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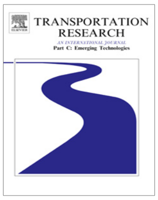

Towards data-driven car-following models

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A B S T R A C T

Car following models have been studied with many diverse approaches for decades. Nowadays, technological advances have significantly improved our traffic data collection capabilities. Conventional car following models rely on mathematical formulas and are derived from traffic flow theory; a property that often makes them more restrictive. On the other hand, data-driven approaches are more flexible and allow the incorporation of additional information to the model; however, they may not provide as much insight into traffic flow theory as the traditional models. In this research, an innovative methodological framework based on a data-driven approach is proposed for the estimation of car-following models, suitable for incorporation into microscopic traffic simulation models. An existing technique, i.e. locally weighted regression (loess), is defined through an optimization problem and is employed in a novel way. The proposed methodology is demonstrated using data collected from a sequence of instrumented vehicles in Naples, Italy. Gipps' model, one of the most extensively used car-following models, is calibrated against the same data and used as a reference benchmark. Optimization issues are raised in both cases. The obtained results suggest that data-driven car-following models could be a promising research direction.

1. Introduction

Simulation models allow the evaluation of traffic networks and are used as the fundamental tool of traffic management and safety research (Barceló, 2010). Modeling traffic behavior has also contributed significantly to the development of intelligent transportation systems (ITS) (Koutsopoulos and Farah, 2012). According to the level of detail that traffic flow is modeled, simulation models may be classified as microscopic, mesoscopic and macroscopic. In microscopic models vehicles are described individually and interactions between vehicles or between vehicles and the road network are included (Yang and Koutsopoulos, 1996). Microscopic models include gap-acceptance, speed adaptation, lane changing, ramp merging, overtaking, and car-following models (Olstam and Tapani, 2004). Each vehicle is described by parameters such as its origin, destination, desired speed, acceleration and deceleration, the type of vehicle and the driver's characteristics (Yang and Koutsopoulos, 1996). Macroscopic traffic models use aggregated variables to describe traffic phenomena. Such models simulate the movement as a continuous flow, using theories often inspired by the fluid dynamics. Macroscopic measurements include speed, traffic flow and traffic density (Boxill and Yu, 2000). Finally, mesoscopic models provide an intermediate situation, in which they model individual vehicles but at an aggregate level, usually using speed–density relationships and queuing models to model vehicle dynamics. Thus, mesoscopic models share common characteristics with both macroscopic and microscopic models (Boxill and Yu, 2000) and aim to combine the benefits of both, while overcoming their respective limitations.

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An ongoing debate among traffic modelers relates to the relative benefits of each level of simulation models. The microscopic representation of traffic flow offers high accuracy at a computational cost and car following models are an essential component (Koutsopoulos and Farah, 2012; Brackstone and McDonald, 1999; Aycin and Benekohal, 1999). The objective of this paper is not to enter this debate, but to provide an alternative modeling approach for car-following model within microscopic traffic simulation models. This modeling approach can take advantage of a wide range of available data, and is therefore suitable to implementation in the context of ITS systems. While microscopic traffic simulation models have a higher computational complexity, compared to mesoscopic or macroscopic models, they are more suited to the evaluation and operation of ITS, as they can model in detail more complex aspects of such systems. For example, it would be harder to model managed lanes, vehicle actuated traffic control systems and public transport priority systems with a mesoscopic or macroscopic model.

Car following models typically inspect driving behavior with respect to the preceding vehicle in the same lane. A vehicle is limited by the movement of the preceding vehicle, because driving at the desired rate may lead to a crash (Olstam and Tapani, 2004). According to Olstam and Tapani (2004) car following models are divided into categories according to the logic used, such as Gazis–Herman–Rothery models (Gazis et al., 1961), safe distance models (Kometani and Sasaki, 1958; Gipps, 1981), psycho-physical models (Wiedemann and Reiter, 1992; Fritzsche, 1994) and fuzzy logic models (Kikuchi and Chakroborty, 1992; Chakroborty and Kikuchi, 1999; Al-Shihabi and Mourant, 2003).

Initially, car following models were developed to represent a single state of traffic, such as the traffic state, where the subject vehicle reacts to the actions of the preceding vehicle (Reuschel, 1950; Pipes, 1953). Moreover, as Liu and Li (2013) mention, many of the earlier car following models, including the General Motors models (Chandler et al., 1958; Gazis et al., 1961) refer to low-speed situations and may not be suitable for high-speed networks. Recently, more and more researchers tend to adopt the concept that drivers behave differently in different traffic conditions (Yang and Koutsopoulos, 1996; Ahmed, 1999; Toledo, 2003; Wang et al., 2005; Koutsopoulos and Farah, 2012). In this case, sub-phases can be recognized, such as free-flowing, approaching, close-following, car-following, emergency braking, and stop-and-go. This has led to the development of multi-regime car following models, according to which different rules are adopted under different traffic states, so that driving behavior can be best captured (Liu and Li, 2013).

A generalization of such multi-regime approaches is an attractive perspective. However, a large number of regimes may result to overly complex models and developing the equations to model them can become cumbersome. Furthermore, incorporating additional measurement data to these models is very complicated. These restrictions have motivated us to suggest with this research an alternative methodology for the estimation of car-following models, combining flexible, data-driven components. Such methods have been used in several transport-related applications such as estimation or prediction of speed and classification of traffic data (e.g. Vlahogianni et al., 2005, 2008; van Lint, 2005, 2008; Antoniou and Koutsopoulos, 2006; Dunne and Ghosh, 2012; Antoniou et al., 2013; Elhenawy et al., 2014). Data-driven methods are more flexible than traditional models, allowing the incorporation of additional parameters, which influence driving behavior, thus leading to richer models.

Nowadays, the rapid development of technology has contributed to the availability of high-quality traffic data, leading the way for the development of more advanced car following models. Methods such as differential GPS and real time kinematic allow the collection of high fidelity traffic data (Ranjitkar et al., 2005) and consequently may improve the accuracy of traffic simulation models. On the other hand, ubiquitous sensors (e.g. accelerometers and gyroscopes) from regular smartphones could provide a much richer sample of heterogeneous data, which could allow much richer calibration, e.g. utilizing distributions rather than point values (Antoniou et al., 2014). For a review of novel data collection techniques and their applications to traffic management applications see Antoniou et al. (2011).

Zhang et al. (2011) have suggested and implemented the use of machine learning approaches to support a shift from conventional technology-driven systems into data-driven intelligent transportation system. Data-driven approaches have already been used in developing a fully adaptive cruise control system (Simonelli et al., 2009; Bifulco et al., 2013) and in modeling car-following behavior via artificial neural networks (Colombaroni and Fusco, 2013; Chong et al., 2013; Zheng et al., 2013).

In this paper an alternative methodology based on a machine learning method is suggested for the development of simple and reliable car following models that can be incorporated to microscopic traffic simulators. The focus is given on simulation optimization of car-following models, mainly the error between simulation and real traffic to be minimized, using a flexible method. A literature review on car following models is first presented, with an emphasis on Gipps' model, as it is selected as the reference model in the application. The proposed methodology is then described and applied to a number of available data sets collected in Naples, Italy. Optimization problems, such as finding the optimal values for parameters of Gipps' model and of the proposed method, have been raised and solved through a sensitivity analysis. Finally, benefits and limitations of the proposed method are pointed out and conclusions are drawn.

2. Literature review

2.1. Car-following models

A historical review of car following models can be found in Brackstone and McDonald (1999). The concept of car following was first introduced by Reuschel (1950) and Pipes (1953). Representative microscopic traffic models between the 1950s and

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