Physica A 449 (2016) 1–17

Contents lists available at ScienceDirect

Physica A

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

An improved car-following model considering velocity fluctuation of the immediately ahead car

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HIGHLIGHTS

- An improved car-following model considering velocity fluctuation of the immediately ahead car was proposed.
- The effects of velocity fluctuation of the immediately ahead car on traffic flow are investigated.
- It has significant effects on car-following behaviors and fuel consumptions.
- Considering it can improve traffic flow stability and reduce fuel consumptions.

ARTICLE INFO

Article history:
Received 16 August 2015
Received in revised form 26 November 2015
Available online 22 December 2015

Keywords:
Car-following models
Velocity fluctuation of the immediately ahead car
The time window length
The adaptive cruise control system
Fuel consumption

ABSTRACT

To better describe car-following behaviors in the adaptive cruise control strategy and further increase roadway traffic mobility and reduce fuel consumptions, the linkage between velocity fluctuation of the immediately ahead car and the following car's acceleration or deceleration is explored with respect to the measured car-following data by employing the gray correlation analysis theory and then an improved car-following model considering velocity fluctuation of the immediately ahead car on basis of the full velocity difference model is proposed. Numerical simulations are carried out and the effects of velocity fluctuation of the immediately ahead car on each car's velocity, acceleration, vehicular gap, fuel consumptions and the total fuel consumptions of the whole car-following system with different time window lengths are investigated in detail. The results show that velocity fluctuation of the immediately ahead car has significant effects on car-following behaviors and fuel consumptions, and that considering velocity fluctuation of the immediately ahead car in designing the adaptive cruise control system can improve traffic flow stability and reduce fuel consumptions.

1. Introduction

Mathematics has been applied in the field of the traffic flow microscopic modeling since the 1930s. The proposed microscopic traffic models are aimed at obtaining a more clear understanding of the underlying mechanisms that govern traffic flow, which focus on the stability of traffic flow and the emergence of traffic jams.

Generally speaking, the longitudinal traffic flow consists of an interactive car-following state and a free state, and car-following models are focused on in this paper. Car-following theory is based on the follow-the-leader concept. How one driver follows her\his immediately ahead car has been explored for many years based on both experimental observations

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http://dx.doi.org/10.1016/j.physa.2015.12.040
0378-4371/

and theoretical analyses, which include the early linear models proposed by Chandler et al. [1], the early nonlinear models presented by Pipes [2], Gazis et al. [3] and Newell [4], the recent remarkable work of Bando et al. [5], Helbing and Tilch [6] and Jiang et al. [7] and some others in the literatures [8–38]. The optimal velocity model proposed by Bando et al. [5] is one of favorable car-following models that can describe many properties of real traffic flow such as the instability of traffic flow, the evolution of traffic congestion and the formation of stop-and-go waves. Helbing and Tilch calibrated the optimal velocity model with the measured car-following data and found that the optimal velocity model may result in impractical high acceleration and unrealistic deceleration, and then they further proposed the generalized force model by considering the negative velocity difference [6]. Subsequently, many efforts have been made based on the optimal velocity model or the generalized force model. Jiang et al. [7] took both negative and positive velocity differences into account and put forward the full velocity difference model. Gong et al. [8] considered the asymmetric characteristic of the cars' velocity differences in a traffic stream and presented an asymmetric full velocity difference car-following model. Zhu and Zhang [9] introduced a speed feedback control mechanism into the system to improve the dynamical performance of the traffic flow. Peng et al. [10] presented a new optimal velocity difference model based on the full velocity difference model. Wang et al. [11] presented a multiple velocity difference model by considering multiple preceding cars' velocity differences based on the full velocity difference model. Peng and Sun [12] took the effects of multiple preceding cars' velocity differences and headways into account and proposed a dynamical model of car-following with the consideration of the multiple information of preceding cars based on the full velocity difference model. Yu and Shi [13] took multiple preceding cars' velocity changes with memory into account and developed an improved cooperative car-following model used as the connected cruise control strategy.

One driver has memory if his speed at a later time depends on his speed at the previous time. Zhang [39] developed a continuum macroscopic model arising from a car-following model with driver memory and found that the driver's memory in car-following behaviors can lead to viscous effects in continuum traffic flow dynamics. Tang et al. [34] put forward an extended car-following model considering the driver's memory and found that considering driver's memory in modeling car-following behaviors can improve the traffic flow stability. Yu and Shi [38] proposed an extended car-following model by considering vehicular gap changes with memory and found that considering vehicular gap changes with memory in designing the adaptive cruise control system can improve the traffic flow stability and reduce fuel consumptions.

Under the above-mentioned perspectives, the car-following model considering driver's memory is further investigated. The field car-following data are measured to explore the linkage between velocity fluctuation of the immediately ahead car and the following car's acceleration or deceleration, and then an improved car-following model considering velocity fluctuation of the immediately ahead car is developed for further analysis.

2. Traffic flow data collection and data mining analysis

2.1. Traffic flow data collection

The traffic flow data used to analyze the linkage between velocity fluctuation of the immediately ahead car and the following car's acceleration or deceleration all come from the traffic survey carried out by our research group.

Here, the traffic flow videos for collecting the field car-following data are obtained in the Jingshi Road/Shanshi East Road intersection of Jinan in China by using digital video camera, which is installed on the windowsill of a tall building adjacent to the intersection rather than on the roadside to avoid the interference of the pedestrian flow and public transport.

It is supposed that car 1 follows car 2 and the difference between velocity at time t and the mean velocity of the time cycle before time t of car 2 is defined as the velocity fluctuation of car 2.

The field car-following data of every 1 s are extracted by using the frame differential method, which contain each car's velocity, acceleration, velocity difference, the relative distance and velocity fluctuation of car 2 with different time window length. Due to the limitation of visual angle for the time being, only the field car-following data with the maximum time window length of 4 s are obtained. The partial measured car-following data are listed as shown in Tables 1–3.

The gray correlation analysis theory can be employed to analyze the geometric similarity between the behavior factors within a system and the gray correlation degree is a quantitative value of the similarity between the behavior factors. Higher is the value of gray correlation degree, more relevant are the main-factor and sub-factor. The car-following process can also be regarded as a dynamic system.

Here, we utilize gray correlation analysis theory to explore the linkage between velocity fluctuation of car 2 and the acceleration of car 1. The linkages with different time window lengths of 2 s, 3 s and 4 s are respectively explored and the correlation degrees are respectively listed as shown in Table 4.

From Table 4, it can be found that the similarities between sub-arrays and the acceleration or deceleration of car 1 in order of importance are Δv_{12}, Δv_{2f}, v_1 and then d_{21}, that Δv_{2f} and Δv_{12} are more similar with the acceleration or deceleration of car 1 than v_1 and d_{21}, that the similarities of Δv_{2f} and Δv_{12} with the acceleration or deceleration of car 1 are much the same, and that the similarities between sub-arrays and the following car's acceleration or deceleration gradually increase with the increase of the time window length.

It can be concluded that velocity fluctuation of the immediately ahead car has significant effects on car-following behaviors and that velocity fluctuation of the immediately ahead car should be taken into account in modeling car-following behaviors and designing the advanced adaptive cruise control strategy.