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Review Article

Lagrangian generic second order traffic flow models for node

Asma Khelifi [a,b,*], Habib Haj-Salem [a], Jean-Patrick Lebacque [a], Lotfi Nabli [b]

[a] Engineering of Surface Transportation Networks and Advanced Computing Laboratory, IFSTTAR/GRETTIA, Marne la Vallée 77447, France

[b] Department of Electrical Engineering, Research Laboratory of Control, Signal Processing and Imaging, National Engineering School of Monastir, Monastir 5000, Tunisia

HIGHLIGHTS

- The generalized higher order macroscopic traffic flow model is reformulated in the Lagrangian coordinate system to develop more efficient numerical method.
- Providing a new node model based on the Lagrangian coordinate system which is compatible with both microscopic and macroscopic descriptions.
- Adding discretization of node model that describe inflow and outflow boundaries to perform simulations on networks of roads.
- Include internal initial boundary conditions to improve the use of floating vehicle data.
- Node in- and out-flows calculated as asymptotic flows as a function of the demands and supplies.

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ABSTRACT

This study sheds light on higher order macroscopic traffic flow modeling on road networks, thanks to the generic second order models (GSOM family) which embeds a myriad of traffic models. It has been demonstrated that such higher order models are easily solved in Lagrangian coordinates which are compatible with both microscopic and macroscopic descriptions. The generalized GSOM model is reformulated in the Lagrangian coordinate system to develop a more efficient numerical method. The difficulty in applying this approach on networks basically resides in dealing with node dynamics. Traffic flow characteristics at node are different from that on homogeneous links. Different geometry features can lead to different critical research issues. For instance, discontinuity in traffic stream can be an important issue for traffic signal operations, while capacity drop may be crucial for lane-merges. The current paper aims to establish and analyze a new adapted node model for macroscopic traffic flow models by applying upstream and downstream boundary conditions on the Lagrangian coordinates in order to perform simulations on networks of roads, and accompanying numerical method. The internal node dynamics between upstream and downstream links are taken into account of the node model. Therefore, a numerical example is provided to underscore the efficiency of this approach. Simulations show that the discretized node model yields accurate results. Additional

* Corresponding author. Engineering of Surface Transportation Networks and Advanced Computing Laboratory, IFSTTAR/GRETTIA, Marne la Vallée 77447, France. Tel.: +33 1 81668959.

E-mail addresses: asma.khelifi@enit.rnu.tn (A. Khelifi), habib.haj-salem@ifsttar.fr (H. Haj-Salem), jean-patrick.lebacque@ifsttar.fr (J.-P. Lebacque), lotfinabli@yahoo.fr (L. Nabli).

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kinematic waves and contact discontinuities are induced by the variation of the driver attribute.

1. Introduction

Traffic flow models have been developed for many purposes such as traffic operations, management, control, evaluation, planning, prediction, congestion monitoring, and safety. For most of these applications, macroscopic models are well suited, as they are simple and robust with modest requirements in terms of data processing and analysis, low computational cost and precision as well as identification and calculation. This study revolves road network modeling applying macroscopic traffic flow models. First order traffic flow models have been used for quite a long time for modeling traffic flows on networks (Garavello and Piccoli, 2006; Lebacque and Khoshyaran, 2002; Zhang et al., 2009). In particular, the seminal LWR model has been widely used (Lighthill and Whitham, 1955; Richards, 1956). The LWR model is simple, and still takes various elements into consideration, for instance, capacity, storage, fundamental diagram, and traffic phase. However, first order models are not able to accurately recapture specific traffic flow phenomena such as the capacity drop, the bounded acceleration of vehicles or the stop- and go-waves, without being specifically adapted. They implicitly assume instantaneous speed change (Zhang, 2000). It can easily be extended in order to accommodate individual behavioral attributes that may be needed for assignment, for communication, and information and for traffic management methods involving V2X (including vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, i.e., the generic second order models (GSOM). The GSOM family encompasses a large variety of higher order traffic flow models, such as the LWR standard model which is basically a GSOM model with no specific driver attribute, the LWR model with bounded acceleration (Lebacque, 2002, 2003), the ARZ model standing for the multi-commodity models (Aw and Rascle, 2000; Jin and Zhang, 2004; Khoshyaran and Lebacque, 2008; Zhang, 2002), and the 1-phase Colombo model deduced from the 2-phase Colombo model (Colombo, 2002; Lebacque et al., 2007).

The present study focuses on the GSOM family. Authors developed an efficient numerical method to be applied to GSOM family. It includes methods to simulate traffic flow over nodes, which are required elements to simulate networks traffic, including inflows, outflows, and nodes at which roads merge or diverge or road properties change. Therefore, the next step in the development of the traffic flow model and accompanying numerical method is the introduction of nodes. GSOM models have been already well studied on homogeneous roads but little attention has been drawn to their implementation on nodes (as it is discussed in Section Methodology for the Lagrangian modeling of nodes). However, nodes (geometry, phases, traffic light operations, etc) are the main source of congestion for traffic streams on a network. Thus, the GSOM model (Section GSOM family) can be further developed. Consequently, the numerical method can be further improved (Section Lagrangian discretization of the GSOM family). The node model in Lagrangian coordinates deserves a special attention (Section Methodology for the Lagrangian modeling of nodes). In this paper, authors will discuss how to deal with inflow and outflow boundaries and inhomogeneity. Inhomogeneity is, for instance, changes in the fundamental relations due to changes in the number of lanes or speed limit, off ramps (diverges) and on ramps (merges). In the authors' model links are homogenous road stretches connected by nodes. Boundaries and inhomogeneity are located at the nodes. Therefore, authors refer to models for inflow and outflow boundaries, inhomogeneity, merges, and diverges as node models.

High-order macroscopic traffic models concerning nodes (intersections and geometry changes) are fundamental studies. Over the past years, many node models have been proposed, such as point-wise and non point-wise. Integration of node modeling seems to be a promising research area for some aspects of transportation planning, improving the quality of identification and calibration, extensive and sophisticated networks modeling, understanding of the capacity drop (hysteresis), traffic management and control applications (such as ramp metering, speed control, reactive and dynamic allocation, etc) (Bhouri et al., 2016; Buisson et al., 1996; Jin and Zhang, 2003; Lebacque, 1996, 2003; Lebacque and Khoshyaran, 2001, 2005). Hence, node modeling is therefore crucial for the simulation tool and the accuracy of the developed model. Still, this is a difficult, complex and delicate process. Vehicles and drivers already have plans (specific origin and destination) and therefore precise itineraries, which made node modelization difficult.

The traditional numerical methods are generally easier to extend with these node models, but also node models based on the Lagrangian coordinate system can be implemented and lead to satisfying results. The main challenge of node modeling in Lagrangian formulation is that nodes move with respect to the coordinate system, which moves with the vehicles. Therefore, one may develop node models similar to the ones that are used in microscopic models. However, the continuous link model describes the average vehicle behavior. Therefore, the node model and its discretization should also describe the average vehicle behavior and thus authors did not resort to microscopic node models depicting the behavior of individual vehicles. Authors consider macroscopic node models and introduce node models in Lagrangian formulation in analogy to those in Eulerian formulation. Thus, the aim of this paper is to develop a new node model based on non point-