal phase.

In regard to the relatively low penetration rate of such systems in the nearer future, drivers with systems will encounter drivers without systems most of the times. How do these unequipped vehicles' drivers (UVDs) react to drivers with systems? So far, studies focussed primarily on drivers with systems, but neglected how UVDs may be affected by assisted drivers (e.g., Farah et al., 2012; Staubach et al., 2014). Traffic simulation studies considered mixed equipment rates for calculating the benefit of C-ITS (e.g. Krajzewicz, Bieker, & Erdmann, 2012; van Arem, van Driel, & Visser, 2006). However, these studies considered UVDs as unaffected by assisted drivers. This assumption is, however, critical. Gouy (2013) reported that UVDs adapted their behavior to automated vehicle platoons with short headways when driving next to it: They also showed shorter headways to preceding vehicles. This result shows that UVDs may adapt their driving behavior to assisted drivers. In this case, an adaptation of UVDs to assisted drivers comes along with safety issues. However, an adaptation of UVDs may also have positive consequences: If UVDs would adapt their driving behavior to assisted drivers with traffic light assistance system, they may also benefit from it. Li and Gao (2013) discussed that the key for a reduction of environmental impact and optimization of traffic flow is that drivers synchronize their driving behavior. Therefore, we asked the question whether UVDs adapt their driving behavior to drivers with traffic light assistance system.

Some studies discussed that drivers with traffic light assistance systems may also have negative impacts on surrounding traffic (Mori, Kitaoka, Ishida, & Asakura, 2010; Qian, 2013). Driving behavior of drivers with systems may be perceived as aversive as it differs from what UVDs may expect. Frehse (2015) showed that driving behavior of others is perceived as more aversive, when it is not understood or expected. First studies showed that UVDs felt bothered when they experienced how drivers with traffic light assistance systems coasted for long distances when approaching traffic lights (Mühlbacher, 2013; Rittger, Muehlbacher, Maag, & Kiesel, 2015). Therefore, we also asked the question how UVDs in our study perceive the driving behavior of a driver with a traffic light assistance system.

To answer these two research questions, we conducted a study with two UVDs experiencing the driving behavior of a driver with traffic light assistance system. These three drivers were driving in a line (i.e., platoon) in the same driving scenario. We realized this scenario with the help of a multi-driver simulator. Multi-driver simulators are discussed to be valid tool to examine interactions of drivers (Mühlbacher, 2013; Mühlbacher, Zimmer, Fischer, & Krüger, 2011; Oeltze & Schießl, 2015). In traditional driving simulator studies, interactions of drivers are examined by one participant encountering simulated drivers. The driving behavior of these simulated drivers is predefined based on driver models. However, these driver models lack realism: They do not sufficiently represent the human factors of driving (e.g., cognitions in terms of emotions or aspects of information processing) (Krajzewicz & Wagner, 2004; Olstam & Tapani, 2004). Consequently, simulated drivers may act differently than real drivers. To address this issue, the idea of multi-driver simulators came up. Here, multiple participants drive together in the same virtual environment by coupling multiple driving simulators. Mühlbacher (2013) showed that participants driving in a car-following scenario within a multi-driver simulator study showed more realistic driving behavior than simulated drivers. Friedrich (2012) showed that participants that knew they were driving with other human drivers tended to be more cooperative. Multi-driver simulator studies also offer a higher degree of controllability and internal validity compared to, for example, on-road-assessments (e.g. Naturalistic Driving Studies). A high degree of experimental control may be necessary as participants have to encounter each other within experimental scenarios in order to examine interactions of drivers. In terms of studying encounters of UVDs with assisted drivers, the use of multi-driver simulators has three additional advantages: First, a multi-driver simulator enables upscaling effects that an assisted driver may have on more than one UVD. Second, we are able to take into account that how an UVD reacts to an assisted driver may also be affected by other surrounding UVDs. Third, we are also able to take into account that UVDs may be affected differently by an assisted driver depending on the position they are driving in the platoon. Studies showed that different positions of drivers within a platoon lead to different driving behavior (Limanond, Prabjabok, & Tippayawong, 2010; Rittger, 2015).

In our study, we did not inform the UVDs about the equipment of the driver with a traffic light assistance system. The traffic light assistance system consisted of two C-ITS applications for two use cases. The first one, the Green Light Optimal Speed Advisory (GLOSA), aimed at preventing unnecessary deceleration behavior when approaching traffic lights that switched its signal from red to green (use case "red-green"). Thus, the assisted driver approached these traffic lights with a higher speed. The second C-ITS application, the start-up assistance system, aimed at reducing the start-up lost time (i.e., time to react to signal change) (use case "red"). Here, we tested two different parametrizations.

We wondered whether the UVDs ($N = 60$) in our study may adapt the assisted driving behavior as well. Additionally, we studied whether the UVDs noticed the assisted driving behavior and how they rated it. We assumed that the benefit of the