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An extended heterogeneous car-following model with the consideration of the drivers' different psychological headways

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HIGHLIGHTS

- Considering the driver's psychological headways, an extended heterogeneous car-following model is presented.
- Applying the linear stability theory, the new model's linear stability criteria are proposed.
- The performance of this heterogeneous model is investigated by numerical simulations.
- Under drivers' appropriate psychological headways, this new heterogeneous model can enhance the stability of traffic flow.

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ABSTRACT

In this paper, based on the full velocity difference model, and with the consideration of the difference between the driver's psychological and actual headways, an extended heterogeneous car-following model is developed to investigate the effect of drivers' different psychological headways. The analytical linear stable criterion for this extended heterogeneous traffic model is studied by using linear stability theory. The evolution of the heterogeneous traffic flow under a small perturbation is investigated by numerical simulations. The numerical and analytical results all show that the factor of psychological headway has important influence on the stability of the traffic flow. Different driver's psychological headways have different effects on the traffic stability at different traffic densities. Compared with the full velocity difference model, the heterogeneous car-following model with smaller psychological headway can improve the stability at high traffic density, but the heterogeneous model with larger psychological headway lead to higher stability at the low traffic density.

1. Introduction

With increasing the owning amount of automobile, the problems of traffic jams and excessive carbon dioxide emissions are becoming more and more severe, and it is an imperative problem what kinds of traffic control can be applied to lighten it. Researchers pay more and more attention on the problems of traffic congestions [1–3]. In the macroscopic traffic model [4], the compressible fluid is used to approximate the discrete traffic flow. Lattice hydrodynamic models [5–11], gas kinetic models [12] and continuum models [13–17] are the frequently used macroscopic traffic models. Besides the macroscopic

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models, the cellular automata model [18,19], intelligent driver model (IDM) [20,21] and the car-following model [22] are the commonly used methods to reveal the traffic phenomena, such as traffic congestion, stop-and-go traffic waves and traffic jamming transition.

Accounting for the convenience in describing the movement of individual car, researchers pay continuous research attention on the study of car following models [23–33]. The earliest car-following model [34] is developed by Reuschel based on the idea that a vehicle will try to adjust its speed to that of the vehicle ahead. Bando constructed a common optimal velocity function, and then based on the idea that a vehicle should turn its speed to the optimal velocity related to the relative headway, Bando put forward the very famous optimal velocity model (OVM) [35]. The OVM can be used to reveal qualitative characteristics of the actual traffic flow, such as the stop-and-go phenomenon, traffic instability and the congestion evolution and so on. By improving the disadvantage of unrealistic deceleration and acceleration in OVM, Helbing and Tilch [36] proposed a generalized force model by considering the factor of negative relative velocity. Because of using Heaviside step function, the generalized force model has low smoothness. Then by adding the positive relative velocity into generalized force model, Jiang et al. presented the full velocity difference model (FVDM) [37]. Because of the high smoothness, the linear stability criterion and the nonlinear wave equations all can be derived to reveal all kinds of traffic characteristics in FVDM.

Based on the OVM or FVDM, many extended optimal velocity car-following models were presented by accounting for all kinds of factors influencing the traffic stability. By adding the optimal velocity difference into the FVDM, Peng et al. put forward the optimal velocity difference car-following model [38] Incorporating the multiple headway, velocity and acceleration, Li et al. presented an improved optimal velocity model [39]. Peng et al. proposed anticipation optimal velocity model by considering a headway anticipation of the next time step [40]. By considering the anticipation of headway influencing by the relative velocity difference, Zheng et al. presented an anticipation driving car-following model [41]. Considering the difference between the current and the history velocities, Li et al. presented an extended optimal velocity model [42]. Supposing driver adjust the optimal velocity based on the current traffic situations and the driving memory, Shi et al. developed an extended car-following model considering short-term driving memory [43]. Ou and Tang presented an extended two-lane car-following model accounting for inter-vehicle communication [44]. In addition, regenerative energy [45], traffic jerk [46], memory effect [47,48], variable vehicular gap policies [49], etc., are considered in the car-following models.

Due to the difference in vehicle type or driving strategy of each vehicle traveling on the lane is not exactly the same. The homogeneous traffic models may not well simulate the mixed traffic flow characteristics. Then some researchers pay much attention on the heterogeneous traffic [50]. Ngoduy studied the stability threshold of heterogeneous traffic flow based on the Intelligent Driver Model (IDM) [51]. Ward presented a mathematical approach to analysis the linear stability of heterogeneous traffic model [52]. Tang developed a macroscopic heterogeneous traffic model [53]. Replacing $v_{\max}$ in the original Bando model with heterogeneous maximum speeds, Yang et al. developed a heterogeneous car-following model with heterogeneous maximum speeds [54]. Yang et al. proposed cellular automata based traffic flow model to investigate the characteristics of car-truck heterogeneous traffic flow [55]. Two styles of self-stabilizing control in historical velocity difference are investigated by Li et al. [56]. Liu et al. studied the car-truck heterogeneous traffic flow based on the IDM [57]. The second-order macroscopic continuum model was applied to study the heterogeneous traffic flow by Mohan [58]. Li studied the heterogeneous traffic with two kinds of sensitivities [59].

By designing some scenarios and analyzing the data gathered from the scenarios, Naseri et al. [60] have shown that the traffic system of car following model is affected by the factor from the psychological view. However, the optimal velocity car-following models seldom take into account the influence from the psychological view. Because of the individual difference, different people may have different feel about the same headway. For same actual headway, some people feel it is far, while some people may feel it is quite close. Due to this point, there exists difference between the driver's psychological and the actual headways, and different people may have different psychological headways. High psychological headway can more easily lead to high driving speed at same actual distance. Until now, the factor of the difference between the psychological and actual headways has been rarely considered in previous optimal velocity car-following models.

In this paper, accounting for the difference between the driver's psychological and actual headways, we will develop an extended heterogeneous car-following model considering the driver's different psychological headways. The analytical linear stable criterion for this extended heterogeneous traffic model is studied by using linear stability theory. Numerical simulations are carried out to explore the influence caused by the heterogeneous psychological headways.

2. The extended car-following model

Based on the idea that a driver try to adjust the velocity to the optimal velocity, Bando et al. [35] developed the OVM as follows:

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

where a is the driver's sensitivity coefficient, x_n and v_n respectively is the position and velocity of the vehicle n, $\Delta x_n = x_{n+1} - x_n$ is the headway between the preceding vehicle $n+1$ and the following vehicle n, and $V(\Delta x_n)$ is the optimal velocity function defined as [35]