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Modelling acceleration decisions in traffic streams with weak lane discipline: A latent leader approach

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ABSTRACT

Acceleration is an important driving manoeuvre that has been modelled for decades as a critical element of the microscopic traffic simulation tools. The state-of-the art acceleration models have however primarily focused on lane based traffic. In lane based traffic, every driver has a single distinct lead vehicle in the front and the acceleration of the driver is typically modelled as a function of the relative speed, position and/or type of the corresponding leader. On the contrary, in a traffic stream with *weak lane discipline*, the subject driver may have multiple vehicles in the front. The subject driver is therefore subjected to multiple sources of stimulus for acceleration and reacts to the stimulus from the *governing leader*. However, only the applied accelerations are observed in the trajectory data, and the governing leader is unobserved or *latent*. The state-of-the-art models therefore cannot be directly applied to traffic streams with weak lane discipline.

This prompts the current research where we present a *latent leader* acceleration model. The model has two components: a random utility based dynamic class membership model (latent leader component) and a class-specific acceleration model (acceleration component). The parameters of the model have been calibrated using detailed trajectory data collected from Dhaka, Bangladesh. Results indicate that the probability of a given front vehicle of being the governing leader can depend on the type of the lead vehicle and the extent of lateral overlap with the subject driver. The estimation results are compared against a simpler acceleration model (where the leader is determined deterministically) and a significant improvement in the goodness-of-fit is observed. The proposed models, when implemented in microscopic traffic simulation tools, are expected to result more realistic representation of traffic streams with weak lane discipline.

1. Background

Microscopic traffic simulation tools, which model individual driver manoeuvres (e.g. longitudinal and lateral movements, route choice, etc.) and deduce the network condition from those, can be used as laboratories for testing the effectiveness of candidate traffic improvement initiatives before their actual field implementation. These tools are increasingly being popular worldwide for selecting the optimum transport scheme. In particular, they can potentially play a very significant role in the context of developing countries where the transport landscape is changing very rapidly but the resources are often constrained.

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Acceleration is an important driving manoeuvre and has been significantly modelled for several decades. However, majority of this research is conducted for homogeneous traffic conditions which prevail in developed countries. The developed models range from simple models with minimum parameters, to comparatively complex and comprehensive models with much detailed considerations and can be grouped as car-following models (e.g. Chandler et al., 1958; Gazis et al., 1959, 1961; Edie, 1961; Herman and Rothery, 1965; May and Harmut, 1967; Ozaki, 1993; Ahmed , 1999; Toledo et al., 2007; Choudhury et al., 2009), psychophysical models (e.g. Ludmann et al., 1997; Schulze and Fliess, 1997; Brackstone et al., 2002), fuzzy-logic models (e.g. Kikuchi and Chakroborty, 1992; Brackstone et al., 1997; Chakroborty and Kikuchi, 2003), cellular automata models (e.g. Wolfram, 1986; Nagel and Schreckenberg, 1992; Hafstein et al., 2004), and general acceleration models (e.g. Gipps, 1981; Benekohal and Treiterer, 1988; Yang and Koutsopoulos, 1996; Hidas, 2002). The state-of-the-art acceleration models however have several limitations. For example, as highlighted by Kim et al. (2003) and Punzo and Simonelli (2005), some acceleration models (e.g. Chandler et al., 1958; Gazis et al., 1959; Edie, 1961; Herman and Rothery, 1965; Gipps, 1981) are based on the assumption that drivers always follow the same driving decision rules. Whereas, in reality, these rules may differ among different drivers, for the same driver in different conditions, or even for same driver in similar or nearly identical situations (Punzo and Simonelli, 2005). Other limitations include inadequate emphasis on the errors and uncertainty in the data used for calibrating the models (Punzo and Simonelli, 2005), exclusion of factors beyond vehicle kinematics and surrounding conditions in the model framework, limited stochasticity, etc. Moreover, the most important setback of these models is that these are developed for homogeneous lane-based traffic (Fig. 1a) and cannot be directly applied to heterogeneous traffic stream where the traffic characteristics are significantly different (Fig. 1b).

The heterogeneous traffic scenarios have a mix of motorized and non-motorized vehicles which have wide differences in size, speed and acceleration-deceleration capabilities. The required driving skills for operating motorized and non-motorized vehicles are very different as well. Moreover, in most cases, there is an absence of strict lane discipline in such mixed traffic. In presence of weak lane discipline, a single lane can be occupied by multiple narrow vehicles. Also, even if there are lane-markings, in congested conditions, drivers very often position themselves in between other vehicles in an attempt to make use of the entire available space and thus occupy multiple lanes.

The research work on modelling such heterogeneous traffic stream is quite limited. In the earlier models for heterogeneous traffic, the acceleration models for homogenous traffic have been recalibrated using simulation runs (e.g. Hossain, 1996; Hoque, 1994; Maini, 2001). Mallikarjuna and Rao (2011) have focused on the analysis and modelling of heterogeneous traffic observed on mid-block sections of urban and rural roads in the context of India using a cellular automata approach. Some studies have identified significant effects of lead-vehicle size (e.g. Maini, 2001; Sayer et al., 2003) and type of vehicle pair (e.g. Ravishankar and Mathew, 2011) in vehicle-following behaviour in mixed traffic streams. Lee and Polak (Lee et al., 2009) have developed a desired headway based model for motorcycles which are assumed to have the option to either decelerate or overtake a decelerating front vehicle. But the behaviour of other types of vehicles in presence of motorcycles is beyond the scope of their study. Gunay (2007) has proposed a staggered car-following model which accounts for lateral discomfort while longitudinal movement is in action. Imran (2009) has focused on development of car-following model for mixed traffic using fuzzy-logic inference system and in addition to vehicle types and composition, traffic factors (e.g. traffic density) have been identified as a factor affecting acceleration decisions. However, though these models address the issue of lead vehicle type and/or vehicle pair type and traffic factors in detail, there has not been much research on how the models can be extended when there are multiple candidate leaders and the governing leader cannot be determined deterministically. There is a marked research gap regarding identification of governing leader vehicle and the existing models are therefore not robust in the context of weak lane discipline. This has motivated this research where a latent leader model has been formulated and calibrated using detailed trajectory data.

The rest of the paper is organized as follows: the model structure is presented first followed by the descriptions of the data. The estimation results are presented next. The findings are summarized in the concluding section with directions of future research.

2. Model structure

In the state-of-the-art acceleration models, the observed actions of the lead vehicle in front of the driver have a significant role in predicting the acceleration/deceleration decisions of the subject driver. However, in traffic streams with weak lane discipline, there are often multiple candidate leaders in front of the subject driver (SD), particularly in congested situations (denoted by Front Left (FL), Front Direct (FD) and Front Right (FR) (Fig. 2). Therefore, though the longitudinal acceleration/deceleration of the subject driver are governed by the actions of one of these vehicles either consciously or inadvertently, the leader is often not distinctly observed (hence latent) in the data.

The acceleration decision of the driver is thus modelled using a two level structure. The first level is a dynamic class membership model that predicts the probability of a front vehicle being the governing leader of the subject driver at a given time. The second level denotes the acceleration of the subject driver conditional on the specific leader vehicle (Fig. 2).

The first level is formulated using a random utility based discrete choice framework where the *choice-set* can consist of up to three vehicles (denoted by Front Left, Front Direct and Front Right). The probability of any front vehicle being the governing lead vehicle can be affected by the relative positions, speeds and types of the vehicles, etc. The second level is formulated