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Research paper

Enhanced stability of car-following model upon incorporation of short-term driving memory

Da-Wei Liu, Zhong-Ke Shi*, Wen-Huan Ai

College of Automation, Northwestern Polytechnical University, Xi'an, Shaanxi, 710072, China

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A B S T R A C T

Based on the full velocity difference model, a new car-following model is developed to investigate the effect of short-term driving memory on traffic flow in this paper. Short-term driving memory is introduced as the influence factor of driver's anticipation behavior. The stability condition of the newly developed model is derived and the modified Korteweg-de Vries (mKdV) equation is constructed to describe the traffic behavior near the critical point. Via numerical method, evolution of a small perturbation is investigated firstly. The results show that the improvement of this new car-following model over the previous ones lies in the fact that the new model can improve the traffic stability. Starting and breaking processes of vehicles in the signalized intersection are also investigated. The numerical simulations illustrate that the new model can successfully describe the driver's anticipation behavior, and that the efficiency and safety of the vehicles passing through the signalized intersection are improved by considering short-term driving memory.

1. Introduction

Microscopic traffic simulation based on microscopic traffic models is of great importance in analysis of road transportation system. Car-following models are the most widely used models in microscopic traffic models. Since Pipes [1] presented the first car-following model in 1953, an increasing number of models have been proposed. Newell [2] derived a car-following model with time delay which is important to explore the evolution of traffic jam. Bando et al. [3] proposed an optimal velocity model (OVM) to reveal the complex dynamic characteristics of traffic flow. To solve the problem of excessively high acceleration and unrealistic deceleration in OVM, generalized force model (GFM) has been developed by Helbing et al. [4]. Based on the GFM, Jiang et al. [5] developed a car-following model called full velocity difference model (FVDM). With the consideration of drivers reaction time delay, Yu et al. [6] presented an extended car-following model based on the FVDM and found that the time delay have effect on the stability of traffic. Davis [7] modified the OVM and found that small delay times are needed for lengthy platoons of vehicles to avoid collisions. Sipahi et al. [8] conducted the stability analysis of car-following system with gamma distributed time lag. Nagatani [9] found that the car interaction before the next car ahead can stabilize the traffic flow. Ge et al. [10] proposed an improved car-following model by taking an arbitrary number of vehicles ahead into account on a single-lane highway. Yu et al. [11] developed a new car-following model in ITS environment by taking the effect of headway of multiple-vehicle in front into account and analyzed the traffic characteristics near the critical point in instability region of traffic flow by using the reductive perturbation method. Tang et al. [12] presented a

* Corresponding author.
E-mail addresses: liudawei20120901@163.com (D.-W. Liu), shizknwpu@126.com (Z.-K. Shi).

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car-following model on two lanes by considering the lateral effects in traffic. They believed that vehicle drivers always worry about the lane changing actions from neighbor lane and the consideration of lateral effects could stabilize the traffic flows on both lanes. Jia et al. [13] proposed an improved car-following model with the consideration of lateral influence from adjacent lane by introducing the combination of two OV functions. Ge et al. [14] investigated the two-lane traffic flow with lane changing behaviors and derived the stability condition by using the control method. Zhou [15] proposed an improved full velocity difference model for car-following theory with the consideration of human driver's visual angle. Aghabayk et al. [16] investigated the heavy vehicle (HV) interactions with the other vehicles using real data. Ngoduy [17] explore effect of the four car-following types including car-car (CC), car-truck (CT), truck-car (TC) and truck-truck (TT) on the overall linear stability condition of the heterogeneous traffic flow. Liu et al. [18] found that depending on the combination type and the equilibrium velocity, cars and truck can both stabilize and destabilize the traffic flow. Yang et al. [19] focused on the effect of real-time maximum deceleration in car-following, and established a car-following model accordingly to modify the desired minimum gap and structure of the intelligent driver model. Zheng et al. [20] derived a similar backward-looking model reflecting drivers' response to upstream traffic stimuli and then put forward a continuum traffic flow model to investigate the bidirectional information impact. Xu et al. [21] proposed a new asymmetric optimal-velocity car-following model by introducing a exponential function with an asymmetrical factor, they find that the deceleration is stronger than acceleration with the same velocity difference.

In recent years, research on driving behaviors has undergone a rapid development. As a kind of typical driving behaviors, driver's anticipation behavior has therefore been widely studied. A wide class of time-continuous microscopic traffic models has been generalized by Treiber et al. [22] to include essential aspects of driver behavior. They found that the destabilizing effects of reaction times and estimation errors can essentially be compensated for by spatial and temporal anticipation. Tang et al. [23] extended the OVM with the consideration of the driver's forecast effect. Ngoduy et al. [24] developed an improved multi-anticipative macroscopic model from a gas-kinetic model in which the multi-anticipative driving behavior is explicitly described through an extended generalized force model. Zheng et al. [25] presented an anticipation optimal velocity model and derived the modified Korteweg–de Vries equation to study the nonlinear character of the new model. Peng et al. [26] developed an extended model based on FVDM through substituting an anticipation optimal velocity with optimal velocity and discussed the impact of driver's forecast on traffic flow stability. Tian et al. [27] improved the FVDM by introducing the velocity anticipation and found that the new model could avoid accidents under urgent braking cases when the anticipation time interval was increased enough. Hu et al. [28] constructed an extended multi-anticipative delay model by introducing multiple velocity differences and incorporating the reaction-time delay of drivers. Ge et al. [29,30] proposed a car-following model considering anticipation driving behavior and derived the KdV–Burgers equation in a new anticipation continuum model. Ngoduy [31] believed that the multi-anticipative driving behavior describes the reaction of a vehicle to the driving behavior of many vehicles in front. Kang et al. [32] presented a new car-following model of traffic flow by considering the driver's individual anticipation behavior (forecast behavior and response delay behavior).

The above studies believed that the driver's anticipation behavior depend on the current observed traffic conditions. However, besides the current observed traffic conditions, there is another factor that can affect the driver's anticipation behavior, namely, short-term driving memory. Studies explore that drivers have the memory effect on the historical information of driving state. In real traffic system, short-term memory effect has obvious influence on anticipation behavior. A driver often estimates the impending traffic situation and performs decision according to the driving situation of a few seconds before. Therefore, short-term driving memory has a role of feedback for drivers. Until now, short-term driving memory has been rarely considered in previous car-following models. In this paper, a new car-following model with a modified term about the short-term driving memory is derived to investigate its impact on traffic flow.

2. Model

Among the existing car-following models, the full velocity difference model (FVDM) proposed by Jiang et al. [5] is one of the efficient car-following models. The existing studies show that FVDM can describe many complex phenomena in real traffic, such as shock waves, rarefaction waves, stop-and-go waves, and local cluster effects. The full velocity difference model can be formulated as follows:

$$\frac{dx_n^2(t)}{dt^2} = a\left[V(\Delta x_n(t)) - \frac{dx_n(t)}{dt}\right] + \lambda\Delta v_n(t), \tag{1}$$

where $x_n(t)$ and $v_n(t)$ denote the position and speed of the nth vehicle, $\Delta x_n\ (t)=x_{n+1}(t)-x_n(t)$, $\Delta v_n(t)=v_{n+1}(t)-v_n(t)$ represents the headway and relative velocity between the nth vehicle and the $(n+1)\ th$ vehicle respectively. a is the sensitivity coefficient for the difference between the optimal and the current velocities, and λ represents the sensitivity coefficient of response to $\Delta v_n(t)$. The notation $V(\Delta x_n(t))$ is the optimal velocity function and can be defined as follows:

$$V(\Delta x_n(t))=V_1 + V_2 \tanh\left(c_1(\Delta x_n(t) - Lc) - c_2\right) \tag{2}$$

Parameters in the Eq. (2) are set as:

$$\begin{cases} V_1 = 6.75m/s, & V_2 = 7.91m/s \\ c_1 = 0.13m^{-1}, & c_2 = 1.57, \qquad Lc = 5m \end{cases} \tag{3}$$