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Stability analysis of dynamic collaboration model with control signals on two lanes

Zhipeng Li *, Run Zhang, Shangzhi Xu, Yeqing Qian, Juan Xu

The Key Laboratory of Embedded System and Service Computing supported by Ministry of Education, Tongji University, Shanghai 201804, China

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ABSTRACT

In this paper, the influence of control signals on the stability of two-lane traffic flow is mainly studied by applying control theory with lane changing behaviors. We present the two-lane dynamic collaboration model with lateral friction and the expressions of feedback control signals. What is more, utilizing the delayed feedback control theory to the two-lane dynamic collaboration model with control signals, we investigate the stability of traffic flow theoretically and the stability conditions for both lanes are derived with finding that the forward and lateral feedback signals can improve the stability of traffic flow while the backward feedback signals cannot achieve it. Besides, direct simulations are conducted to verify the results of theoretical analysis, which shows that the feedback signals have a significant effect on the running state of two vehicle groups, and the results are same with the theoretical analysis.

1. Introduction

In recent years, the traffic flow problems have become one of the most concerned issues in our daily life and have been widely studied by scientists with different background. Confronting the serious traffic problems, the governments of the world have taken a variety of countermeasures with poor effects from these measures of traffic engineering. At the same time, some scholars have been trying to understand the nature governing the traffic flow using theoretical approaches. The most essential ingredients which describe the general features of real traffic fields are incorporated to develop traffic flow models with the approach of mathematics. What is more, according to the details of the different descriptions of traffic flow, conceptual frameworks for modeling traffic flow are divided into microscopic model, mesoscopic model and macroscopic model. Car following model is one of the microscopic models of vehicular traffic, which focuses on individual vehicles each of which is represented by a particle and the nature of the interactions among these particles. What is more, the movement of considered vehicle is only determined by the way of the nearest preceding vehicle's movement [1,2]. In 1953, Pipes [3] first proposed the car following model (the classic car following model) the basic idea of which is: the vehicle accelerate when the speed of nearest preceding vehicle is greater than that of current vehicle; the current vehicle decelerate when the speed of nearest following vehicle is greater than that of current vehicle. In 1995 Bando [4] proposed the optimal velocity model (OVM), which can successfully describe the dynamical formation of traffic congestion and solve the infinite acceleration problem. Thereafter, various vehicular traffic models have been put forward based on the OVM model in the

* Corresponding author. Tel.: +86 13585647318; fax: +86 21 69589224.
E-mail address: lizhipeng@tongji.edu.cn (Z. Li).

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past decades [5–30]. The theoretical analysis and simulations of these models not only provide deep exploring into the properties of the model but also help in better understanding of the complex phenomena observed in real traffic fields.

Besides, the characteristics of the traffic flow has been mainly studied for car following model of single-lane, and recently some researchers try to expand the original idea to the traffic flow modeling on two lanes. Although two-lane car-following models are evolved from single-lane models, there are some different characteristics in two-lane models. Under the circumstance of two-lane traffic, the lateral effects should also be taken into account to establish two-lane model apart from the effects in front. Tang [31–33] first presented an extended car-following model on two lanes by incorporating the lateral effects in traffic flow to analyze the stability of two-lane traffic flow and obtained that the consideration of lateral effects could stabilize the traffic flows on both lanes. Zheng [34] proposed a two-lane optimal velocity (OV) model focusing mainly on the stability analysis of two-lane traffic flow with lateral friction and had obtained its stability condition from the viewpoint of control theory.

Feedback control method is being paid more and more attention, and it was considered as an important factor to apply to traffic flow modeling [34–40]. In order to suppress the traffic jam in a discrete-time OV model, Konishi [35–37] proposed a dynamic version of the decentralized delayed feedback control (DDFC) method firstly by investigating the traffic jams phenomena under periodic boundary condition in 2000. Besides, Zhao et al. [38,39] proposed the alternative control method under open boundary with which the traffic system can move into a homogeneous phase in 2005, and their results show that the alternative control method could suppress the disorder state in the traffic system. In addition, Chen et al. [40] extended the single-lane feedback control model to the two-lane case and the computer simulation results show that the introduction of a feedback signal makes serious traffic congestion nonoccurrence.

In this paper, we extend the form of control signals [38] to our two-lane dynamic collaboration model with the consideration of the lateral effects, and our two-lane control signals consist of not only the speed differences between the vehicles in the same lane but also the velocity differences between the considered vehicle and the nearest vehicles in the neighbor lane. Namely, we have not only proposed a two-lane traffic flow model with the consideration of the lateral interference from neighbor lane, but also introduced the lateral feedback signals into our control signals to investigate the effect of the lateral feedback signals on the stability of traffic flow. The theoretical analysis is applied by utilizing the DDFC method under the two-lane case and the numerical simulations are provided to confirm the theoretical results.

This paper is organized as follows: In Section 2, the dynamic collaboration model and the feedback signals are explained with lane changing behaviors for two-lane traffic flow. In Section 3, the stability conditions are analyzed by extended DDFC method with the feedback signals under two-lane case. In Section 4, the numerical simulations are presented to study the traffic characteristics with the feedback signals to confirm the theoretical results. Finally, the conclusions are drawn in Section 5.

2. Model

It is easily known that the vehicle's movements are not only influenced by the block interference from the front and behind vehicles in the same lane but also affected by the friction interference from vehicles in the neighbor lane, which should not be neglected when two-lane or multi-lane traffic flow are modeled. Now, let us consider the location of vehicles on two-lane case (see Fig. 1).

Zheng [34] proposed a two-lane optimal velocity (OV) model by taking the lateral effects into account as follows.

$$\begin{cases} \frac{dv_{l,n_l}(t)}{dt} = a_l[V_l(y_{l,n_l}(t), q_{l,n_l}(t)) - v_{l,n_l}(t)] \\ \frac{dy_{l,n_l}(t)}{dt} = v_{l,n_l-1}(t) - v_{l,n_l}(t), \qquad (n_l = 1 \cdots N_l) \\ \frac{dq_{l,n_l}(t)}{dt} = v^f_{l,n_l}(t) - v_{l,n_l}(t) \end{cases} \tag{1}$$

where $v_{l,n_l}(t)$ is the velocity of vehicle n_l at time t in lane l; $V_l(y_{l,n_l}(t), q_{l,n_l}(t))$ is the OV function of the vehicle in lane l, $y_{l,n_l}(t)$ is the headway between vehicles $(n_l - 1)$ and n_l in the same lane l at time t, $q_{l,n_l}(t)$ is the lateral distance between the vehicle n_l

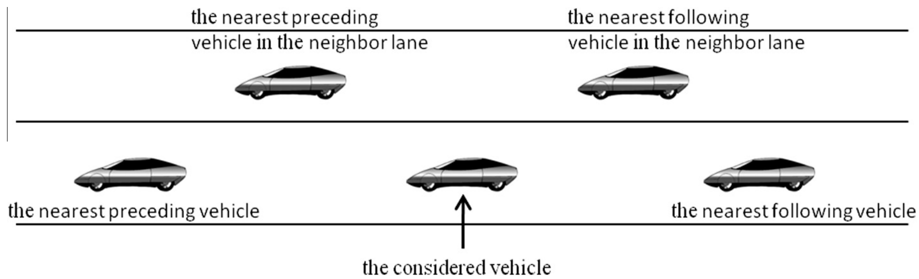

Fig. 1. Location of vehicles.