Transportation Research Part C 68 (2016) 144–159

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Online calibration for microscopic traffic simulation and dynamic multi-step prediction of traffic speed

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ARTICLE INFO

Article history:
Received 21 June 2015
Received in revised form 5 April 2016
Accepted 5 April 2016

Keywords:
Speed prediction
Traffic simulation
Car-following models
Dynamic calibration

ABSTRACT

Simulating driving behavior in high accuracy allows short-term prediction of traffic parameters, such as speeds and travel times, which are basic components of Advanced Traveler Information Systems (ATIS). Models with static parameters are often unable to respond to varying traffic conditions and simulate effectively the corresponding driving behavior. It has therefore been widely accepted that the model parameters vary in multiple dimensions, including across individual drivers, but also spatially across the network and temporally. While typically on-line, predictive models are macroscopic or mesoscopic, due to computational and data considerations, nowadays microscopic models are becoming increasingly practical for dynamic applications. In this research, we develop a methodology for online calibration of microscopic traffic simulation models for dynamic multi-step prediction of traffic measures, and apply it to car-following models, one of the key models in microscopic traffic simulation models. The methodology is illustrated using real trajectory data available from an experiment conducted in Naples, using a well-established car-following model. The performance of the application with the dynamic model parameters consistently outperforms the corresponding static calibrated model in all cases, and leads to less than 10% error in speed prediction even for ten steps into the future, in all considered data-sets.

1. Introduction

Developments of Advanced Traveler Information Systems (ATIS) rely significantly on the capability to perform accurate estimates of the current traffic state and short-term predictions of driving behavior and traffic characteristics, such as speed (Vlahogianni et al., 2005; van Lint et al., 2005; Vlahogianni et al., 2008). Due to a number of practical, data and computational considerations, during the past two decades, ATIS applications have been mostly supported by mesoscopic or macroscopic traffic simulation models. Data collection and computational advances are making it possible to consider more detailed, microscopic models for this kind of applications. Naturally, such models introduce a number of complications, and therefore their adoption should be clearly motivated and justified.

While such systems have been around for decades, current developments, such as the increasing interest in Active Traffic Management, make them more relevant (Kurzhanskiy and Varaiya, 2010). Indeed, ATIS can be effective in supporting active traffic management policies by Real-Time Decision Support Systems, whose core engine is a real-time traffic simulation model. The real-time requirements bring to the forefront the limitations of static calibration, and accelerate the need for

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http://dx.doi.org/10.1016/j.trc.2016.04.006
0968-090X/

procedures like the ones discussed in this research. An example of such applications is the Integrated Corridor Management initiative in the US (Miller and Skabardonis, 2010).

Simulation models do not always adequately reflect field conditions outside of the time period for which they have been calibrated (Balakrishna et al., 2007; Daamen et al., 2014; Henclewood et al., 2012). Microscopic models often comprise different detailed models, including car-following, lane-changing and gap-acceptance models. In most cases, the parameters of these models are assumed to be stable, both across space and time, and also across drivers. The online calibration of car-following models is a promising approach to capture the heterogeneity of driver behavior and traffic conditions. By continuously supplying a car-following model with surveillance data, an online calibration process could be applied in order to adapt model parameters to the current traffic state. In this view, the use of richer data, such as real-time Floating Car Data (FCD), based on traces of Global Navigation Satellite Systems (GNSS), could be leveraged as a reliable and cost-effective way to gather accurate traffic data (De Fabritiis et al., 2008; Antoniou et al., 2011).

Calibration of car-following models (Brackstone and McDonald, 1999) has been an issue for a long time (Aycin and Benekohal, 1999), but nowadays it has received a new boost (Hoogendoorn and Hoogendoorn, 2010; Monteil et al., 2014), in light of new data-collection techniques, mostly related to the increasing availability of trajectory data (Kesting and Treiber, 2008; Punzo et al., 2005; Papathanasopoulou and Antoniou, 2015), which of course introduce other challenges (Punzo et al., 2012).

Online calibration has been used in many macroscopic and mesoscopic modeling approaches (Papageorgiou et al., 1989; Kim, 2002; Antoniou et al., 2005; Fei et al., 2011). The use of the Kalman Filter (and its extensions) for online parameter calibration has shown encouraging results (Antoniou et al., 2007). However, in recent years there has been an increasing interest in online applications of microscopic traffic models. Moreover, Henclewood et al. (2012) suggest that a real-time calibration algorithm should be included in online, data-driven microscopic traffic simulation tools.

The objective of this paper is to motivate, develop and demonstrate with real data a practical approach for the online calibration of microscopic traffic simulation models, which considers dynamic parameters for individual drivers, in time and space. At each time instance, the dynamically obtained model parameters are being used for short-term prediction (up to ten steps into the future), and the performance of this prediction is compared with the reference case of static model parameters.

This paper presents an alternative methodology for microscopic online calibration and multiple step prediction and is organized as follows. Firstly, a literature review is presented in the following section. Then, the overall methodological framework is presented. A case study setup to demonstrate the feasibility and superiority of the approach, over previous techniques, is then presented, followed by the presentation of the dynamic calibration procedure and an analysis of the results. A discussion of the results follows in the concluding section, and future prospects are proposed.

2. Literature review

Reliable representation of driving behavior is a crucial issue for traffic simulation. Appropriate simulation models are chosen according to the requirements of each application; when considering the modeling detail, traffic simulation models can be divided into microscopic, mesoscopic and macroscopic. Microscopic models provide the highest level of detail for advanced transport applications (Antoniou and Koutsopoulos, 2006). However, the traditional static calibration approach may not allow the incorporation of driving heterogeneity in the simulation.

In recent years there has been a tendency towards more flexible and dynamic methods than static car-following models. It is widely accepted that driving behavior in general (and therefore car-following parameters) vary in multiple dimensions, i.e. exhibit inter-personal, temporal and spatial heterogeneity. Higgs and Abbas (2014) compare car-following models at different levels of analysis: driver, car-following period and cluster of drivers. For example, Ossen and Hoogendoorn (2005) have identified considerable differences between the car-following behavior of individual drivers. Ma (2006) has developed a neural fuzzy framework for modeling car-following behavior. It illustrates human knowledge of car-following in a more understandable manner and can be rather flexible as the regime parameters and model forms may vary according to the application context. According to Hoogendoorn et al. (2006) and Ellison et al. (2013), real driving behavior is variable in time and space. Some researchers have attempted to capture heterogeneity across drivers spatially (e.g. Papathanasopoulou and Antoniou (2015)) or temporally, which is one of the aspects investigated in this research.

Many car-following models predict a stable car-following behavior with a very small fluctuation around an equilibrium value. However, in reality these fluctuations are much larger than these models predict. Wagner (2012) has attributed them not due to driver heterogeneity, but to an internal stochasticity of the driver itself. Randomness is thus incorporated in traffic flow and model calibration requires the flexibility to adapt to it. On the other hand, several empirical analyses performed by Ossen and Hoogendoorn (2007) showed a high degree of driver heterogeneity in car-following. Inter-driver differences could be described not only by different parameter values, but also different model specifications may be needed. All above researchers conclude that different optimal parameter values, as well as different optimal car-following models, should be applied to overcome this problem.

Static calibration requires a database with historical data. It could feed a simulation model with initial parameter values, which allow a good representation of a general traffic state (Balakrishna, 2006). However, dynamic calibration could take advantage of real-time data and adapt model parameters to the current traffic state. Dynamic estimation of model