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Transportation Research Procedia 10 (2015) 71 – 81

Transportation Research Procedia

www.elsevier.com/locate/procedia

18th Euro Working Group on Transportation, EWGT 2015, 14-16 July 2015, Delft, The Netherlands

Vehicle specific behaviour in macroscopic traffic modelling through stochastic advection invariant

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Abstract

In this contribution a new model to include stochastic vehicle specific behaviour and interaction in traffic flow modelling is presented. The First Order Model with Stochastic Advection (FOMSA) is presented as a first order macroscopic kinematic wave model in a platoon-based Lagrangian coordinate system. The use of Lagrangian coordinates allows characteristics of specific vehicles or vehicle-groups to propagate along with the traffic flow using a vehicle specific invariant. The invariant reflects how vehicle or platoon specific characteristics propagate with the vehicles and influence the local behaviour of a vehicle or platoon on a macroscopic level and in interaction with other surrounding vehicles. It represents a local vehicle specific adjustment to the critical density and makes use of two parameters: a stochastic boundary parameter and a transition parameter. These parameters indicate the extent of differences between vehicles or platoons. A case study is also presented in which a demonstration of the model is given and the face validity and sensitivity of the parameters are shown. Previously, similar approaches have made use of second order model descriptions. The formulation of this model as a first order model makes use of the advantages of first order models and also applies the improved accuracy of Lagrangian coordinates over the Eulerian coordinate system in time-stepping.

Peer-review under responsibility of Delft University of Technology

Keywords: stochastic; macroscopic modelling; advection invariant; traffic behaviour

1. Introduction

Traffic is a highly dynamic and complex system, which encompasses human behaviour through the act of driving. Human driving behaviour is complex in itself, but exists of a general core behaviour related to the general rules of driving, i.e. traversing a lane in a certain direction at a certain speed without collision, and of intrinsic behavioural aspects that can be driver specific (Fuller 2005; Toledo 2007). The core behaviour is seen as something

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Peer-review under responsibility of Delft University of Technology
doi:10.1016/j.trpro.2015.09.057

that is easily understood, observable and reproducible in models. However individual driver behaviour is somewhat harder to capture and reproduce. Efforts to capture and understand stochastic driver behaviour have been successful and have described many aspects of driving behaviour. Driver behaviour has a direct effect on vehicle behaviour, which can be seen as the consequence thereof. In this contribution the focus is on the latter, which is of course influenced by the former. With an increase in microscopic modelling, and especially agent-based models, much stochastic behaviour of individual vehicles and interaction between vehicles has been included in modelling. This easily allows stochastic behaviour in longitudinal and lateral movements to be included by simply adding terms describing this to a vehicles behavioural algorithm (Arasan and Koshy 2005; Mallikarjuna and Rao 2009; Treiber, Kesting, and Helbing 2006). However, in macroscopic traffic modelling each individual vehicle is often considered to adhere to identical or similar behaviour. This is especially the case in deterministic modelling. Although this has a number of advantages and often seems to produce acceptable results, interaction between vehicles is generally ignored. However observations of traffic flows show that considering differences between vehicles and their stochastic behaviour is relevant, especially for constrained or critical traffic states (Kerner 2013; Persaud, Yagar, and Brownlee 1998; Polus and Pollatschek 2002). This is also demonstrated later in this contribution.

Capturing such fluctuations in behaviour between vehicles in macroscopic traffic flow however demands a certain levels of disaggregation of the macroscopic flow, which is not traditionally inherent to such models. In this contribution we aim to overcome this difficulty to allow stochastic behaviour from vehicles and between vehicles to be modelled in a first order macroscopic setting. This is achieved through the use of a Kinematic Wave Model, which considers the movement of vehicles according to first order traffic theory in a platoon-based Lagrangian coordinate system (Leclercq, Laval, and Chevallier 2007). Consideration of the stochastic behaviour of vehicles is included through the application of a vehicle specific invariant term that describes local stochastic characteristics of vehicles and drivers within and between individual vehicles or platoons. These characteristics implicitly describe aspects of driver behaviour such as desired time headway . The use of Lagrangian coordinates allows the vehicle specific invariant term to propagate along with the vehicles for which it is valid and thus avoids numerical diffusion of driver behaviour variables (Leclercq, Laval, and Chevallier 2007; van Wageningen-Kessels et al. 2009). This approach is unique to first order macroscopic models, and is generally found in the more elaborate second order models. Details on this process are described later in the paper.

This contribution offers a unique approach based on proven theories to include vehicle specific behaviour in first order macroscopic modelling, filling a void that has been previously solved for microscopic models, but lacking in macroscopic models. The modelling principles applied in the described approach are first explained in section 2 to give the reader the required knowledge to understand the approach. The developed approach is then described in section 3, including the assumptions made and the limitations. In section 4 an experimental case is given to demonstrate the approach, in which a further comparison is made with a non-stochastic reference case to demonstrate the necessity of considering stochastic driving behaviour in macroscopic modelling. Finally the conclusions are given in section 5.

2. Modelling principles

2.1 Kinematic Wave Model

The kinematic wave model (KWM) is one of the most fundamental types of macroscopic traffic flow models. It captures the aggregated propagation of traffic flow described as the propagation of traffic waves and the adhering traffic characteristics. The concept of modelling kinematic waves of traffic was first introduced by Lighthill and Whitham (1955) and by Richards (1956) and is therefore often referred to as the LWR model. Since the introduction of the KWM various extensions have been proposed, however the underlying theory as originally described in the LWR model remains intact. Construction of the kinematic waves is achieved through use of the fundamental relationship of traffic flow which is generally described by the relationship between the density ρ and the flow q of traffic. The model further relies on the conservation equation and initial boundary conditions. The conservation equation and the fundamental relation are denoted by:

$$\partial_t \rho + \partial_x q = 0 \tag{1}$$

$$q = Q(\rho) \tag{2}$$