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Discussion

An extended car-following model considering the appearing probability of truck and driver's characteristics

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ABSTRACT

In this paper, the appearing probability of truck is introduced and an extended car-following model is presented to analyze the traffic flow based on the consideration of driver's characteristics, under honk environment. The stability condition of this proposed model is obtained through linear stability analysis. In order to study the evolution properties of traffic wave near the critical point, the mKdV equation is derived by the reductive perturbation method. The results show that the traffic flow will become more disorder for the larger appearing probability of truck. Besides, the appearance of leading truck affects not only the stability of traffic flow, but also the effect of other aspects on traffic flow, such as: driver's reaction and honk effect. The effects of them on traffic flow are closely correlated with the appearing probability of truck. Finally, the numerical simulations under the periodic boundary condition are carried out to verify the proposed model. And they are consistent with the theoretical findings.

1. Introduction

With tremendous increasing in automobiles, roads in developing countries are more and more congested, and the traffic flow in these countries is strongly disordered and even heterogeneous. As a result, traffic problem has become an increased and serious problem in modern cities in recent years, which not only limited the development of cities but also caused serious air pollution and road security issues [1,2]. In order to solve the serious problems, various scientists and researchers devoted to explore the complex mechanism behind the phenomena of vehicular flow by physical models. Traffic flow models can be categorized as microscopic, mesoscopic and macroscopic models [3–7]. Car-following model is one of the significant branches of microscopic models for traffic flow, which are widely studied by scholars [8–10]. Its aim is to describe the interactions with preceding vehicles by using the dynamic method, and further research the traffic characteristics on the road. It can efficiently link the microscopic behavior and the macroscopic phenomenon of traffic flow together.

As one of the most important representatives of car-following model, the optimal velocity model (OVM) was firstly proposed by Bando et al. [11], in 1995. After that, many models have been developed to investigate the properties of traffic flow from diverse aspects [12–15]. For human interaction aspect, in 2015, Sharma [16] analyzed the influence of driver's driving behavior (timid or aggressive) on the two-lane lattice hydrodynamic model. And later, Li et al. [17] studied the driver's aggressive characteristics on traffic flow and suggested that the driver's aggressive effect can increase the traffic stability. Cheng et al. [18] explored the effect of driver's timid and aggressive behaviors on traffic flow through a continuum model, and suggested that the aggressive driver behavior can not only enhance the traffic stability but also reduce the energy consumption. Besides, Vujanić et al. [19] tested the psychophysical characteristics of professional drivers and found that the drivers' psychophysical characteristics is indeed in regards to driving safety. In terms of honk effect, in 2011, Tang et al. [20] developed an extended OV model and Peng et al. [21] presented a new lattice model to study the influence of honk on the stability of traffic flow. They suggested that the honk effect could improve the stability of traffic flow. And in 2016, Wen et al. [22] proposed a modified optimal velocity model by considering the drivers' characteristics under the honk environment. It is found that the honk effect on traffic flow differ from diverse characteristic of drivers. Right after this, Kuang et al. [23] presented an extended car-following model to study the honk effect on traffic flow. And they also pointed out it is more realistic to take account the honk effect during modeling.

The aforementioned models are all homogeneous. However, with the development of economy in developing countries, the heterogeneous traffic crop up seriously and it has received considerable attention recently. Ossen et al. [24] showed that the behavioral differences exist among different passenger car drivers

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according to large sample of trajectory observations. And authors found that the drivers' desired headways are lower when they are following a truck than when following a car. Geng et al. [25] suggested that the following distance and following time headway are all affected when there is a light truck in front. Sun et al. [26] introduced the mixed maximum speeds and incorporated the anticipation driving behavior to analyzed the heterogeneous traffic, and found that both the mixed maximum speeds from different types of vehicles and traffic densities had significant influence on the stability of traffic flow. Li et al. [27] proposed a heterogeneous traffic flow model for two types of vehicles with different sensitivities, and analyzed the corresponding effect of the percentage of low-sensitivity vehicle on traffic stability. Yuan et al. [28] analyzed the crashes data from 2011 to 2013 in Beijing, which involve trucks as the front vehicle, and found that night time, weekdays, non-local drivers and car-truck as the travel mode significantly increased the likelihood of rear drivers being fatal. In addition, Kalaiselvi et al. [29] developed a horn correction method for traffic noise prediction models in heterogeneous traffic conditions and found that the horn events increase noise level by 0.5–13 dB in heterogeneous traffic than in homogenous one. Throughout the above, the intervention of trunk not only affected the stability of traffic flow, but is also likely to endanger the security of road and even drivers. Even so, however, in the literature, very limited studies have been recorded to develop an understanding of traffic flow for synthetically considering the appearing probability of truck, driver's characteristics and honk effect. Thus, we introduce the appearing probability of truck, and propose an extended car-following model to analyze the traffic flow, by synthetically considering the driver's characteristics, under honk environment.

The rest of this paper is organized as follows: In Section 2, the modified OV model considering the appearing probability of truck is established in detail. In Section 3, the stability condition of traffic flow is derived by means of linear stability theory. In Section 4, the mKdV equation is obtained by applying the reductive perturbation method, and the evolution feature of traffic flow is further described by the kink–antikink wave. The numerical simulations are carried out to validate the theoretical findings in Section 5. And finally, the conclusions are drawn in Section 6.

2. Model formulation

The classical optimal velocity model is proposed by Bando et al. [11], in 1995. It is one of the simplest but significant traffic flow models to study the microscopic car-following behavior, which is given by

$$\frac{dv_n(t)}{dt} = \frac{V(\Delta x_n(t)) - v_n(t)}{\tau} \tag{1}$$

where $v_n(t)$, $x_n(t)$ are the velocity and position of nth vehicle at time t, respectively; $\Delta x_n(t) = x_{n+1}(t) - x_n(t)$ is the corresponding headway for nth vehicle between $(n+1)$th and nth one; τ is the delayed time to reach the optimal velocity of nth vehicle for the varying traffic; and $V(\Delta x_n(t))$ is the optimal velocity of nth vehicle, which is determined by the headway $\Delta x_n(t)$, given as

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

where, $v_{\max}$ is the maximum velocity of vehicle; h_c is the average headway; and $\tanh(\cdot)$ is the hyperbolic tangent function.

In real traffic, when a truck appears in front immediately, drivers with different characteristics may have diverse reaction to it, especially under the honk environment. However, there is no one report to study how the appearing probability of truck affects the traffic flow for different driver's characteristics as well as honk effect up to our best knowledge. Motivated by this reason, an extended car-following model based on [21] is proposed by considering the appearing probability of truck and the driver's characteristics under honk environment, as follows,

$$\begin{aligned}\frac{dv_n(t)}{dt} = {} & \frac{V(\Delta x_n(t)) - v_n(t)}{\tau} \\ & + p\mu g_1(v_{exp}(\Delta x_{n-1}(t)), v_n(t+\tau_1)) \\ & + (1-p)\mu g_2(v_{exp}(\Delta x_{n-1}(t)), v_n(t-\tau_2))\end{aligned} \tag{3}$$

with the honk effect function resulting from the $(n-1)$th vehicle's headway and nth vehicle's velocity corresponding to the aggressive and timid drivers, respectively:

$$\begin{aligned}& g_1(v_{exp}(\Delta x_{n-1}(t)), v_n(t+\tau_1)) \\ & \quad = \frac{v_{exp}(\Delta x_{n-1}(t)) - v_n(t+\tau_1)}{\tau_1}\end{aligned} \tag{4}$$

$$\begin{aligned}& g_2(v_{exp}(\Delta x_{n-1}(t)), v_n(t-\tau_2)) \\ & \quad = \frac{v_{exp}(\Delta x_{n-1}(t)) - v_n(t-\tau_2)}{\tau_2}\end{aligned} \tag{5}$$

It means that the effect of the honk g_i $(i = 1, 2)$ is not only relevant to the desired velocity of $(n-1)$th vehicle determined by the headway $\Delta x_{n-1}(t)$, but also restricted by nth vehicle's current velocity. In the literatures [20] and [22], which was under the hypothesis that the vehicular flow was homogeneous, they supposed that the desired velocity of $(n-1)$th vehicle during traveling was the maximum velocity $v_{\max}$ of vehicle directly. However, for the heterogeneous traffic, the drivers may reduce their expectations to the ideal velocity for safety, especially when there is a truck in front immediately. In this case, it was unreasonable to hold the maximum velocity as the desired one for drivers all through. Thus, we introduce the appearing probability of truck, as follows,

$$v_{exp}(\Delta x_{n-1}(t)) = \omega V(\Delta x_{n-1}(t)) + (1-\omega)v_{\max}, \tag{6}$$

herein, ω is the appearing probability of truck; $V(\Delta x_{n-1}(t))$ and $v_{\max}$ are the optimal and maximal velocity of $(n-1)$th vehicle, respectively. That is the desired velocity for $(n-1)$th vehicle is the maximum one when the leading vehicle is not truck (the corresponding probability is $1-\omega$), while it reduces to the optimal one when it follows one truck (the corresponding probability is ω). It is worth noting that the maximum velocity of cars and trucks is assumed the same, in this paper. Indeed, this situation often occurs in the speed limit section of highway. However, even through their maximum velocity is the same, the velocity of trucks is usually lower than the one of cars for the safety of roads, which may reduce the expectation of following vehicle on velocity. Thus, it is also reasonable and meaningful to study the traffic flow by considering the appearing probability of truck.

Besides, as [22], in Eq. (2), μ is the honk effect coefficient; p is the parameter representing the intensity of influence of driver's characteristics in the traffic flow; and τ_1 and τ_2 are the reactive time corresponding to aggressive and timid drivers, respectively.

Substitute Eqs. (4)–(6) into Eq. (3), and rewrite Eq. (3) as

$$\begin{aligned}\frac{dv_n(t)}{dt} = {} & \frac{V(\Delta x_n(t)) - v_n(t)}{\tau} \\ & + \frac{p\mu}{\tau_1}[\omega V(\Delta x_{n-1}(t)) \\ & + (1-\omega)v_{\max} - v_n(t+\tau_1)] \\ & + \frac{(1-p)\mu}{\tau_2}[\omega V(\Delta x_{n-1}(t)) \\ & + (1-\omega)v_{\max} - v_n(t-\tau_2)]\end{aligned} \tag{7}$$

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