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Validation of Traffic Simulation Models Based on the Macroscopic Fundamental Diagram

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Abstract

Urban traffic simulation models could benefit significantly from new validation methods with potential to reduce the time-consuming calibration and validation work needed before application of the model to evaluate city infrastructure or policy implementations. Current practice is to validate simulation models locally through comparison with point flow measurements and travel times on some important routes. However, for many applications, the level of congestion in an entire area is important. During the last decade, several studies have found empirical evidence of a relation between flow and density on city district level, the existence of a so-called macroscopic fundamental diagram (MFD). This paper shows how the MFD can be used to validate results from a traffic simulation model for a city district. Furthermore, the paper shows empirical results for Stockholm, Sweden.

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Keywords: Traffic Simulation Model; Macroscopic Fundamental Diagram; Model Validation; Empirical Analysis

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1. Introduction

Many cities, including Stockholm, face major congestion and air quality problems. Policy measures to tackle these problems are often first evaluated using transport models. In urban transport modelling, there is a trend towards more detailed microscopic dynamic urban models (Wegener 2011). Stockholm, for instance, has initiated work on applying the microscopic model Transmodeler to the Stockholm car network. This trend is driven by cities' need for analysis of detailed changes to the network, and also by the difficulties of macroscopic models to capture travel time gains of car travel demand reduction policies in highly congested areas with blocking back of upstream links (Eliasson et al. 2013). However, long computing times, uncertainty due to stochastic variation and large data requirements for calibration has delayed the introduction of microsimulation models in urban transport planning (Wegener 2011). Current practice is to calibrate and validate simulation models locally through comparison with point flow measurements and travel times on some important routes. However, for many applications, the level of congestion in an entire area is important. Calibration using only a few data points runs the risk that the model will match reality only locally.

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In recent years, progress has been made in traffic data collection and modelling. An important addition to previous data sources is GPS data from vehicles, which can give much better coverage of the street network at a fraction of the cost of stationary sensors. GPS sensors provide travel time and distance data from all parts of the network where equipped vehicles are moving. These floating car data, combined with other data sources, provide unprecedented opportunities to dynamically monitor congestion levels throughout the city. It is now possible to study how congestion varies over the day, between days, months and even years in different parts of the city as a result of changes in travel demand, infrastructure, accessibility initiatives etc.

It has recently been discovered that the relationship between vehicle speed and density, as normally measured at the link level, under certain conditions also exists for larger areas such as neighbourhoods and districts. This so-called macroscopic fundamental diagram (MFD) links the number, or density, of vehicles in an area to the average speed or flow in that area (Daganzo 2007). Furthermore, a robust linear relation has been found between the average flow in the area and total outflow (Geroliminis and Daganzo 2007). It has also been shown that MFD is a property of the network itself (infrastructure and traffic control), i.e., it does not depend on travel demand (Geroliminis and Daganzo 2008). This implies that the average network flow reaches a maximum at the same density or average speed regardless of travel demand patterns. Furthermore, it has been shown (Geroliminis and Daganzo 2008; Leclercq et al. 2014; Ambühl and Menendez 2016) that MFD can be estimated accurately using the data sources that are available in Stockholm, such as traffic counts from fixed sensors and floating car data.

Daganzo and Geroliminis (2008) formulate regularity conditions for a well-defined MFD to exist:

1. a slowly varying and dispersed demand
2. a meshed networks (i.e., redundancy)
3. a homogeneous networks with similar links
4. links with an approximate fundamental diagram that is not significantly affected by turning movements under steady flow

The first application of MFD concerned the strategies for ramp metering on motorways (Geroliminis et al. 2011) and Tu et al. (2014) examined at which time the ramp-metering should be applied. As for the urban network, analysis has focused on identifying suitable, relatively homogeneous areas where the flow can be controlled so that the desired level of congestion is reached in the area. The inflow may be controlled by means of, e.g., signal control, congestion charges, route guidance or information. Several studies have used simulation to investigate how MFD can be applied to regulate the in-flow of vehicles to an area in order to keep congestion at reasonable levels within the area (Keyvan-Ekbatani et al. 2013; Keyvan-Ekbatani et al. 2012; Geroliminis et al. 2013; Ramezani et al. 2015).

The aim of this paper, in contrast to existing MFD studies, is to investigate the possibility of using MFD as a way to validate microscopic traffic models for urban areas. A simulation model calibrated for the City area in central Stockholm is used to produce analogous traffic data as collected by empirical measurements from fixed sensors and floating car data. By examining how well traffic simulations reflect the empirical MFD of the study area, the ability of the model to represent network properties at a macroscopic level is evaluated.

2. Methodology

In this study, empirical measurements and simulation are used and compared. Two types of empirical measurements are used: fixed sensor measurements via pneumatic tubes on selected streets (Section 3.1.1), and floating car data via taxis travelling in the entire study area (Section 3.1.2). For simulation, the microscopic model Transmodeler has been used, see further Section 3.2. MFD are generated from both empirical and simulated data, and results are compared in common plots.

2.1. MFD from fixed sensors

Let q_{it} be the vehicle flow per hour and lane at location i during time interval t, let k_{it} be the density (veh/km/lane), and let N be number of measurement locations. The average flow, density and network speed are computed as (Geroliminis and Daganzo 2008):

$$\overline{q}_t = \frac{\sum_i q_{it}}{N} \tag{1}$$

$$\overline{k}_t = \frac{\sum_i k_{it}}{N} \tag{2}$$

$$\overline{v}_t = \frac{\overline{q}_t}{\overline{k}_t} \tag{3}$$