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An extended car-following model accounting for cooperation driving system with velocity uncertainty

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HIGHLIGHTS

- A new car-following model is studied by considering vehicle's velocity uncertainty.
- The asymptotic and local stability conditions of the new model are derived.
- The vehicle's velocity uncertainty can impact traffic stability importantly.

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ABSTRACT

In this paper, an extended car-following model accounting for cooperation driving system with vehicle's velocity uncertainty is proposed based on the full velocity difference car-following model. To analyze the influence of vehicle's velocity uncertainty on traffic evolution properties, the asymptotic and local stability conditions of the new car-following model are derived respectively by using the stability theory in control theory. Numerical simulation is carried out and it shows that the vehicle's velocity uncertainty can impact vehicle starting process and the stability of traffic flow importantly.

1. Introduction

In recent years, traffic congestion has becoming more and more serious in our modern society and has attracted considerable attention from physicists and governments all over the world. In order to reveal the mechanism of traffic congestion, A variety of traffic models have been constructed [1–30]. Among them, the car-following models aiming at revealing the motion of an individual vehicle to a stimulus from its preceding vehicle are widely studied.

In 1953, Pipes [8] assumed that the vehicle's motion is controlled by the velocity difference of two successive vehicles and proposed a pioneering car-following model. In 1995, Bando et al. [9] constructed a well-known car-following model called the optimal velocity (for short, OV) model. In the OV model, the following vehicle's motion is determined by an optimal velocity. Even the dynamical equation of the OV model is simple, it can reproduce many real traffic phenomena such as the instability of traffic flow, the transition of traffic jamming and so on. After that, the OV model was calibrated with empirical

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data by Helbing and Tilch [10] and extended to the generalized force (for short, GF) model. In 2001, on the basis of the GF model, Jiang et al. [11] proposed the full velocity difference (for short, FVD) model which is more reasonable to describe some properties of real traffic. Since then, lots of extended car-following models with consideration of various real traffic information have been developed. Generally, one category of the considered traffic information is relating to the road and vehicle [12–22], the other is mainly concerning driver's behaviors [23–30].

However, the information introduced in the aforementioned models are determinate and they are unable to reveal the impact of uncertain traffic condition on traffic flow. In real traffic, due to the irregular road surface, bad weather, traffic interruption, equipment failure, and driver's personality, the operation of traffic system is affected by many uncertain traffic factors and the uncertain traffic condition would influence the traffic evolution properties and traffic stability significantly. On the other hand, the preceding vehicle's velocity is an important information for the following vehicle to adjust its movement in the car-following process, so we think that the uncertainty of the vehicle's velocity will impact the traffic evolution properties importantly. But how will the velocity uncertainty affect the traffic flow has not been explored so far to our knowledge.

In order to reveal the effect of uncertain traffic information on traffic flow, a new car-following model with consideration of vehicle's velocity uncertainty is proposed in the following section. The asymptotic and local stability analyses is carried out for the new model in Sections 3 and 4 respectively. Numerical simulation is carried out in Section 5 and a conclusion is given in Section 6.

2. The new model

In 1995, Bando et al. [9] proposed the following OV model based on the assumption that the following driver always seeks a safe and optimal velocity in the car-following process and the dynamical equation for the model is

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

where $x_n(t)$ and $v_n(t)$ are the position and velocity of vehicle n at time t respectively, a is driver's sensitivity, $\Delta x_n(t) = x_{n+1}(t) - x_n(t)$ denotes the headway between the preceding vehicle $n+1$ and the following one n, V refers to the optimal velocity function.

After that, Helbing and tilch [10] made a comparison of the OV model with field data and proved that high acceleration and unrealistic deceleration appear in the OV model. To overcome the deficiency, Jiang et al. [11] proposed the following FVD model:

$$\frac{dv_n(t)}{dt} = a\left[V(\Delta x_n(t)) - v_n(t)\right] + ak\left[v_{n+1}(t) - v_n(t)\right], \tag{2}$$

where $\Delta v_n(t) = v_{n+1}(t) - v_n(t)$ denotes the velocity difference between vehicle $n+1$ and vehicle n, and k represents driver's response coefficient to the velocity difference.

It is proved that the velocity difference information plays an important role in the car-following process. As the OV model can describe many properties of real traffic flow, it was widely extended by considering many real traffic factors like the road condition or driver's behaviors, and it is found out that these information influence the stability of traffic flow significantly. But to the authors' knowledge, these information introduced in the extended car-following models are quite deterministic and cannot be used to uncover the traffic properties caused by uncertain traffic situation. Actually, in the car-following process, whether the road condition, or driver's behaviors, these informations are quite uncertain for the varied traffic environment and driver's individual difference, and the real traffic is running under the influence of many uncertain traffic factors. To study the influence of uncertain traffic information on traffic flow is more practical and important. In order to study the effect of vehicle's velocity uncertainty on traffic evolution behavior in the car-following process, the following car-following model with consideration of uncertain velocity (for short, UVCF) is proposed and the motion equation of the UVCF model is given as follows:

$$\frac{dv_n(t)}{dt} = a\left[V(\Delta x_n(t)) - v_n(t)\right] + ak\left[(1+p)v_{n+1}(t) - v_n(t)\right], \tag{3}$$

where p is the coefficient reflecting the level of uncertainty of the preceding vehicle's velocity and a big absolute value of p indicates a higher level of uncertainty.

The optimal velocity function V adopted here is the same as that in Ref. [9]:

$$V(\Delta x_n(t)) = \frac{v_{\max}}{2}\left[\tanh(\Delta x_n(t) - h_c) + \tanh(h_c)\right]. \tag{4}$$

where $v_{\max} = 2$ m/s is the maximal velocity and $h_c = 4$ m represents the safety distance.

Based on the UVCF model, this paper would use the stability methods in control theory to reveal the influence of vehicle's velocity uncertainty on the asymptotic and local stability conditions in the car-following theory.