Physica A 492 (2018) 2154–2165

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

A new car-following model for autonomous vehicles flow with mean expected velocity field

Zhu Wen-Xing [a,*], Zhang Li-Dong [a,b]

[a] School of Control Science and Engineering, Shandong University, Jinan, 250061, China
[b] School of Rail Transit, Shandong Jiaotong University, Jinan 250023, China

HIGHLIGHTS

- A new car-following model was proposed with mean expected velocity field.
- Two lemmas and one theorem were proven as criteria for judging stability.
- Stability and fundamental diagram were examined with different parameters.

ARTICLE INFO

Article history:
Received 6 July 2017
Received in revised form 30 September 2017
Available online 5 December 2017

Keywords:
Car-following model
Autonomous vehicle
Mean expected velocity field

ABSTRACT

Due to the development of the modern scientific technology, autonomous vehicles may realize to connect with each other and share the information collected from each vehicle. An improved forward considering car-following model was proposed with mean expected velocity field to describe the autonomous vehicles flow behavior. The new model has three key parameters: adjustable sensitivity, strength factor and mean expected velocity field size. Two lemmas and one theorem were proven as criteria for judging the stability of homogeneous autonomous vehicles flow. Theoretical results show that the greater parameters means larger stability regions. A series of numerical simulations were carried out to check the stability and fundamental diagram of autonomous flow. From the numerical simulation results, the profiles, hysteresis loop and density waves of the autonomous vehicles flow were exhibited. The results show that with increased sensitivity, strength factor or field size the traffic jam was suppressed effectively which are well in accordance with the theoretical results. Moreover, the fundamental diagrams corresponding to three parameters respectively were obtained. It demonstrates that these parameters play almost the same role on traffic flux: *i.e.* before the critical density the bigger parameter is, the greater flux is and after the critical density, the opposite tendency is. In general, the three parameters have a great influence on the stability and jam state of the autonomous vehicles flow.

1. Introduction

Autonomous vehicles has been a hot topic all over the world for many years. Many scientists and scholars devoted to researching in this field. Car-following model firstly proposed by Pipes [1] was widely used to describe the moving behavior of a stream of the moving vehicles. Based on classical car-following model, Ioannou and Chien [2] developed an autonomous

* Corresponding author.
E-mail address: zhuwenxing@sdu.edu.cn (Z. Wen-Xing).

https://doi.org/10.1016/j.physa.2017.11.133
0378-4371/

intelligent cruise control system for automatic vehicle following to examine its effect on traffic flow and to compare the performance with the driver manual vehicle. It exhibits that the performance is superior to the human driving models and it has a faster and better transient response that leads to a much faster and smoother traffic flow. Bando et al. [3] improved Pipes' classical car-following model by incorporating an optimal velocity function to describe the evolution of the traffic congestion. Holland [4] developed a general criterion to determine whether a catastrophic event will occur. The general criterion was in accordance with the stability condition of the car-following models. Nagatani [5] extended the car-following model by considering the next-nearest-neighbor interaction, which stabilize the traffic flow. Sawada [6] analyzed the Newell–Whitham-type car-following model with a differential–difference equation. The immediately preceding vehicle was considered and nonlinear analysis was taken to obtain the propagating kink solution. In addition, the numerical simulation checked the fundamental diagram and headway-reaction time relation. Jiang et al. [7] proposed a full velocity difference model for car-following theory. The model was more effective in describing the traffic flow testified by the analytical and numerical analysis. Based on Bando's model, Lenz et al. [8] considered multi-anticipative interaction and the stability region increases. Furtherly Nakayama et al. [9] proposed an improved car-following model with backward looking effect. Hasebe et al. [10] extended an optimal velocity model, which might apply to the cooperative driving system. Each vehicle is controlled by the information of an arbitrary number of the vehicles that precede and follow. Bose et al. [11] analyzed the traffic flow with mixed manual and semiautomatic vehicles. The traffic flow characteristics was investigated when automatic vehicles operate with the manually driven vehicle together. It was verified that the slinky phenomena does not occur with semiautomatic vehicles when the lead manual vehicle perform the smooth acceleration maneuvers. The automatic vehicles may contribute to smooth the traffic flow by filtering the response of the rapidly accelerating lead vehicle. Zhang et al. [12] proposed a new car-following model to describe the multiphase traffic. The so-called capacity drop and traffic hysteresis loop was reproduced. Ge et al. [13] extended the car-following model by incorporating intelligent transportation system and backward-looking effects. The stability of traffic flow is affected by not only the forward-looking information but also the backward-looking information. Li et al. [14] extended the car-following model based on the full velocity difference model under intelligent transportation system. An arbitrary number of front relative velocities play an important role in stabilizing traffic flow. Jin and Wrecker [15] discussed the reliability of the inter-vehicle communication in a traffic stream. The reliability was measured by the probability of success for information to travel beyond a location. Stochastic models were presented for both the uniform and general streams. Yu et al. [16] analyzed an extended car-following model considering the preceding cars and relative velocity. Kink–antikink solution was obtained from the mKdV equation. Lee and Park [17] investigated a cooperative vehicle control system at intersection when all vehicles are fully automatic. One and more algorithm were proposed to realize the safe operation of the autonomous vehicles approaching to the intersection without any collision. Peng [18] analyzed a new lattice model with the consideration of individual difference of anticipation driving behavior based on car-following theory. Yu et al. [19] improved the optimal velocity model with a consideration of not only the full velocity difference but also the acceleration difference. Ngoduy [20] studied the instability of the traffic flow analytically. An application of intelligent vehicle was a potential solution to eliminate the instability of the traffic flow. The stability threshold of heterogeneous traffic flow was found with a linear analysis method. Tang et al. [21,22] proposed a new extended version car-following model by considering the communication of inter-vehicle and its reliability. Jin et al. [23] proposed a delayed-feedback control of both displacement and velocity differences. Ge et al. [24] applied delayed-feedback control method for lattice hydrodynamic model of traffic flow. The linear stability condition with and without control signal are derived through linear and nonlinear analysis. Redhu et al. [25] investigated delayed-feedback control (DFC) method for lattice hydrodynamic traffic flow model on a unidirectional road. By using the Hurwitz criteria and the condition for transfer function in term of H_∞-norm, the feedback gain was designed to stabilize the traffic flow and suppress the traffic jam. The above literatures applied the delay-feedback control scheme to improve the traffic flow behavior and the methods were proved valid in suppressing the traffic jam. Milanes and Shladover [26] described the models of both adaptive cruise control and cooperative adaptive cruise control systems based on the experimental data. Simple but accurate models were derived from the actual measured response of the vehicles and were applied to simulations of some multi-vehicle car-following scenario. Zhu et al. [27] proposed a compound compensation method to improve car-following system. It is verified that the exterior control method play the same role on car-following behavior as those interior mechanism. Zheng et al. [28] designed a new feedback control strategy considering multiple information before the current vehicle. The control inputs incorporate the speed differences and headway differences. Traffic safety was enhanced and traffic jam was suppressed effectively. Tang et al. [29,30] proposed an extended macro traffic flow model accounting for the driver's bounded rationality and a speed guidance model accounting for the driver's bounded rationality at a signalized intersection. The driver's bounded rationality plays important role in influencing the behavior of traffic flow. Moreover, Tang et al. [31] investigated the impacts of energy consumption and emissions on the trip cost without late arrival at the equilibrium state. Cheng et al. [32–35] investigated KdV–Burgers equation in a new continuum model based on full velocity difference model considering anticipation effect and extended macro-traffic-flow models accounting for multiple optimal velocity functions with different probabilities, the driver's timid and aggressive attributions, and the driver's memory during a period. These investigations are helpful in the development of traffic flow theory.

The above literatures reported the development of the traffic flow model from the classical one to a modern version and promoted the development of traffic flow theory. As well known that autonomous vehicles will be manufactured and move in the real traffic system. While autonomous vehicles move according to an information center has been few discussed theoretically. In this paper, we will discuss the moving behavior of autonomous vehicles with car-following theory.