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The effects of velocity difference changes with memory on the dynamics characteristics and fuel economy of traffic flow

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HIGHLIGHTS

- The field data at a signalized intersection of Jinan in China were collected for factorial analysis.
- An improved model considering velocity difference changes with memory was put forward.
- The velocity difference changes with memory has significant effects on the following car's motion.
- It can improve the stability of traffic flow and suppress the appearance of traffic jams.

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ABSTRACT

To evaluate the effects of velocity difference changes with memory in the intelligent transportation environment on the dynamics and fuel consumptions of traffic flow, we first investigate the linkage between velocity difference changes with memory and car-following behaviors with the measured data in cities, and then propose an improved cooperative car-following model considering multiple velocity difference changes with memory in the cooperative adaptive cruise control strategy, finally carry out several numerical simulations under the periodic boundary condition and at signalized intersections to explore how velocity difference changes with memory affect car's velocity, velocity fluctuation, acceleration and fuel consumptions in the intelligent transportation environment. The results show that velocity difference changes with memory have obvious effects on car-following behaviors, that the improved cooperative car-following model can describe the phase transition of traffic flow and estimate the evolution of traffic congestion, that the stability and fuel economy of traffic flow simulated by the improved car-following model with velocity difference changes with memory is obviously superior to those without velocity difference changes, and that taking velocity difference changes with memory into account in designing the advanced adaptive cruise control strategy can significantly improve the stability and fuel economy of traffic flow.

1. Introduction

The improvement of traffic efficiency and energy economy are becoming two crucial priorities for the world society. Some studies have been focusing on employing the car-following theory to explore different causes that potentially lead to traffic congestion, while others have been working on developing intelligent transportation systems like the advanced

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Adaptive Cruise Control systems and the Cooperative Adaptive Cruise Control systems to help drivers to form an eco-driving style as much as possible [1].

Car-following theory has been not only of great importance with regard to the advanced adaptive cruise control system, but also regarded as important evaluation tools for intelligent transportation system strategies since the early 1990s [2]. Car-following theory that studies how one driver follows her/his immediately ahead car have been explored for many years on the basis of both theoretical analyses and experimental observations, which includes the early linear models proposed by Chandler et al. [3] and Herman et al. [4], the early nonlinear models presented by Pipes [5], Gazis et al. [6] and Newell [7], the recent remarkable work of Bando et al. [8], Helbing and Tilch [9] as well as Jiang et al. [2], the Intelligent Driver Model [10] and its expansions [11] as well as some others in the research studies [12–34]. Subsequently, with the rapid development of wireless communication technology and widespread applications of intelligent transportation systems, many scholars have focused on cooperative car-following drivers and presented corresponding car-following models. Nagatani [35] extended the optimal velocity car-following model to take into account the car interaction before the next car ahead. Ge et al. [36] proposed an extended car following model by taking into account an arbitrary number of vehicles ahead on a single lane highway based on the optimal velocity model. Lenz et al. [37] put forward the multi-anticipative car-following model. Nakayama et al. [38] presented the backward looking optimal velocity car-following model. Hasebe et al. [39] proposed an extended optimal velocity model applicable to cooperative driving control system. Wilson et al. [40] put forward multiple look-ahead models considering many-neighbor interaction based on the optimal velocity model. Ge et al. [41] presented the two velocity difference model by considering navigation in modern traffic in the light of the optimal velocity model based on the full velocity difference model. Wang et al. [42] presented the multiple velocity difference model by considering multiple preceding cars' velocity differences. Kesting et al. [43] studied connectivity statistics of store-and-forward inter-vehicle communication by using the Intelligent Driver Model in the simulator. Peng and Sun [44] put forward the multiple car-following model by considering the effects of multiple preceding cars' velocity differences and headways into account. Li et al. [45] proposed a new car-following model termed as multiple headway, velocity, and acceleration difference. Yu and Shi [46] put forward an extended car-following model considering multiple preceding cars' accelerations. Ge and Orosz [47] modeled the car-following dynamics of the connected cruise control vehicle by considering a platoon of cars traveling on a single lane. Li et al. [48] extended the Intelligent Driver Model and conducted its numerical simulation under open boundary condition. Yu and Shi [49] proposed an improved car-following model considering multiple vehicular gap changes with memory to study the influences of multiple vehicular gap changes with memory on car's speed, acceleration and the relative distance.

Adaptive Cruise Control systems have been actively developed and introduced into the consumer market by extending earlier Conventional Cruise Control systems [50]. Nowadays, Adaptive Cruise Control systems are primarily installed on premium vehicles besides a few introductions on middle-class vehicles. The effects of Adaptive Cruise Control systems on traffic flow have been deeply and widely studied. Brackstone et al. [51] conducted an extensive review about different car-following models for traffic flow analysis. Treiber et al. [10] used the Intelligent Driver Model to model ACC car-following behavior in traffic flow simulations. Ngoduy [52] carried out analytical studies on the instabilities of heterogeneous intelligent traffic flow simulated by the Intelligent Driver Model. Jerath and Brennan [53] used the General Motors car-following model to analyze traffic flow and found that highway capacity drastically increases when the percentage of ACC-equipped vehicles approaches 100%. Swaroop and Rajagopal [54] studied the intelligent cruise control system and the traffic flow stability. Li and Shrivastava [55] analyzed the traffic flow stability induced by constant time headway policy for adaptive cruise control vehicles. Davis [56] has shown that traffic jams can be suppressed in a mixed traffic of human-driven but the adaptive cruise control cars constituting at least 20% of the traffic flow. Davis [57] analyzed the stability of adaptive cruise control systems taking account of vehicle response time and delay. Integrating the adaptive cruise control system and wireless communication was experimented on a closed highway in the PATH program in 1997 [58]. The SARTRE project has been experimenting with car platoons since 2009 [59]. In 2011, the grand cooperative driving challenge in the Netherlands carried out the idea of feedback from the car immediately ahead and the platoon leader [60–62] and proved the benefits of using information received from cars farther ahead, which is in accordance with those ideas in the above-mentioned research studies [35–49,63,64].

Firstly, it is very necessary to enhance the traffic current, prevent the traffic jam and reduce fuel consumptions for the public demand. We are interested in the enhancement, stabilization and fuel economy of traffic flow with the help of more and accurate information. Secondly, the automobile can receive more and accurate information of the related cars in the intelligent transportation environment and velocity, velocity difference, the relative distance and velocity difference changes are easier to be obtained. Thirdly, velocity difference changes may have an important effect on the stability and fuel consumptions of traffic flow and considering accurate velocity difference changes information from multiple cars ahead may enable the following cars to better respond to the front traffic conditions. It is an open question as to whether or not velocity difference changes from multiple cars ahead affect effectively the dynamics and fuel economy of traffic flow and the related car-following models have been unknown to us until now. Finally, a driver has memory if his speed at a later time depends on his speed at a previous time and the automobile can receive memory information. Zhang [65] developed a continuum macroscopic model arising from a car-following model with driver memory and found that driver memory in car-following behaviors can lead to viscous effects in continuum traffic flow dynamics. Tang et al. [66] proposed an extended OV model with consideration of driver's memory and found that considering driver's memory in modeling car-following behaviors can improve the stability of traffic flow.

Synthetically considering from the above-mentioned perspectives, we first study the linkage between velocity difference changes with memory and car-following behaviors by using the gray correlation analysis method with the measured data