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A new car-following model with consideration of the prevision driving behavior

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ABSTRACT

In the paper, a new car-following model is presented with the consideration of the prevision driving behavior on a single-lane road. The model's linear stability condition is obtained by applying the linear stability theory. And through nonlinear analysis, a modified Korteweg–de Vries (mKdV) equation is derived to describe the propagating behavior of traffic density wave near the critical point. Numerical simulation shows that the new model can improve the stability of traffic flow by adjusting the driver's prevision intensity parameter, which is consistent with the theoretical analysis.

1. Introduction

Traffic jam has been a serious problem in modern city traffic and many traffic models [1–10], such as car-following models, cellular automaton models, gas kinetic models, and hydrodynamic models, have been developed to investigate the properties of traffic jams. The optimal velocity (OV) model proposed by Bando et al. [11], one of the favorable car-following traffic models on studying traffic flow, has successfully described the formation of traffic jams and revealed the transition mechanism in a simple way. Subsequently, inspired by the OV model, some new car -following models were successively put forward to more realistically describe the traffic nature. Some of them were extended by introducing multiple headway or relative velocity information of car [11–14], and others considered the two factors at the same time [15–20].

These car-following models mentioned above can reproduce many complex actual traffic phenomena, but they cannot be employed to study the influence of the prevision driving behavior since they did not consider the factor. In the transportation cyber physical systems (T-CPS) [21], a leading car can send the future speed control command of the leading car to the follower before the leading car's the current speed changes, and thus the following one can obtain in advance the leading car's future running state information to control his current acceleration for achieving the optimal state. However, few scholars have studied the prevision driving behavior in car-following model [22].

In this paper, a new car following model is proposed by taking the prevision driving behavior on a single-lane road into account. In the following section, the new car following model is introduced. In Section 3, linear stability analysis is conducted. In Section 4, nonlinear analysis is done. In Section 5, numerical simulation is carried out to validate the analytic results. Conclusions are given in Section 6.

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2. Models

In 1995, Bando et al. [11] proposed the OV model to describe the car-following behavior on a single lane highway. The motion equation is given as follows:

$$\frac{dv_j(t)}{dt} = a\left[V\left(\Delta x_j(t)\right) - v_j(t)\right], \tag{1}$$

where $x_j(t)$ is the position of car j at time t, $\Delta x_j(t) = x_{j+1} - x_j$ represents the headway of two successive vehicles, a is the sensitivity of a driver, and $V(\Delta x_j(t))$ is the optimal velocity function. The comparison with empirical data shows that the OV model appears too high acceleration and unrealistic deceleration.

In order to overcome the deficiency, Helbing and Tilch [23] proposed a generalized force (GF) model, i.e.

$$\frac{dv_j(t)}{dt} = a\left[V\left(\Delta x_j(t)\right) - v_j(t)\right] + \lambda H\left(-\Delta v_j(t)\right)\Delta v_j(t), \tag{2}$$

where H is the Heaviside function, λ is a sensitivity coefficient different from a, $\Delta v_j(t) = v_{j+1} - v_j$ is the velocity difference between the leading car $j + 1$ and the following car j. The simulation results indicate that the GF model is poor in the delay time of car motion. In view of the problem, in 2001, by introducing the positive relative velocity into the GF model, Jiang et al. [24] developed full velocity difference (FVD) model as follows:

$$\frac{dv_j(t)}{dt} = a\left[V\left(\Delta x_j(t)\right) - v_j(t)\right] + \lambda \Delta v_j(t), \tag{3}$$

The results illustrate that FVD model has better agreement with the field data than the OV and GF model.

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 prevision driving behavior since they doesn't consider it at all. In fact, by applying T-CPS, the leading car can sense and process traffic information, then make a decision to control its speed, and then immediately send the decision to its following one before it performs control command. Thus the following one can adjust his speed in advance to reduce relative velocity difference and keep the traffic flow stable. The following car's speed can be adjusted without waiting for the running state change of the leading car. In view of the above reason, we develop a new prevision driving car-following (for short, PD-CF) model with considering the prevision driving behavior, whose dynamics equation is

$$\frac{dv_j(t)}{dt} = a\left\{V\left(\Delta x_j(t)\right) - v_j(t)\right\} + \lambda \Delta v_j(t) + k\left(v_{j+1}(t+1) - v_{j+1}(t)\right), \tag{4}$$

where $\Delta F_{j+1} = v_{j+1}(t+1) - v_{j+1}(t)$ represents the velocity difference between the future speed and the current speed of the leading car $j + 1$. FVD model did not take the velocity difference term into consideration, however, we consider that term impact the traffic stability, and thus it is introduced in our model by response factor k. When $k = 0$, Eq. (4) of the extended model reduce into those of FVD model. In this paper, we adopt the same optimal velocity function as that used by Bando et al.[11]:

$$V\left(\Delta x_j(t)\right) = \frac{1}{2} v_{\max}\left[\tanh\left(\Delta x_j(t) - h_c\right) + \tanh(h_c)\right], \tag{5}$$

where the $v_{\max} = 2$ is the maximum velocity and $h_c = 4$ is the safe distance. For later convenience of simulation and nonlinear analysis, Eq. (4) can be rewritten in terms of the headway:

$$\begin{aligned}\Delta x_j(t+2\tau) = {} & \Delta x_j(t+\tau) + \tau\left[V\left(\Delta x_{j+1}(t)\right) - V\left(\Delta x_j(t)\right) - \Delta v_j(t)\right] + \tau\lambda\left[\Delta v_{j+1}(t) - \Delta v_j(t)\right] \\ & + \tau k\left[v_{j+2}(t+1) - 2v_{j+1}(t+1) + v_{j+1}(t)\right].\end{aligned} \tag{6}$$

3. Linear stability analysis

In order to investigate the impact of the prevision driving behavior on the traffic flow, the linear stability analysis can be conducted for PD-CF model. The vehicles move with the uniform headway b and the optimal velocity $V(b)$. Therefore, the steady-state solution is given as

$$x_j^0(t) = bj + V(b)t, \quad b = L/N \tag{7}$$

where L is the road length and N is the car number. Suppose $y_j(t)$ is a small deviation from the steady state:

$$x_j(t) = x_j^0(t) + y_j(t). \tag{8}$$

Substituting Eq. (8) into Eq. (6) and linearizing the resulting equation, we can obtain

$$y_j''(t) = a\Big[V'(b)\Delta y_j(t) - y_j'(t)\Big] + \lambda \Delta y_j'(t) + \frac{k}{2} y_{j+1}''(t), \tag{9}$$