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Feedback control scheme for traffic jam and energy consumption based on two-lane traffic flow model

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ABSTRACT

In this paper, a coupled map car-following model is extended to two-lane traffic system. Based on it, the numerical simulations for one stop and series stops situations are performed respectively under the open boundary condition. The evolution of traffic jam and corresponding energy consumption are then explored and compared each other. Additionally, the influences of the lane changing rule and control scheme on traffic jam and energy consumption are investigated separately. The results show that lane changing rule and control scheme are found not only to suppress the traffic jam but also to reduce the energy consumption. The control scheme exhibit better behavior than lane changing rule does in suppressing traffic jam and reducing energy consumption in two-lane traffic system. The outputs of these findings demonstrate the potential of the proposed model to be applicable to evaluate the control schemes for suppressing traffic jam and reducing energy consumption in real traffic condition.

Introduction

In recent years, many traffic problems, such as traffic jam, fuel consumption and accident, have become more and more series in many cities and attracted much attention. In order to deeply understand them, several car-following models have been proposed, i.e., optimal velocity (OV) model, generalized force (GF) model, coupled map (CM) model and so on (Bando et al., 1995; Helbing and Tilch, 1998; Madireddy et al., 2011; Tang et al., 2015; Ge et al., 2015; He et al., 2009; Konishi et al., 1999, 2000; Zhao and Gao, 2005). Among them, the CM model is one of the favorable car-following models for explaining the real traffic flow. It could reveal the dynamical evolvement process of traffic jam successfully and has been applied in many traffic systems (Konishi et al., 1999, 2000; Zhao and Gao, 2005).

The CM car-following model is a corresponding discrete version of the OV model, which plays an important role in suppressing traffic jam. In 1999, Konishi et al. (1999) proposed a CM model and suggested a delayed-feedback control method to suppress the traffic jam. They investigated the noise effects under open boundary bottleneck conditions via computer simulations, showing that the traffic system could run well under proper control scheme. Based on it, Zhao and Gao (2005) presented a simple scheme for congested traffic induced by bottlenecks in the traffic system. Han et al. (2007) takes into account both the forward- and backward looking information and proposed a modified CM model. In 2011, Ge et al. (2011) modified the OV function of the CM model, which depends not only on the headway distance of the current vehicle but also on the preceding ones. In 2013, Zhou et al. (2013) investigated the influence of the feedback control scheme on traffic jam based on CM model. From these studies, the CM model is verified to be an effective method in explaining the

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evolution of traffic jam (Konishi et al., 1999, 2000; Zhao and Gao, 2005; Han et al., 2007; Ge et al., 2011, 2012; Zhou et al., 2013; Ge, 2011; Cheng et al., 2013). It not only represents the traffic phenomena in a simple way, but also takes a short time in computer simulation.

Although these control schemes in CM model can suppress traffic jam effectively, they just use the feedback control scheme to control the velocity of the studied vehicle for suppressing traffic jam in a single lane. The influence of the control scheme on two-lane traffic system is not clear. In fact, when the CM model is extended to multilane, the lane changing rule and control scheme have cross influence on traffic jam. Hence, it is necessary to indentify which one plays more important role in suppressing the traffic jam. Additionally, the energy consumption is a recently concerned problem and we also attempt to discover the influences of the lane changing rule and control scheme on energy consumption in two-lane traffic system.

The paper is organized as follows. In section 'Model', a CM car-following model with control scheme in two-lane traffic system is proposed in details. The numerical simulation and discussion are carried out in section 'Results and discussion'. The summarizes of our findings are drawn in section 'Conclusion'.

Model

CM car-following traffic model

Let us consider a CM car-following traffic model. Fig. 1(a) shows the schematic illustration of the two-lane traffic model. The lead vehicle in every lane is described as (Konishi et al., 1999)

$$x_0(n+1) = v_0 T + x_0(n) \tag{1}$$

where $x_0(n) > 0$ is the position of the leading vehicle at time $t = nT$, $v_0 > 0$ is its velocity, and $T > 0$ is the sampling time. We assume that the lead vehicle is not influenced by others. The following vehicles are given as

$$x_i(n+1) = v_i(n)T + x_i(n) \quad (i = 1 \ldots N) \tag{2}$$

where $x_i(n) > 0$ is the position of the ith vehicle, $v_i(n) > 0$ is the ith vehicle velocity, and N is the number of the following vehicles. The velocity of the following vehicles is governed by

$$v_i(n+1) = \alpha_i \left[V_i^{op}((y_i(n)) - v_i(n)\right]T + v_i(n) \tag{3}$$

where $\alpha_i > 0$ is the sensitivity of the ith vehicle driver. $V_i^{op}(y_i(n))$ is the OV function, which depends only on a headway distance $y_i(n)$ between the $(i-1)$th and ith vehicles:

$$y_i(n) = x_{i-1}(n) - x_i(n) \tag{4}$$

For simplicity, this paper adopts the following piecewise linear functions as the OV function (Ge, 2011; Ge et al., 2012):

$$V_i^{op}(y_i(n)) = \frac{v_i^{\max}}{2}\left[1 + \overline{H}_{sat}\left(2\frac{y_i(n) - \eta_i}{\zeta_i}\right)\right] \tag{5}$$

where $v_i^{\max} > 0$ is the maximum velocity, $\eta_i > 0$ is the safe headway, and $\zeta_i > 0$ is a parameter. The saturation function $\overline{H}_{sat}(\cdot)$ is described as (Ge, 2011; Ge et al., 2012)

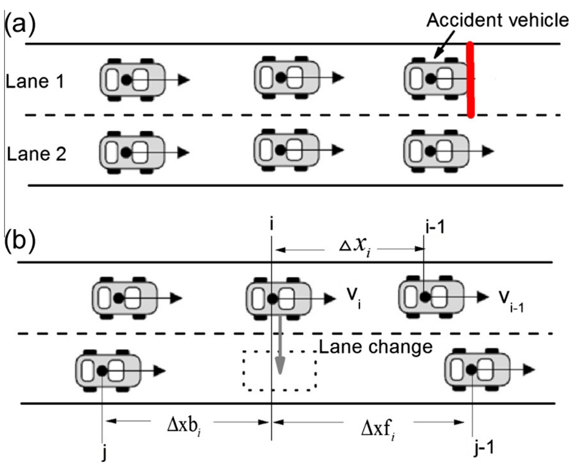

Fig. 1. Schematic illustration of two-lane traffic system.

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