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On actions of long combination vehicle drivers prior to lane changes in dense highway traffic – A driving simulator study

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ABSTRACT

In this paper we address drivers' actions prior to mandatory lane changes of long combination vehicles in dense highway traffic. The studied driver actions were: turn indicator activation, speed reduction and lateral intrusion. We categorised and compared the drivers' actions with respect to the surrounding traffic cooperation and the level of urgency. Urgency here was based on the remaining distance to a targeted exit ramp. The results show that when the subject vehicle is close to the exit ramp, drivers used speed reduction significantly more than when the vehicle is further away. No significant difference was found for the use of lateral intrusion considering the distance to the exit ramp. As regards traffic cooperation, significant differences were found for both speed reduction and lateral intrusion. The drivers' speed reduction and lateral intrusion were significantly greater when the surrounding traffic cooperation was low.

1. Introduction

Driving automation is likely as the next revolution to improve the productivity and safety of road transport systems. A primary application for driving automation of heavy-vehicle freight transports is highway driving with and without a driver (Flämig, 2016). An important part of highway driving is lane-change manoeuvres, which have substantial impact on both traffic safety (Sen, Smith, & Najm, 2003) and traffic flow characteristics (Zheng, Ahn, & Monsere, 2010). Today's professional drivers of heavy-vehicle freight transports are skilled in driving in dense traffic and performing mandatory lane changes. We believe that studying the important actions and metrics of manual driving will give insight into how to design driving automation, especially considering mixed traffic with both manually driven and automated vehicles. In this study we address mandatory lane changes in dense highway traffic.

An interesting starting point considering future heavy freight transports and driving automation would be the utilisation of modular long combination vehicles (LCVs), such as the one illustrated in Fig. 1. This is likely to further improve productivity, traffic safety and uptime. LCVs are road vehicles that are longer and heavier than the currently permitted dimensions in Europe. However, various applications of LCVs already exist in Australia, Brazil, Canada, Mexico, New Zeeland and the United States (Mellin & Ståhle, 2010). Typically, LCVs include at least two articulated joints and their length generally varies between 27 m and 34 m. The weight and/or volume of transported goods in an LCV is typically doubled that of a conventional tractor semi-trailer combination. Sweden is in the process of implementing initiatives for a general introduction of

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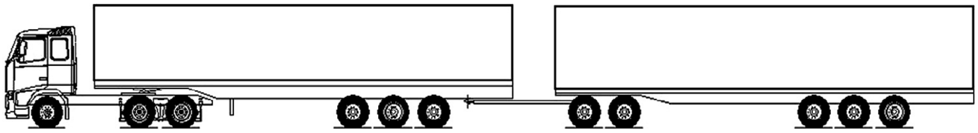

Fig. 1. An example of a long combination vehicle, referred to as an A-double combination.

LCVs in traffic (Swedish Ministry of Enterprise & Innovation, 2014; Swedish Transport Agency, 2014). The intention is to allow LCVs mainly on roads with the highest weight class. Before driving on other roads, LCVs can be decoupled into shorter conventional combinations. For example, the A-double combination, which consists of a tractor unit, semi-trailer, converter dolly and a second semi-trailer, can be converted to a standard tractor semi-trailer when approaching city areas. However, using LCVs can further amplify lateral motions in high-speed manoeuvres such as lane changes, compared to conventional vehicle combinations. Typical performance characteristics are rearward amplification of the lateral acceleration between the first and last vehicle units and lateral off-tracking between the first and last axles in the vehicle combination (Aurell & Wadman, 2007). For example, during an LCV lane-change manoeuvre at 80 km/h and with a critical steering wheel frequency of 0.3 Hz, the rearward amplification and the lateral off-tracking can be as high as 2 and 0.5 m, respectively. The corresponding values for a tractor semi-trailer combination are typically 1 and 0.2 m.

To address driver actions performed during lane changes, it is of interest to review research regarding microscopic traffic simulation. Most existing models can be categorised based on whether they address the lane-changing decision-making process or the impact on surrounding vehicles (Zheng, 2014). Further, lane-changing manoeuvres are often classified as mandatory lane changes (MLCs) or discretionary lane changes (DLCs). An MLC is performed when a driver must change lanes in order to reach his/her destination, while a DLC occurs when a driver seeks to improve driving conditions, e.g. to gain a speed advantage. Considering rule-based models aiming to describe the lane-changing behaviour, a lane change is usually modelled in a sequence of three steps (Moridpour, Rose, & Sarvi, 2010). First, the motivation to change lanes; second target lane selection; and finally the execution of the lane change. The first two stages of the manoeuvre incorporate the lane-changing decisions while the final stage is linked to the execution of the lane-changing manoeuvre. Among the first rule-based models for an urban street context was developed by Gipps (1986). The decision-making process in Gipps's model included factors such as the drivers' instantaneous gap acceptance and predicted deceleration, the presence of heavy vehicles, the presence of special-purpose lanes e.g. transit lanes, the distance to an intended turning movement in the case of an MLC and the possibility of gaining a speed advantage. Yang and Koutsopoulos (1996) extended the Gipps model to freeways and included a stochastic approach for decision-making. Further, they found the level of gap acceptance for an MLC to follow three sequential stages as the vehicle approaches its target turning point. Hidas (2005) suggested a modelling framework that included lane-change traffic interactions. The lane-change manoeuvres were divided into three categories: free, cooperative, and forced. In a cooperative or forced lane change, close interactions occur between the subject vehicle and the adjacent vehicles in the target lane, in which the adjacent vehicle slows down either reluctantly (i.e., in a forced lane change) or willingly (i.e., in a cooperative lane change) to create sufficient space for the subject vehicle to enter. Factors that may have impact on the adjacent vehicles' decision to slow down or not include the subject and adjacent vehicles' aggressiveness, the driving experience of the adjacent vehicle driver, the necessity and urgency of the lane change, the drivers' mental states, traffic conditions, etc. Hidas assumed the adjacent vehicle driver to be willing to accept a certain maximum speed decrease and adopted the "time-to-end-of-lane" to reflect the urgency of the lane change. Zheng (2014) conducted a comprehensive review of existing lane-changing models.

The lane-changing models discussed above (Gipps, 1986; Hidas, 2005; Yang & Koutsopoulos, 1996) mainly focus on the lane-changing behaviour of passenger car drivers. The distinction between heavy vehicles and passenger cars consists primarily of differences in total vehicle length and acceleration/deceleration capabilities. Moridpour et al. (2010) showed that the behaviour of heavy vehicles on freeways differs significantly from that of passenger cars when drivers decide on or execute a lane-change manoeuvre. For example, in a heavy-vehicle DLC, the subject vehicle mainly moved into a slower lane to prevent obstructing fast-moving vehicles approaching from the rear. Passenger cars mainly move into the faster lanes to gain a speed advantage. Furthermore, with heavy vehicles the speed varies very little over the execution of the lane changing manoeuvre. In corresponding situations for a passenger car, the drivers mainly increase their speeds to move into the faster target lane. Moreover, the time needed to complete a lane-change manoeuvre increases with the total length of the vehicle. This is due to lateral vehicle dynamics amplification and the resulting increased risk of subject-vehicle roll-over; thus the heavy vehicle lane-change manoeuvre needs to be performed in a smooth fashion. This is generally not needed for a passenger car.

In addition to the DLC findings by Moridpour et al. (2010), this study also examined MLCs. LCVs and heavy-vehicle freight transports in general, are driven by productivity[1] to a much greater extent than passenger cars. This means that missing a mandatory road departure can result in both time delay and increased transportation cost. The motivation for urgency, espe-

[1] Vehicle productivity can be defined as the difference between revenues and fixed and variable costs summed over the number of transport missions.