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Modeling car-following behavior on urban expressways in Shanghai: A naturalistic driving study

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ABSTRACT

Although car-following behavior is the core component of microscopic traffic simulation, intelligent transportation systems, and advanced driver assistance systems, the adequacy of the existing car-following models for Chinese drivers has not been investigated with real-world data yet. To address this gap, five representative car-following models were calibrated and evaluated for Shanghai drivers, using 2100 urban-expressway car-following periods extracted from the 161,055 km of driving data collected in the Shanghai Naturalistic Driving Study (SH-NDS). The models were calibrated for each of the 42 subject drivers, and their capabilities of predicting the drivers' car-following behavior were evaluated.

The results show that the intelligent driver model (IDM) has good transferability to model traffic situations not presented in calibration, and it performs best among the evaluated models. Compared to the Wiedemann 99 model used by VISSIM®, the IDM is easier to calibrate and demonstrates a better and more stable performance. These advantages justify its suitability for microscopic traffic simulation tools in Shanghai and likely in other regions of China. Additionally, considerable behavioral differences among different drivers were found, which demonstrates a need for archetypes of a variety of drivers to build a traffic mix in simulation. By comparing calibrated and observed values of the IDM parameters, this study found that (1) interpretable calibrated model parameters are linked with corresponding observable parameters in real world, but they are not necessarily numerically equivalent; and (2) parameters that can be measured in reality also need to be calibrated if better trajectory reproducing capability are to be achieved.

1. Introduction

Over the last few decades, microscopic traffic simulation programs have become increasingly important tools for traffic and traffic safety engineering (e.g., capacity analysis, traffic impact studies, junction design, accident analysis, network analysis) (Ranjitkar et al., 2005). The cornerstones of microscopic traffic simulation are car-following models that describe the vehicle-by-vehicle following process in a traffic flow (Brackstone and McDonald, 1999). The performance of the car-following model used in simulation is one of the determinants of the traffic simulation validity.

Since the early investigation of car-following dynamics in 1953, numerous car-following models have been developed. The development and investigation of these models have been almost entirely based on experiments conducted in Western countries.

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However, drivers in different countries have different driving styles, drive different types of vehicles, and are subject to different traffic regulations as well as driving cultures (Daamen et al., 2013; Treiber and Kesting, 2013a; Lindgren et al., 2008b). For example, Chinese drivers face the challenging driving environment of frequent lane changing, aggressive driving, considerable presence of large trucks, and omnipresent pedestrians, electric bikes, and bicycles (Huang et al., 2006; Lindgren and Chen, 2007). China also struggles with infrastructural issues such as inadequate road design and control, poor road maintenance, and insufficient road construction management (Lindgren et al., 2008a).

These influences may result in considerable differences in driving behavior and traffic operation (Daamen et al., 2013). Huang et al. (2006) found Chinese drivers to be more aggressive than drivers in the U.S.; for example, the Chinese tend to drive more offensively and to disobey traffic rules. Because car-following models are based on certain assumptions about driving behavior, a car-following model that performs well for drivers in Western countries may perform poorly when applied to drivers in developing countries.

With the rapid motorization in developing countries such as China, there is an increasing need to evaluate and to adjust, if needed, the existing car-following models applied to non-Western drivers. To address this need, Shanghai was chosen as a case study, and real-world driving data were collected in the Shanghai Naturalistic Driving Study (SH-NDS). The data collection procedure started in December 2012, and by December 2015 driving data had been collected for 60 drivers who drove 161,055 km in total. In the SH-NDS, driver behavior was observed as it occurred in the full context of real-world driving, and vehicle kinematic data (e.g., acceleration, velocity, position) were recorded continuously at high resolution. The availability of these detailed naturalistic driving data provides an unprecedented opportunity for investigating car-following behavior in China.

Car-following behavior on urban expressways is the focus of the current study. Urban expressways form the backbone of city road networks, carrying a disproportionately large percentage of city traffic. In Beijing, for example, major urban expressways account for only 8% of the total road network length, but carry nearly 50% of the traffic flow; in Shanghai, urban expressways are only 5% of the city's road network, but they bear more than 35% of the city's traffic (Chen et al., 2014). Although car-following behavior on non-freeway arterials should also be studied, the presence of intersections introduces additional variables into car-following behavior that are beyond the scope of this study. Therefore, urban expressway data from the SH-NDS were used in the current study to calibrate and cross-compare five different car-following models, with the final aims of attaining better insight into the car-following behavior of Chinese drivers and determining the best model for use in Shanghai.

2. Literature review

2.1. Car-following models

A car-following model describes the movements of a following vehicle (FV) in response to the actions of the lead vehicle (LV). The first car-following models (Pipes, 1953; Chandler et al., 1958) were proposed in the middle 1950s. Since then, a large number of models were developed, for example, the Gazis-Herman-Rothery model (Gazis et al., 1961), the intelligent driver model (Treiber et al., 2000), the optimal velocity model (Bando et al., 1995), and the models proposed by Helly (1959), Gipps (1981), and Wiedemann (1974). For a review and historical development of the subject, one should consult Brackstone and McDonald (1999), Olstam and Tapani (2004), Panwai and Dia (2005), and Saifuzzaman and Zheng (2014). Generally, car-following models can be divided into five categories: stimulus-based, safety-distance, desired measures, optimal velocity, and psycho-physical models.

The main idea of a stimulus-based model is that the acceleration of a following vehicle is determined by the driver's reaction to the speed and position differences of the vehicle in front (May, 1990). The General Motors models are some of the best known stimulus-based models. They have been developed since the late 1950s, with one of their latest modifications proposed by Ozaki (1993).

The safety-distance models are based on the idea that the driver of a following vehicle would adopt a speed and maintain a distance such that he/she can bring the vehicle to a safe stop should the vehicle in front brake to a sudden stop. The Gipps model (Gipps, 1981) is based on the safety-distance idea.

The desired measures models assume that a driver has a preferred situation represented by certain measures (e.g., following distance and following speed) and a driver continuously attempts to eliminate the difference between the actual situation and the preferred. The intelligent driver model (IDM) (Treiber et al., 2000) is one of the most widely used models using desired measures.

The optimal velocity models assume that each following vehicle has an optimal safe velocity that depends on the distance from the lead vehicle. The acceleration of the following vehicle can be determined according to the difference between the actual velocity and the optimal velocity (Saifuzzaman and Zheng, 2014). Closely related to the optimal velocity model is the full velocity difference (FVD) model (Jiang et al., 2001).

The psycho-physical models suggest that a driver's behavior would vary depending on the traffic state he/she is in, such as whether the driver is in the free-flow condition, approaching the vehicle in front, following the vehicle in front, or braking. The boundary conditions defining the different states are usually expressed as a combination of relative speed and relative distance to the lead vehicle (Wiedemann, 1974).

2.2. Calibrating car-following models with microscopic data

Calibration involves finding a set of model parameters that minimize the difference between the values of the simulated and observed variables (Kesting and Treiber, 2008). Previous studies have calibrated car-following models with microscopic data