Physica A 494 (2018) 294–301

Contents lists available at ScienceDirect

Physica A

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

The influence of continuous historical velocity difference information on micro-cooperative driving stability

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HIGHLIGHTS

- A new car-following model is proposed by considering the continuous historical information.
- Theoretical analysis and simulation are conducted for the new model.
- The continuous historical information can enhance the stability of traffic flow.

ARTICLE INFO

Article history:
Received 10 July 2017
Received in revised form 14 November 2017
Available online 11 December 2017

Keywords:
Traffic flow
Car-following model
Continuous historical velocity difference
Stability

ABSTRACT

In this paper, a new micro-cooperative driving car-following model is proposed to investigate the effect of continuous historical velocity difference information on traffic stability. The linear stability criterion of the new model is derived with linear stability theory and the results show that the unstable region in the headway-sensitivity space will be shrunk by taking the continuous historical velocity difference information into account. Through nonlinear analysis, the mKdV equation is derived to describe the traffic evolution behavior of the new model near the critical point. Via numerical simulations, the theoretical analysis results are verified and the results indicate that the continuous historical velocity difference information can enhance the stability of traffic flow in the micro-cooperative driving process.

1. Introduction

Traffic modeling is the basic work to uncover the operation rules of road traffic and has attracted considerable research due to the increasing seriousness of traffic problem in our daily life. Lots of traffic models mainly including the macroscopic traffic models [1–11] and the microscopic traffic models [12–54] have been proposed. The car-following models are the most widely used category of traffic models in the microscopic traffic modeling. The basis idea of the car-following models is that the following vehicle's motion is determined by the stimulus from the vehicle ahead of him.

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https://doi.org/10.1016/j.physa.2017.12.044
0378-4371/

The early car-following models were constructed by Pipes [20] and Chandler et al. [21]. In these works, the following vehicle's acceleration is relating to the velocity difference information of two successive vehicles. After that, Newell [22] developed a car-following model with time delay in which the concept of optimal velocity is introduced. In 1995, Bando et al. [23] proposed the famous Optimal Velocity (OV) car-following model which can reproduce many complex dynamic characteristics of real traffic. Afterwards, the OV model was modified to the Generalized Force (GF) model by Helbing and Tilch [24] by considering the negative velocity difference and further extended to the Full Velocity Difference (FVD) model by Jiang et al. [25] by considering the full velocity difference. Subsequently, an increasing number of car-following models [26–54] have been put forward with consideration of many different traffic factors on the basis of the OV model.

In real traffic, the vehicle's motion is not only depends on the traffic states at the current time, but also relates to the past information of traffic flow. In 2009, Tang et al. [50] proposed a car-following model with consideration of driver's memory effect in sensing the past headway information happened in one time step. Later, Liu et al. [51] developed another car-following model by considering multiple time steps historical headway information. Also, Li et al. [52] studied the influence of the velocity difference of the target vehicle's historical velocity and its current velocity on traffic stability. And all these works shown that the traffic stability will be enhanced by considering the past information of traffic flow at a fixed previous time.

Recently, Cao et al. [53] pointed out that the traffic information between a fixed previous time and the current time is needed for the following vehicle to adjust its motion and constructed a new car-following model with consideration of driver's continuous memory effect in sensing headway and it is shown that the continuous previous headway information is of great importance to the stability of traffic flow. Meanwhile, as pointed out by Jiang et al. [25], the velocity difference information is significant for the following vehicle to adjust its velocity. So it is reasonable to conclude that the continuous historical velocity difference information should influence the traffic stability significantly. But this topic has not been explored so far to our knowledge.

In this paper, a new car-following model is proposed to reveal the impact of continuous historical velocity difference information on traffic flow. The new model will be presented in the following section. The linear and nonlinear analyses of the new model are carried out in Sections 3 and 4, respectively. Section 5 is numerical simulation and Section 6 gives a conclusion.

2. The new model

The OV model proposed by Bando et al. [23] is one well-known and widely extended car-following model in microscopic traffic modeling. The dynamic equation of the OV model is as follows:

$$\frac{dv_n(t)}{dt} = a\left(V(\Delta x_n(t)) - v_n(t)\right), \tag{1}$$

where $x_n(t)$ denotes the position of the nth vehicle at time t and $v_n(t)$ represents its velocity, $\Delta x_n(t) = x_{n+1}(t) - x_n(t)$ indicates the headway between the leading vehicle $n+1$ and the following one n, a is driver's sensitivity and V is an optimal velocity function.

Later, by introduce the velocity difference of two successive vehicles into the OV model, Jiang et al. [25] proposed the following FVD model:

$$\frac{dv_n(t)}{dt} = a\left(V(\Delta x_n(t)) - v_n(t)\right) + ak\Delta v_n(t), \tag{2}$$

where $\Delta v_n(t) = v_{n+1}(t) - v_n(t)$ is the velocity difference between vehicle $n+1$ and vehicle n and k refers to the response coefficient.

Recently, by incorporating driver's continuous memory information of traffic state, Cao et al. [53] proposed a new car-following model as follows:

$$\frac{dv_n(t)}{dt} = a\left(V\left(\frac{1}{\tau_0}\int_{t-\tau_0}^{t} \Delta x_n(u)du\right) - v_n(t)\right), \tag{3}$$

where τ_0 is driver's memory time.

In Cao's model, the following vehicle's acceleration at time t is determined by the continuous headway information at time gap $[t-\tau_0, t]$ and it is proved that the continuous historical headway information affects the stability of traffic flow significantly. On the other hand, as the FVD model indicated, the velocity difference information is also of great importance in the car-following process. So in order to study the influence of continuous historical velocity difference information on traffic stability in the car-following driving process, a novel car-following model on the basis of the FVD model is developed as follows:

$$\frac{dv_n(t)}{dt} = a\left(V(\Delta x_n(t)) - v_n(t)\right) + ak\int_{t-\tau_0}^{t} \Delta v_n(s)ds, \tag{4}$$

where t_0 is the considered historical time, and the integral of $\Delta v_n(s)$ from $t - t_0$ to t indicates that the velocity difference information is continuous.