Physica A 421 (2015) 1–14

Contents lists available at ScienceDirect

Physica A

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

An improved car-following model considering headway changes with memory

Shaowei Yu, Zhongke Shi *

Shaanxi Province Engineering Laboratory of Transportation Safety Supervisory Control Network, Northwestern Polytechnical University, Shaanxi Xi'an 710072, China
College of Automation, Northwestern Polytechnical University, Shaanxi Xi'an 710072, China

HIGHLIGHTS

- The linkage between headway changes with memory and car-following behaviors was explored.
- An improved car-following model considering headway changes with memory was proposed.
- Headway changes with memory have significant effects on car-following behaviors and fuel consumptions.
- Considering headway changes can improve the traffic flow stability and minimize cars' fuel consumptions.

ARTICLE INFO

Article history:
Received 21 May 2014
Received in revised form 12 October 2014
Available online 8 November 2014

Keywords:
Car-following model
Headway changes with memory
The adaptive cruise control strategy
Traffic flow stability
Fuel consumption

ABSTRACT

To describe car-following behaviors in complex situations better, increase roadway traffic mobility and minimize cars' fuel consumptions, the linkage between headway changes with memory and car-following behaviors was explored with the field car-following data by using the gray correlation analysis method, and then an improved car-following model considering headway changes with memory on a single lane was proposed based on the full velocity difference model. Some numerical simulations were carried out by employing the improved car-following model to explore how headway changes with memory affected each car's velocity, acceleration, headway and fuel consumptions. The research results show that headway changes with memory have significant effects on car-following behaviors and fuel consumptions and that considering headway changes with memory in designing the adaptive cruise control strategy can improve the traffic flow stability and minimize cars' fuel consumptions.

1. Literature review

Many mathematical models on car-following behaviors have been developed to describe interacting driver–car units without lane-changing on a single lane, which include the early linear models proposed by Chandler et al. [1] and Herman et al. [2], the early nonlinear models presented by Reuschel [3], Pipes [4], Gazis et al. [5] and Newell [6], the recent remarkable work of Bando et al. [7], Helbing and Tilch [8] and R. Jiang et al. [9] and some others in the literature [10–25]. The optimal velocity model proposed by Bando et al. [7] is one of favorable car-following models because of its distinctive feature in describing many properties of traffic flow such as the instability of traffic flow, the evolution of traffic congestion

* Corresponding author at: Shaanxi Province Engineering Laboratory of Transportation Safety Supervisory Control Network, Northwestern Polytechnical University, Shaanxi Xi'an 710072, China.
E-mail addresses: shizknwpu@126.com (Z. Shi), yushaowei0505@126.com (S. Yu).

http://dx.doi.org/10.1016/j.physa.2014.11.008
0378-4371/

and the formation of stop-and-go waves. Helbing and Tilch [8] proposed a generalized force model by considering the negative velocity difference. R. Jiang et al. [9] put forward a full velocity difference model by considering both the negative and the positive velocity differences. Subsequently, much work has been done based on the optimal velocity model or the full velocity difference model with the consideration of the headway in different combinations.

H.X. Ge et al. [26] put forward an extended car-following model considering an arbitrary number of cars ahead on a single-lane highway with the following differential equation:

$$\frac{\mathrm{d}x_n(t+\tau)}{\mathrm{d}t} = V\left(\Delta x_n(t), \Delta x_{n+1}(t), \ldots, \Delta x_{n+j-1}(t)\right). \tag{1}$$

R. Jiang and Q.S. Wu [27] studied the night driving behaviors in the car-following model under periodic boundary conditions based on the full velocity difference model by redefining the optimal velocity function, which is formulated as follows:

$$V(\Delta x) = \begin{cases} \tanh(\Delta x - x_c) + \tanh(x_c), & \Delta x < x_{c1}, \\ a - \Delta x, & x_{c1} < \Delta x < x_{c2}, \\ b, & \Delta x > x_{c2}. \end{cases} \tag{2}$$

T.Q. Tang et al. [28] proposed a new car-following model with the consideration of the driver's memory, which is formulated as follows:

$$\frac{\mathrm{d}x_n(t+\tau)}{\mathrm{d}t} = \beta_1 V(\Delta x_n(t)) + \beta_2 V(\Delta x_n(t-\tau)). \tag{3}$$

G.H. Peng et al. [29] presented a new optimal velocity difference model for a car-following theory based on the full velocity difference model, which is presented as follows:

$$\frac{\mathrm{d}x_n(t)}{\mathrm{d}t} = \kappa\left[V(\Delta x_n(t)) - v_n(t)\right] + \lambda \Delta v_n(t) + \gamma\left[V(\Delta x_{n+1}(t)) - V(\Delta x_n(t))\right]. \tag{4}$$

T.Q. Tang et al. [30] developed a new car-following model with the consideration of the driver's forecast effect, which takes the following form:

$$\frac{\mathrm{d}x_n(t+\tau)}{\mathrm{d}t} = \beta_1 V(\Delta x_n(t)) + \beta_2 V(\Delta x_n(t+\tau)). \tag{5}$$

S. Jin and D.H. Wang [31] presented a new car-following model by incorporating the effects of front traffic situation, which is formulated as follows:

$$\frac{\mathrm{d}^2 x_n(t)}{\mathrm{d}t^2} = \alpha\left\{(1-\rho)V[\Delta x_n(t)] + \rho V\left[\frac{1}{m}\sum_{j=0}^{m-1}\Delta x_{n+j}(t)\right] - v_n(t)\right\} + \lambda \Delta v_n(t). \tag{6}$$

2. The improved car-following model

The above-mentioned car-following models in Refs. [9,26–31] can describe many properties of the real traffic flow, but they were proposed from the qualitative perspective, that is to say, the influencing factors of car-following behaviors before being taken into account were not explored with the measured data. However, it needs a lot of observations and data mining analysis on the real traffic flow before modeling essentially. In the history of traffic flow model study, there have been many important field research achievements including early speed–density relation models such as the Greenshields model [32] and the Greenberg model [33], and early car-following models developed and calibrated by Pipes [4], Chandler et al. [1] and Gazis et al. [5]. On the other hand, a driver has memory if his speed at a later time depends on his speed at the previous time. H.M. Zhang [34] developed a continuum macroscopic model arising from a car-following model with driver memory and found that the driver's memory in car-following behaviors can lead to viscous effects in continuum traffic flow dynamics. T.Q. Tang et al. [28] put forward an extended car-following model considering the driver's memory and found that driver's memory in car-following behaviors can improve the traffic flow stability.

Under the above perspective, the field car-following behavior data will be collected and extracted to explore the linkage between headway changes with memory and car-following behaviors, and then an improved car-following model considering headway changes with memory will be put forward for further analysis.

2.1. Field observation and data extraction

The measured car-following data used to explore the impacts of headway changes with memory on car-following behaviors all come from our research group's traffic survey. The Jingshi Road/Shanshi East Road intersection of Jinan in China was selected for the field data collection (see Fig. 1). This signalized intersection is located in the downtown area and on the major arterial. It consists of one left-turn lane, three through lanes, one bus transit lane and one right-turn lane along Jingshi Road.

In this paper, it is supposed that car 1 follows car 2. By using the frame differential method, the field car-following behavior data of every 1 s were extracted, which contain each car's velocity, acceleration, velocity difference, the relative distance and headway changes with memory. Partial measured car-following data are listed as shown in Table 1.