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Effect of the driver's desire for smooth driving on the car-following model

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HIGHLIGHTS

- Considering the driver's desire for smooth driving, an improved car-following model is presented.
- The linear stability condition and the modified KdV equation are derived.
- The numerical simulation is presented to investigate the effect of the factor considered herein.
- The results show that the factor considered herein has a positive role in reducing traffic congestion.

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ABSTRACT

To reduce the fuel consumption caused by the acceleration or deceleration, many drivers wish to drive cars as smoothly as possible, which means that driving behavior is influenced by the driver's desire for smooth driving. In this paper, with the consideration of the driver's desire for smooth driving, an improved car-following model is presented by incorporating the difference of the steady and history velocities into optimal velocity model. To show the effect of the factor discussed herein, the improved car-following model is investigated by the analytical and numerical methods. The linear stability criterion is obtained by the linear analysis method. And then the modified KdV equation is derived to describe the propagating behavior of traffic jams near the critical point. The amplitude of the traffic jam can be relieved by strengthening driver's desire for smooth driving. The numerical simulations are explored to verify the validity of the analytical results and the effect of the driver's desire for smooth driving. The analytical and numerical results demonstrate that the driver's desire for smooth driving plays a positive role in improving traffic stability and flux.

1. Introduction

The continuously worsened traffic congestion has severely affected people's work efficiency and the quality of life. Modeling and managing the mechanism of traffic congestion has remained a significant research topic in transportation science [1–8]. Researchers have developed a considerable number of traffic models from various angles to the traffic flow system, such as the car-following model [9–17], lattice hydrodynamic model [18–26], intelligent driver model (IDM) [27,28], cellular automata model [29,30], continuum model [31–34], gas kinetic models [35].

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Suppose that the acceleration and deceleration are governed by a particular function of the space headway, Reuschel presented the earliest car-following model. Newell developed a new car-following model by introducing the idea of optimal velocity function into traffic model [36]. The famous optimal velocity model (OVM) is presented by Bando et al. [37]. The OVM can describe qualitative characteristics of the stop-and-go phenomenon, traffic jams and congestion evolution.

Following OVM, many new car-following models are proposed [38–42]. Helbing and Tilch [43] proposed a generalized force model, and Jiang et al. [44] proposed the full velocity difference model (FVDM). Ward and Wilson summarized the commonly used stability analysis methods for car-following model [45]. Considering the effect of looking back at the car, Nakayama et al. studied an improved optimal velocity model, which look at the following car as well as the preceding car [46]. Taking the factor of the lane width into traffic, Jin et al. [47] presented a non-lane-based car-following model. Zhao et al. presented a simple control method on the coupled map car-following model to suppress the traffic congestion [48]. Incorporating the multiple distance headways of multiple preceding leading vehicles into the car-following model, Peng et al. put forward multiple car-following models [49]. Lv et al. considered a three-lane changing behavior simulation using a modified optimal velocity model [50]. Jin et al. presented a new staggered car-following model by taking into consideration lateral separation effects [51]. To agree with experimental data, Xu et al. studied a nonlinear optimal velocity car-following model [52]. Sun et al. studied the effect of random safety distance [9] and heterogeneous maximum velocity [10] on the modified optimal velocity model. Li et al. took the linear and nonlinear stability analyses of car-following model considering the self-stabilizing control in historical traffic data [53]. Yu et al. studied the car-following model considering the different factors of green signal countdown device [11], vehicular gap fluctuation [12] and relative velocity fluctuation [13]. Tang et al. studied the inter-vehicle communication [7] on a two-lane car-following model, and also considered the effect of the driver's perceived errors of headway having probability distribution [54]. Tang et al. discussed the speed guidance strategy for multiple signalized intersections based on car-following model [55]. Zhu et al. analyzed the feedback control scheme on the discrete car-following system [56].

Frequent acceleration or deceleration usually leads to more fuel consumption. In order to relieve the fuel consumption caused by the acceleration or deceleration, many drivers may wish to control the vehicles as smoothly as possible. Sometimes, even though the space headway ahead is large enough to allow driver to speed up, the driver may not make acceleration immediately to avoid the behavior of deceleration at the next moment. Therefore, the driving behavior is affected by the driver's desire for smooth driving. Existing researches seldom take into account the influence of deriver's desire for smooth driving on the traffic flow in the car-following model.

For homogeneous traffic flow, all vehicles will have same speed and need not make acceleration or deceleration in the steady state. Then, the driver's desire for smooth driving can also be seen as that a driver may wish to adjust the current traffic situation to the optimal steady state. This paper aims to propose an improved car-following model with the consideration of driver's desire for smooth driving, which is embodied by incorporating the difference between the steady and history velocities into the OVM.

The paper is organized as follows. In Section 2, following the OVM, the formulation of an improved car-following model is presented. The stability criterion of the model presented herein is derived in Section 3 based on the linear analysis method. To describe the characteristic of traffic jams evolution, the nonlinear analysis method is applied to obtain the modified KdV equation in Section 4. And then Section 5 will present the numerical simulation to investigate the influence of the factor discussed herein on the traffic stability and flux. The final section concludes this study.

2. The improved car-following model

Bando et al. [37] proposed the famous optimal velocity model (OVM) as:

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

where v_n depicts the velocity of vehicle n, Δx_n is the headway between the proceeding vehicle $n+1$ and the following vehicle n, a is the sensitivity coefficient, and $V(\Delta x_n)$ represents the optimal speed function defined by [37]

$$V(\Delta x_n) = \frac{v_{\max}}{2}[\tanh(\Delta x_n(t) - h_c) + \tanh(h_c)], \tag{2}$$

where $v_{\max}$ is the maximum speed, and h_c is the safety distance.

The OVM is easily interpretable and can describe many properties of the real traffic flow. Following OVM, many extended car-following models have been presented (see the discussion in the introduction section). In reality, the drivers may desire to move the cars as smoothly as possible so that it can reduce the fuel consumption arisen from the acceleration and deceleration. The driving behavior is affected by the driver's desire for smooth driving. On account of the fact that all vehicles have same speeds and need not accelerate or decelerate in the steady state, the desire for smooth driving can be interpreted as that drivers try to adjust current traffic situation to the steady state. Thus, incorporating the difference between the steady-state velocity and the history velocity into the OVM, an extended car-following model is proposed as

$$\frac{d^2x_n}{dt^2} = a\left[V\left(\Delta x_n\right) - v_n\right] + \lambda\left[V\left(h\right) - v_n(t-\tau)\right], \tag{3}$$