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Does traffic-related calibration of car-following models provide accurate estimations of vehicle emissions?

Thamara Vieira da Rocha [a,b,c], Ludovic Leclercq [a,b,c,*], Marcello Montanino [d], Céline Parzani [a,b,c], Vincenzo Punzo [d], Biagio Ciuffo [e], Daniel Villegas [a,b,c]

[a] Université de Lyon, Lyon, France
[b] IFSTTAR, COSYS-LICIT, Bron, France
[c] ENTPE, LICIT, Vaulx-en-Velin, France
[d] Department of Transportation Engineering, Università di Napoli Federico II, Italy
[e] Institute for the Energy and Transport, European Commission – Joint Research Centre, Italy

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ABSTRACT

Fuel consumption or pollutant emissions can be assessed by coupling a microscopic traffic flow model with an instantaneous emission model. Traffic models are usually calibrated using goodness of fit indicators related to the traffic behavior. Thus, this paper investigates how such a calibration influences the accuracy of fuel consumption and NOx and PM estimations. Two traffic models are investigated: Newell and Gipps. It appears that the Gipps model provides the closest simulated trajectories when compared to real ones. Interestingly, a reverse ranking is observed for fuel consumption, NOx and PM emissions. For both models, the emissions of single vehicles are very sensitive to the calibration. This is confirmed by a global sensitivity analysis of the Gipps model that shows that non-optimal parameters significantly increase the variance of the outputs. Fortunately, this is no longer the case when emissions are calculated for a group of many vehicles. Indeed, the mean errors for platoons are close to 10% for the Gipps model and always lower than 4% for the Newell model. Another interesting property is that optimal parameters for each vehicle can be replaced by the mean values with no discrepancy for the Newell model and low discrepancies for the Gipps model when calculating the different emission outputs. Finally, this study presents preliminary results that show that multi-objective calibration methods are certainly the best direction for future works on the Gipps model. Indeed, the accuracy of vehicle emissions can be highly improved with negligible counterparts on the traffic model accuracy.

Introduction

The assessment of the environmental impact of intelligent transportation systems is a key issue in the context of sustainable mobility, e.g. (Ahn and Rakha, 2013; Madireddy et al., 2011; Barth and Boriboonsomsin, 2009). Thus most of the traffic micro-simulation models available on the market include tools for modeling the exhaust emissions of vehicles and, in particular, instantaneous (modal) emission models, e.g. (Abou-Senna and Radwan, 2013). These models use high frequency

* Corresponding author at: Université de Lyon, Lyon, France. Tel.: +33 472047716.
E-mail address: ludovic.leclercq@ifsttar.fr (L. Leclercq).

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measurements to map emissions at a time to their generating engine state, thus providing specific emission factors (also) for new, unmeasured driving cycles. Once such models are fed with real world driving cycles of a traffic flow, calculations are expected to capture the impact on emissions of those specific traffic conditions and control schemes. Unfortunately driving cycles of all the vehicles within a time–space domain are hardly ever available, e.g. the data collected in the NGSIM program, (Federal Highway Administration, 2006). Their intrinsic complexity, also due to the increasing impact of new technologies, e.g. time responses of the engine electronic management system to the lambda sensor, which considerably differ among vehicles, is the other major drawback of instantaneous modeling. However, the massive development of traffic flow micro-simulation, and hence the chance to simulate driving cycles of all the vehicles on a network, is promoting the adoption of such integrated dynamic traffic-emissions modeling.

Yet the problem with the use of micro-simulation to derive driving cycles is that the whole approach must be validated, e.g. (Int Panis et al., 2006), but at present, the accuracy of the trajectories drawn by the model remains unknown for such an application. Preliminary results (Vieira da Rocha et al., 2013) show that simplified driving cycles classically provided by traffic simulators introduce bias when calculating the fuel consumption. Fortunately, such errors remain relatively low for a given cycle and vanish when a lot of cycles are gathered to determine the total fuel consumption. However, this study has not considered the specific influence of the traffic model: simplified driving cycles are directly derived from real measures by using filtering techniques. Furthermore, traffic models are generally calibrated against aggregate measurements and the objective of calibration is to improve the reproduction of aggregate traffic dynamics rather than individual driving cycles, e.g. (Ciuffo et al., 2008; Toledo et al., 2004). Thus, car-following models have generally underperformed in reproducing real world behaviors of individual vehicles, e.g. (Brockfeld et al., 2004; Punzo and Simonelli, 2005). The problem of reproducing trajectories for emission calculation is even more complex, since the way in which car-following models are calibrated (even when detailed trajectory data are used) may not be the most appropriate with a view to calculating traffic-related externalities. Note that because driving cycles correspond to the derivative of the trajectories, both terminologies are used indifferently in this paper.

This work investigates the accuracy of results when atmospheric emissions and fuel consumption are calculated from simulated trajectories instead of the real ones. A set of 90 vehicle trajectories corresponding to nine different platoons gathered from the NGSIM database (Federal Highway Administration, 2006) is used as reference. These trajectories are filtered to remove measurements noise. Two car-following models are used to generate simulated trajectories from the leader one: Newell (Newell, 2002) and Gipps (Gipps, 1981) models. These two models are calibrated using standard goodness of fit indicators related to vehicle trajectories. Atmospheric emissions and fuel consumption are then calculated using the state-of-the-art PHEM (Passenger Car and Heavy Duty Emission Model) model (Hausberger et al., 2009; Luz et al., 2013). It is an instantaneous vehicle emission model that has been used by the TU Graz since 1999. In this paper, we will focus on fuel consumption, NOx and Particle Matters (PM) and investigate the accuracy of emission calculations at both individual (vehicle) and global (platoon) levels.

The paper is organized as follows: section "Background" provides some background about the two traffic models, their calibration using classical goodness of fit and the emission model. Section "Method" presents the different sensitivity tests that have been carried out to assess the influence of the traffic model calibration on the accuracy of the emission calculations. Section "Results" presents the results for the 90 vehicles and 9 platoons and investigates the connections between the traffic model parameters and the emission estimation. A global sensitivity analysis is also proposed. Finally, section "Discussion" proposes a brief discussion. It notably shows that a multi-objective calibration method clearly improves the emission results while it only slightly deteriorates the accuracy of simulated trajectories.

Background

Traffic data

Vehicle trajectories come from the I-80 NGSIM dataset (Federal Highway Administration, 2006). Video recordings were performed on a 500 m length section of the interstate 80 in Emeryville (California, USA) during the peak hour (congested traffic conditions with speed always lower than 50 km/h). Nine platoons of 10 vehicles were extracted from the whole data with the following requirements: (i) no lane changings should happen within the platoon when crossing the whole section and (ii) the platoon should entail at least 10 vehicles. This guarantees that the interactions between a vehicle and its leader can be characterized by a car-following rule without any external distractions (Chiabaut et al., 2009).

Vehicle positions were automatically extracted from the video recording with a frequency of 10 Hz. This introduces measurement errors that may lead to significant bias when performing the calibration of car-following models, e.g. (Ossen and Hoogendoorn, 2008; Punzo et al., 2011). The bias are even greater when differential variables, like speed or acceleration are calculated. Thus, Treiber et al. (2008) and Rakha et al. (2001) showed that using the raw data without filtering leads to arbitrarily high estimates for fuel consumption.

Trajectories data should then be filtered before performing (i) the car-following model calibration and (ii) the emission calculations. The following filtering process was applied to reduce the measurement noise. First, a filtered trajectory is defined as a succession of n quadratic functions. Such functions continuously connect at $n - 1$ time points named knots (Marczak and Buission, 2012; Xin et al., 2008). Derivatives are also continuous at knots. Thus, the trajectories are