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Simulating Lane-Changing Dynamics towards Lane-Flow Equilibrium Based on Multi-Lane First Order Traffic Flow Model

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Abstract

It is well known that under the condition of high traffic volume lane-flow distribution becomes unbalanced; more traffic tends to use a median lane rather than a middle and outer lane, which causes the deterioration of traffic capacity at bottleneck sections. As intensive development of ITS, active and dynamic lane management has been practically implemented. By employing the technology of ITS, balancing lane-flow distribution is one of the feasible solutions to increase the throughput of bottleneck flow. However, the mechanism of the unbalanced usage among lanes is still unclear and traffic flow models enabling online and network-wide evaluation of dynamic and strategic lane management have not been proposed due to the lack of the method to computing lane-based traffic flow including lane-changing dynamics. This paper developed the multi-lane first order traffic flow model, which depicts the dynamics of lane-changing. It is assumed that each vehicle changes the lane to improve its utility or decrease its disutility, and also that the equilibrium of lane flow distribution is achieved as the condition of stochastic user equilibrium (SUE), where all drivers believe that they cannot improve their utility by changing the lanes. Thus, in the model, lane-changes are represented as the dynamics towards lane-flow equilibrium. As a result of simulating multilane traffic on freeway without any merging and diverging, it is revealed that the proposed model can represent the equilibrium curve of lane-flow distribution, and depict the propagation of traffic congestion at a lane-drop bottleneck section.

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Keywords: lane changing; traffic flow modeling; multi-lane, lane-flow equilibrium; stochastic user equilibrium

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1. Introduction

It is well known that under the condition of high traffic volume lane-flow distribution becomes unbalanced; more traffic tends to use a median lane rather than a middle and outer lane, which causes the deterioration of traffic capacity at bottleneck sections [Knoop et al., 2010; Wu, 2012; Xing et al., 2014]. As intensive development of ITS, active and dynamic lane management has been practically implemented. By employing the technology of ITS, balancing lane-flow distribution is one of the feasible solutions to increase the throughput of bottleneck flow [Xing et al., 2014]. Besides the unbalanced lane usage, lane traffic management and control should be considered as one of the solutions to improve the efficiency and safety in case of lane regulation under roadworks or incidents and at the merging, diverging and weaving sections. For traffic management to be effective, it is needless to say that a model-based decision support system consisting of traffic state estimation, traffic state prediction and optimization and traffic control measures is essential as mentioned in Yuan et al. (2012). However, due to the lack of the method to computing multilane traffic flow including lane-change dynamics, a model-based decision support system enabling lane-based traffic management to be considered has not been realized.

This paper develops the multi-lane first order traffic flow model, which depicts the dynamics of lane-changing. In the model, we assume that each vehicle changes the lane to improve its utility or decrease its disutility, and also that the equilibrium of lane flow distribution is achieved as the condition of stochastic user equilibrium (SUE), where all drivers believe that they cannot improve their utility by changing the lanes. Thus, in the model, lane-changes are represented as the dynamics towards lane-flow equilibrium. The utility function for a vehicle to choose each lane is defined by only two parameters on the basis of the investigation about lane-changing behaviour done by Knoop et al. (2012) and Shiomi et al. (2013): one is a constant value implying cost breaking the keep-left (or right) principle, and the other one is the average speed depending on the fundamental diagram and the density of the lane. Such parsimony representation will be able to online calibration by using the real time data from conventional loop detectors. To compute the possible solution of multilane traffic under the conservation law of traffic volume, IT principle [Laval and Daganzo, 2006] is applied. Then, in this paper, the reproducibility of lane-flow equilibrium curve on the imaginary ring road and the traffic dynamics at the lane-drop bottleneck is verified.

This paper is organized as follow. In section 2, state-of-the-art of modelling multilane traffic is described. In section 3, the concept of lane-change dynamics and the mathematical representation of lane-flow equilibrium are described. In section 4, the computation methods of multilane traffic flow employing IT principle (Laval and Daganzo, 2006) is overviewed. In section 5, the developed model is verified for the following two cases; reproducibility of lane-flow equilibrium curve on imaginary ring road, and traffic dynamics at lane-drop bottleneck. Finally, we conclude the contribution of the paper and mentioned the recommendation for the future works.

2. State-of-the-art

Considerable scientific attention has been paid on the topic of lane-change behaviour and multi-lane flow modelling during the last two decades. Because lane-change is individual vehicle driving behaviour, that is, whether a vehicle changes its lane totally depends on the decision making which the subject vehicle takes and the situation where the subject vehicle is in, it has been the most straightforward way to apply microscopic modelling [Gipps, 1986; Kita, 1999; Salvucci and Liu, 2002; Webster et al., 2007; Toled et al., 2009; and more]. This approach can consider various conditions and variables which may cause making decision to change lanes. However, due to the computational tasks and complicated model framework, it is not appropriate to apply for online and network-wide freeway traffic evaluation. The other approach is mesoscopic modelling [Shvestsov and Helbing, 1999; Hoogendoorn and Bovy, 2001]. In the approach, gas-kinetic model is applied to depict longitudinal multilane traffic dynamics and lateral movement as well. However, in Shvestsov and Helbing (1999), the proportion of lane changers is exogenously given according with the density. Thus, the motivations behind the lane change behavior are not appropriately considered. In Hoogendoorn and Bovy (2001), the probability of a vehicle changing the lane is estimated by applying discrete choice theory. In this case, however, it is required to calibrate various parameters, so that more precise data is required than conventional loop detectors. Also, it is difficult to employ online and dynamic traffic estimation based on the real time data collection.