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Categorization of the lane change decision process on freeways ☆

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A B S T R A C T

Traffic operations for new road layouts are often simulated using microscopic traffic simulation packages. These traffic simulation packages usually simulate traffic on freeways by a combination of a car-following model and a lane change model. The car-following models have gained attention of researchers and are well calibrated versus data. The proposed lane change models are often representations of assumed reasonable behavior, not necessarily corresponding to reality. The current simulation packages apply solely one specific type of model for car-following or lane changing for all vehicles during the simulation. This paper investigates the decision process of lane changing maneuvers for a variety of drivers based on a two-stage test-drive. Participants are asked to take a drive on a freeway in the Netherlands in a camera-equipped vehicle. Afterwards, the drivers are asked to comment on their choices related to lane and speed choice, while watching the video. This paper reveals that different drivers have completely different strategies to choose lanes, and the choices to change lane are related to their speed choice. Four distinct strategies are empirically found. These strategies differ not only in parameter values, as is currently being modeled in most simulation packages, but also in their reasoning. Most remarkably, all drivers perceive their strategy as an obvious behavior and expect all other drivers to drive in a similar way. In addition to the interviews of the participants in the test-drive, 11 people who did not take part in the experiment were interviewed and questioned on lane change decisions. Moreover, the findings of this study have been presented to various groups of audience with different backgrounds (about 150 people). Their comments and feedback on the derived driving strategies have added some value to this study. The findings in this paper form a starting point for developing a novel lane change model which considers four different driving strategies among the drivers on freeway. This is a significant contribution in the area of driving behavior modeling, since the existing microscopic simulators consider only one type of lane change models for all drivers during the simulation. This could lead to significant changes in the way lane changes on freeways are modeled.

1. Introduction

In recent years, due to the growing application of microscopic simulators for the analysis of transportation systems as well as traffic control, interests in developing more reliable driving behavior models and in particular lane changing and car-following models have increased significantly. Existing simulation packages that represent the state-of-the-practice are

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widely criticized as insufficient (Prevedouros and Wang, 1999; Hidas, 2005; Laval and Daganzo, 2006). In practice, microscopic simulation packages are being used to assess the quality of the traffic flow, as well as delays and emissions. The modeling core of the movement of vehicles on freeways is formed by a combination of two sub-models, a longitudinal and a lateral sub-model. The model for the longitudinal movement either describes the car-following behavior or considers the free-flow speed of drivers. The lateral model describes when and how vehicles change lane. For ex-ante evaluations of traffic measures, it is important that the model predicts the driving behavior via a mechanism reflecting real-life driver behavior. This might be achieved by considering a comprehensive driving behavior modeling structure including the decision process, psychological and perceptional information of the driver, etc. This holds for both longitudinal as well as lateral actions.

Despite its great importance, lane changing has not been studied nearly as extensively as longitudinal acceleration and deceleration behavior. This could be due to insufficiency of reliable data (e.g. cross-sectional data from detectors (Hidas and Wagner, 2004)). Clearly, a traffic modeling tool that fully describes lane changing is still lacking. However, in recent years, interest in the development of lane changing models and their implementation in traffic simulators has increased drastically. The modeling efforts in the literature are roughly categorized as: modeling the lane change decision-making process, and modeling the impact of lane changes on surrounding traffic (Zheng, 2014). Zheng et al. (2013) studied the impacts of lane change maneuvers on the immediate follower in the target lane. Some models (e.g. Laval and Daganzo, 2006) emphasize on driver's decision-making process, which contains the decision to consider a lane change, choice of a target lane (i.e. unobservable), and gap acceptance steps. These models generally neglect the detailed modeling of the lane change action itself and model it as an instantaneous action. Current lane changing models are unable to describe correctly the lane changes found in traffic. Understanding lane changing behavior is important in several application fields such as capacity analysis and safety studies (Zheng et al., 2010). Approximately 539,000 two-vehicle lane change crashes occurred in the U.S. in 1999 (Sen et al., 2003). For traffic operations in multi-lane traffic facilities, lane changing is essential. The negative impact of lane changes on traffic breakdowns and bottleneck discharge rate reduction at the onset of congestion (i.e., capacity drop) is reported in Cassidy and Rudjanakanoknad (2005). The significant roles played by lane change in formation and propagation of stop-and-go oscillations have also been revealed (Kerner and Rehborn, 1996; Mauch and Cassidy, 2002; Ahn and Cassidy, 2007). Laval and Daganzo (2006) addressed that lane changes cause disruptions and might influence the capacity of the road by leaving voids.

Recent works studied also the driving behavior of heavy vehicles when making a decision or executing a lane changing maneuver on freeways (Aghabayk et al., 2011). Moridpour et al. (2012) addressed that applying an exclusive heavy vehicle lane changing decision model can raise the precision of the microscopic traffic simulation software in estimating the macroscopic traffic flow measurements.

After Gipps' lane change model (Gipps, 1986), in most lane changing models, the lane changes are classified based on the reason for which the lane changes are performed (e.g. mandatory, discretionary). Mandatory lane changes (MLC) occur when a driver must change lane to follow a path to reach his/her destination. Discretionary lane changes (DLC) occur when a driver changes lane to improve his driving condition (e.g. for higher speed). In most lane changing models (e.g. Kesting et al., 2007; Laval and Daganzo, 2006) discretionary lane changes only look at speed as an incentive to change lane. It should be noted that classifying the lane changing in MLC and DLC may lead to a rigid behavior structure which does not consider the trade-offs between these two. Toledo et al. (2003) developed a model that integrates MLC and DLC in a single utility framework. Toledo's lane changing process consists of two steps: choice of target lanes and gap acceptance decisions. The basic requirements for DLC are as follows: (1) a driver cannot drive with its intended speed in its current lane; (2) the speed in the adjacent lane is preferred over the speed in the current lane; (3) there should be a gap, large enough, in the adjacent lane. These requirements can be found in Gipps (1986). This has been formalized, for instance by the MOBIL (Kesting et al., 2007) lane change model. The fundamental idea behind MOBIL is to include both the appeal of a given lane (i.e., its utility) and the discomfort associated with lane changes in terms of accelerations. That model compares each time-step the utilities, defined as accelerations, of the vehicles involved in a lane change. For each time step, the model calculates the weighted sum of accelerations of the considered vehicle and the other drivers. If this exceeds a threshold value, the lane change is performed. To calculate the expected accelerations a car-following model is applied (e.g. IDM (Treiber et al., 2000)). None of these models provide a full explanation for the phenomena seen in practice where it is for instance observed that the number of lane changes to a certain lane increases if that lane has a higher density (Knoop et al., 2012).

Gap acceptance models (Kita and Fukuyama, 1999) are often applied in MLC models. These models are also not able to describe the observed gap choices in merging areas (Daamen et al., 2010). Marczak et al. (2013) analyzed merging behavior on a freeway using two empirical trajectory data sets (i.e. in France and in the Netherlands). They created a logistic regression model to predict the acceptance of a given gap. Other attempts have been made by modeling gap choice behavior. In all these studies, no questions were asked regarding the incentives of the drivers. Only by asking people, we may get an insight of their intrinsic motivations for merging or not merging into a particular gap.

Empirically, it is shown that for merging traffic, drivers may apply small decelerations and accept smaller time headways (Daamen et al., 2010) than for discretionary lane changes which is called relaxation phenomenon. Also, vehicle speeds are synchronized such that a driver adapts its speed to the speed of the neighboring lane. This is modeled in LMRS lane change model (Schakel et al., 2012), which includes relaxation and synchronization. Generally, this model may be employed with any car-following model which calculates the vehicle acceleration. It basically accounts for the fact that drivers sometimes merge into gaps which are too small, and then create a larger gap. Toledo et al. (2007) introduced a model which integrates the various decisions, such as acceleration, lane changing and gap acceptance. MOBIL provides a lane change using the possible acceleration in the current lane and after a lane change. The integrated model by Toledo et al. (2007) does the opposite, by taking the lane