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A novel car following model considering average speed of preceding vehicles group

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HIGHLIGHTS

- A new car following model is proposed by considering the average speed effect of preceding vehicles group.
- The stable condition of the extended model has been explored.
- By means of the nonlinear analysis, we deduce the mKdV equation and obtain its kink–antikink soliton solution to describe the jamming transition.
- The results show that the average speed effect of preceding vehicles group can efficiently suppress the emergence of traffic jamming.

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ABSTRACT

In this paper, a new car following model is presented by considering the average speed effect of preceding vehicles group in cyber–physical systems (CPS) environment. The effect of this new consideration upon the stability of traffic flow is examined through linear stability analysis. A modified Korteweg–de Vries (mKdV) equation was derived via nonlinear analysis to describe the propagating behavior of traffic density wave near the critical point. Good agreement between the simulation and the analytical results shows that average speed of preceding vehicles group leads to the stabilization of traffic systems, and thus can efficiently suppress the emergence of traffic jamming.

1. Introduction

Over the past decades, serious traffic jam has received much attention because of its complex mechanism. And many traffic flow models [1–10] have been constructed to describe it. The car-following model [11–16] is a favorable type of microscopic traffic model to describe the driver's individual behavior. Among which, the most well-known one is the optimal velocity (OV) model [17], which has successfully revealed the dynamical evolvement process of traffic congestion in a simple way. However, comparison with empirical data shows that too high acceleration and unrealistic deceleration occur in the OV model. Hereafter, many researchers have attempted to improve the OV model. Helbing and Tilch [18] introduced a negative velocity difference term into the OV model, presented the generalized force (GF) model. Starting from GF model, Jiang et al. [19] proposed the famous full velocity difference (FVD) model by further considering the factor of positive velocity

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difference. The study illustrates that FVD model has better agreement with the field data than OV and GF models. Recently, the transportation cyber–physical systems (T-CPS), which can enable the exchange of information among vehicles and provide on-line traffic data about other cars on road, can help to improve the transportation level of service and prevent the traffic jams efficiently. In this direction, scholars successively developed some extended multiple car following models based on OV model or FVD model. Some were extended by introducing multiple information of headway [20–26] or relative velocity [27–29], while others considered both factors at the same time [30–32]. Stability analysis in the aforementioned models all turn out that the stability of traffic flow is greatly improved. Clearly, the information of average speed on road is easy to obtain by making use of the T-CPS. And one can fully expect that the average speed of preceding vehicles group has significant impact on the stability and dynamic characteristics in car following process. However, to our knowledge, the effect of average speed of preceding vehicles group has not been explored in the car-following models up to now.

In view of the above reason, in this paper, a new car-following model is proposed by considering the average speed effect of preceding vehicles group in real traffic. In the following section, the new car following model is constructed. In Section 3, the linear stability analysis is conducted. Nonlinear analysis is presented in Section 4. In Section 5, numerical simulation is carried out to validate the analytic results. Conclusions are given in Section 6.

2. Model

In 1995, Bando et al. [17] proposed the OV model to describe car-following behavior on a single-lane highway. The motion equation is as follows:

$$\frac{\mathrm{d}v_j(t)}{\mathrm{d}t} = a[V(\Delta x_j(t)) - v_j(t)] \tag{1}$$

where $x_j(t)$ and $v_j(t)$ are the position and velocity of the jth car respectively, and t represents time. a denotes the sensitivity of the driver and is given by the inverse of the delay time τ, namely $a = 1/\tau$, $\Delta x_j(t) = x_{j+1} - x_j$, representing the headway of two successive vehicles. $V(\cdot)$ is the optimal velocity function.

Based on the OV model, Helbing and Tilch [18] in 1998 proposed a generalized force (GF) model. Its formulation is as follows:

$$\frac{\mathrm{d}v_j(t)}{\mathrm{d}t} = a[V(\Delta x_j(t)) - v_j(t)] + \lambda H(-\Delta v_j(t))\Delta v_j(t) \tag{2}$$

where H is the Heaviside function and $\Delta v_j(t) = v_{j+1} - v_j$ is the velocity difference between the leading car $j+1$ and the following car j. $\lambda = k/\tau$ is the responding factor to the velocity difference. The simulation results indicate that the GF model is poor in anticipating the kinematic wave speed and the delay time of car motion.

In 2001, by introducing positive relative velocity into the GF model, Jiang et al. [19] developed the full velocity difference (FVD) model as follows:

$$\frac{\mathrm{d}v_j(t)}{\mathrm{d}t} = a[V(\Delta x_j(t)) - v_j(t)] + \lambda\Delta v_j(t) \tag{3}$$

compared with the OV and GF models, the results show that the FVD model is more realistic. However, unrealistically high deceleration also occurs in the FVD model [19].

The aforementioned models can describe some complex traffic phenomena (e.g., congestion, instability, and stop-and-go waves in traffic flow). However, these models are unsuited to study the average speed effect of preceding vehicles group, because they did not consider this factor at all. In fact, the average speed of preceding vehicles group reflects the whole traffic situation on a segment, i.e., whether the traffic flow of preceding cars on a segment will cluster, dissipate, or simply maintain a constant velocity. By applying T-CPS, the following car can sense the whole traffic situation of preceding cars through the indicator of road segment average speed, then make a decision and adjust its velocity in advance to adapt the state change of preceding cars based on sensing information. In view of above reason, we developed a new road segment average speed car-following model (RSAS-CF) that considers the average speed of preceding vehicles group. The model's dynamics equation is as follows,

$$\frac{\mathrm{d}v_j(t)}{\mathrm{d}t} = a[V(\Delta x_j(t)) - v_j(t)] + \lambda[\bar{v}_j(t) - v_j(t)] \tag{4}$$

where the term $\bar{v}_j(t) = \frac{1}{n}\sum_{l=1}^{n} v_{j+l}(t)$ is the road segment average speed term which reflects the locality traffic flow state between the car j and its leading cars $j, j+1, \ldots, j+n$ at time t. n denotes the number of the vehicles ahead considered. λ is the responding factor to the difference between the velocity $v_j(t)$ and road segment average speed term $\bar{v}_j(t)$. The idea of the extended model is that the acceleration of the jth car is determined not only by the velocity $v_j(t)$ and the headway $\Delta x_j(t)$, but also by the velocity difference between velocity $v_j(t)$ and road segment average speed $\bar{v}_j(t)$ at time t. When $n = 1$, the new model is reduced to the FVD model [19].

In this paper, we use the following optimal velocity function (for short, OVF) calibrated with the empirical data by Helbing [18]:

$$V(\Delta x_j) = V_1 + V_2\tanh[C_1(\Delta x - l_c) - C_2]. \tag{5}$$