Physica A 436 (2015) 729–738

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Traffic behavior of mixed traffic flow with two kinds of different self-stabilizing control vehicles

Zhipeng Li [a], Wenzhong Li [a], Shangzhi Xu [a], Yeqing Qian [a], Jian Sun [b,*]

[a] The Key Laboratory of Embedded System and Service Computing, Ministry of Education, Tongji University, Shanghai, 201804, China

[b] Department of Traffic Engineering and Key Laboratory of Road and Traffic Engineering, Ministry of Education, Tongji University, Shanghai, 201804, China

HIGHLIGHTS

- We proposed an extended optimal velocity model to describe mixed traffic flow.
- Linear stability analyses have been conducted.
- Computer simulation has been conducted.

ARTICLE INFO

Article history:
Received 3 March 2015
Received in revised form 13 May 2015
Available online 27 May 2015

Keywords:
Heterogeneous traffic
Traffic flow stability
Self-stabilizing control
Historical velocity difference

ABSTRACT

In this paper, we propose a heterogeneous car following model in terms of an extension to the original optimal velocity model characterizing two classes of different self-stabilizing control vehicles. Linear stability analysis method is utilized to the extended model, for purpose to explore how the varying percentages of the vehicles with short-duration self-stabilizing control influence the stability of the heterogeneous traffic flow. We obtain the neutral stability lines for different percentages of two classes of vehicles, with finding that the traffic flow trends to stable with the decrease of the percentage for short-duration self-stabilizing control vehicles. Moreover, we explore a special case that the same numbers of two different classes of vehicles with self-stabilizing control. We theoretically derive the stability condition of the special case, and conclude the effect of the average value and the standard deviation of two time gaps, on the heterogeneous traffic stability. At last, direct simulations are conducted to verify the conclusion of theoretical analysis.

1. Introduction

The rapid socio-economic development has posed many challenges to urban transportation with more and more serious congestion. Many scientists with different backgrounds actively participate in the studying of identifying the underlying mechanism of traffic jams by an effective way of simulation [1–6]. There is growing interest in the spatio-temporal behavior of highway traffic flow dynamics, with a large number of traffic flow model have been developed and reported in the literature [7–36]. Generally, traffic flow models can be categorized with respect to the level of detail: macroscopic, mesoscopic and microscopic models. Macroscopic models, which are also called hydrodynamic models, describe real-world traffic analogously to liquids in vehicular motion [2,7]. Microscopic models, such as car following models, explain the traffic flow at high

* Corresponding author.
E-mail address: sunjian@tongji.edu.cn (J. Sun).

http://dx.doi.org/10.1016/j.physa.2015.05.090
0378-4371/

level of detail such as the motion equation of individual vehicle. Mesoscopic models combine microscopic and macroscopic approaches to a hybrid model.

Car following models are the most common and most typical type of microscopic models aimed to describe the empirical observations in traffic flow dynamics [1,21–23,31–35]. They select one vehicle as describing object to reveal the characteristics of traffic flow, and describe the driver's behavior in the presence of interactions with the immediately preceding vehicle. One of the simplest but rich and widely used car-following model is the so-called optimal velocity model (OVM, for short) was introduced in Ref. [10]. In the framework of this model, each vehicle controls the acceleration $\mathrm{d}v_j(t)/\mathrm{d}t$ of the jth vehicle at time t is committed to reduce the difference between the current velocity $v_j(t)$ and an optimal velocity $V(\Delta x_j(t))$, which depends on the distance $\Delta x_j(t)$ to the immediately preceding vehicle. Under a certain condition, OVM successfully provides appearance of spontaneous transitions from freely moving traffic to congested traffic, which has been clarified by linear stability analysis.

Starting from the OVM model of car following, a lot of scholars recently put forward many improved models for purpose to enhance the stability of traffic flow when traffic jams of go-and-stop occur [11–13]. An important improving direction is to consider the cooperative driving control which incorporates the traffic information of other vehicles by use of the system of information and communication technologies (ICT) in an environment of intelligent transportation system (ITS) [18,19,21–23,26,27]. Nagatani and Li et al. proposed two car-following models taking into account the next-nearest-neighbor interaction in front [22,23]. Xue suggested a lattice model with the consideration of optimal current of the next immediately preceding vehicle [24]. In addition, some researchers advised some generalized traffic flow model considering the motion information of many preceding or following vehicles in an environment of ITS [29]. All of above work belong to the scope of cooperative driving control, which has been proved to be useful to stabilize the traffic flow with density waves. However, the implementation effect of the cooperative driving control highly depends on the quality of the communication network. A vehicle cannot still carry out the cooperative control without the traffic data of others. To overcome this shortcoming, some scholars take into account of the historical information to improve the traffic flow model [33]. We have develop an extended optimal velocity model taking into account the historical velocity difference $\triangle\ \upsilon_{his}$ between the current velocity $v_j(t)$ and the historical velocity of the considered vehicle $v_j(t-t_d)$, whose dynamics equation is [34]

$$\frac{\mathrm{d}v_j(t)}{\mathrm{d}t} = a\left[v_j(\Delta x(t)) - v_j(t)\right] + \lambda\left[v_j(t) - v_j(t-t_d)\right] \tag{1}$$

where a is the sensitivity of a driver t_d is the duration (or time gap) between the current time t and the historical time $t-t_d$, $\triangle\ \upsilon_{his} = v_j(t) - v_j(t-t_d)$ represents self-stabilizing control in the historical velocity difference, and λ is the control coefficient. The extended new model can stabilize traffic flow only utilizing the traffic data of the considered vehicle itself, i.e., the traffic flow can be stabilized only by each vehicle's self-stabilizing control, without the help of the cooperative driving control from others.

Previous studies of car-following modeling have shown a wide variation in their performance, but they are unsatisfactory in areas of describing different drivers and vehicles, i.e., heterogeneous traffic flow [35,36]. In actual traffic environment, drivers and vehicles are different for a number of factors including individual differences of age, gender, risk-taking behavior, vehicle class and so on. Without the support of motion information of others, traffic system can improve its stability against a small disturbance when each vehicle in fields runs according to dynamic equation (1) of the self-stabilizing control. The smooth realization of such system strongly depends on on-board equipment of read-writing and program. The vehicles also present different self-stabilizing styles since the performance of the on-board equipment, which is tightly related to the time gap t_d. To our knowledge, the modeling and parameterization in self-stabilizing control vehicles are not taken into account in the context of heterogeneous traffic flow.

In this paper, we have concentrated to derive analytical conditions describing the instability of mixed traffic flow utilizing an extended two-class optimal velocity model with different self-stabilizing control and to verify the stability criterion by the means of computer simulations. We apply linear stability analysis method to the extended model, to explore how the varying percentages of the vehicles with short-duration self-stabilizing control influence the stability of the heterogeneous traffic flow. This paper also investigates a special case that the same numbers of two different classes of vehicles from the theoretical analysis to study how the average and the standard deviation of time gaps of two different classes of vehicles affect the stability of traffic flow. We conduct the direct simulations to examine the theoretical result at last.

This paper is organized as follows. Section 2 specifies the extend car-following model for the dynamics of two-class mixed traffic flow with different self-stabilizing control in historical velocity difference. The linear stability analysis of the heterogeneous traffic flow with short-duration self-stabilizing control and long-duration self-duration self-stabilizing control vehicles is presented and the stability condition is concluded in Section 3. Numerical simulations are carried out to validate the analytic results of theory. Finally, we conclude our paper in Section 5.

2. Extended model equation for heterogeneous flow

The microscopic model, which describes how a platoon of vehicles interacts with each other, is an important consideration in traffic simulation. Traffic models may use identical driver–vehicle units or describe mixed traffic. In the latter case, the vehicle pool consists of several vehicle types and the model might incorporate inter-driver variability by using several parameter sets of each type.