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Feedback control for car following model based on two-lane traffic flow

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HIGHLIGHTS

- Two-lane traffic flow has been discussed based on the control theory.
- The friction interference which is from the neighbor lane has been taken into account.
- The feedback signals have been introduced into the model.
- Simulations are conducted to examine the validity and reasonability of the control method.

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ABSTRACT

In the paper, two-lane traffic flow considering lane changing behaviors has been discussed based on the control theory, and the friction interference which is from the neighbor lane has been taken into account. By using the control method, the stability condition is derived. The feedback signals, which include vehicular information from both lanes, acting on the two-lane traffic system have been introduced into the Full Velocity Difference car-following model. In the end, simulations are conducted to examine the validity and reasonability of the control method. It is proven that lane changing behaviors can aggravate the traffic perturbation. The traffic flow congestion could be suppressed by using the control method and the simulation results are in good agreement with the theoretical analysis.

1. Introduction

Nowadays, traffic jams have attracted the interest of many researchers in the field statistical physics. In order to describe the phenomenon of traffic flow, several traffic flow models have been proposed. In 1961, Newell [1] presented a car-following model described by a differential equation of first order. In 1995, Bando et al. [2] proposed a simple car-following model called the optimal velocity (for short, OV) model. Each vehicle of this model is described by a simple differential equation and different OV functions. In 1999, Lenz et al. [3] proposed a much common model based on the OV model—the role of multi-car model. Hasebe et al. [4] have put forward a promotion model, extending the OV function with k variables and done linear analysis. Furthermore, Jiang et al. [5] proposed a full velocity difference model (for short, FVD) by taking both

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negative and positive velocity difference into account to obtain reasonable delay time of car motion and kinematics wave speed at jam density. Based on the FVD model, Xue et al. [6] developed an extended model considering relative velocity. After that, some investigations were carried out [7–11].

In 2005, Kurata and Nagatani [12] and Nagai et al. [13] studied the dynamics of jam in a two-lane highway. Then, Tang et al. [14,15] proposed two-lane car-following models considering the lateral distance and potential lane changing. Obviously, all of the above have demonstrated that most scholars have investigated different factors of the stability condition for single-lane and multi-lane car-following models. As we know, Konishi et al. [16] have introduced a coupled map car-following traffic flow model, which describes the dynamical behavior of a group of vehicles running in a single lane without overtaking. Then in 2006, Zhao and Gao [17] presented a new control method for congested traffic induced by bottlenecks in the coupled map car-following model. However, little attention has been paid to two-lane traffic flow from the standpoint of control theory [18].

In this paper, the FVD car-following model is used to describe two-lane traffic flow. By using the control method, the stability condition for the FVD car-following model is obtained. The friction interference from the neighbor lane is taken into account, and the feedback control signals are given to suppress the traffic jam for two-lane traffic flow. The simulation is conducted to verify the model.

2. FVD car-following model and its stability analysis

2.1. Model

In order to describe the dynamic behaviors of the groups in two-lane roads, the single-lane FVD model is extended to the double-lane model as follows:

$$\begin{cases} \dfrac{dv_{l,n_l}(t)}{dt} = a_l\{V_l(y_{l,n_l}(t), q_{l,n_l}(t)) - v_{l,n_l}(t)\} + \lambda_l(v_{l,n_l-1}(t) - v_{l,n_l}(t)) \\ \dfrac{dy_{l,n_l}(t)}{dt} = v_{l,n_l-1}(t) - v_{l,n_l}(t) \\ \dfrac{dq_{l,n_l}(t)}{dt} = v^f_{l,n_l}(t) - v_{l,n_l}(t) \end{cases} \tag{1}$$

where $a_l > 0$ is the sensitivity of a driver in lane l and λ_l is a sensitivity coefficient different from a_l. $v_{l,n_l}(t)$ is the velocity of vehicle n_l in lane l. $y_{l,n_l}(t)$ is the headway between two vehicles $(n_l - 1)$ and n_l in the same lane l. $q_{l,n_l}(t)$ is the lateral distance which is between the vehicle n_l in lane l and the closest vehicle in the neighbor lane in front of the considering vehicle. $v^f_{l,n_l}(t)$ is the closest vehicle in the neighbor lane in front of the considering vehicle.

The OV function $V_l(\cdot)$ has been given by [2]

$$V_l(y_{l,n_l}(t), q_{l,n_l}(t)) = V_l(\bar{y}_l(t)) = \tanh(\bar{y}_l(t) - h^d_l) + \tanh(h^d_l) \tag{2}$$

where $\bar{y}_l(t) = \alpha^y_l y_{ln_l}(t) + \beta^q_l q_{l,n_l}(t)$ is a comprehensive distance including both block and friction interferences. α^y_l and β^q_l are the weights of $y_{l,n_l}(t)$ and $q_{l,n_l}(t)$ in lane l, respectively, $\alpha^y_l + \beta^q_l = 1$ and $\alpha^y_l \geq \beta^q_l$, and h^d_l is the comprehensive safe distance in lane l.

Moreover, we define the desired velocity of vehicles as v^*_l in lane l. The desired headway y^*_l is given by $\overline{y_l}^* = V_l^{-1}(v^*_l)$. The desired lateral distance q^*_l is fixed when weight coefficients α^y_l, β^q_l and the desired headway y^*_l are determined. Therefore, the final steady state of the whole vehicular system can be given as follows:

$$(v^*_l, y^*_l, q^*_l)^T. \tag{3}$$

2.2. Lane-changing rules

We introduce the rules to describe lane changing behaviors, which is presented in Ref. [13]. The vehicle n_l will conduct the lane changing behavior if the following conditions are satisfied, which are

$$y_{l,n_l}(t) < 2h^f_l \tag{4}$$

$$y_{l,n_l}(t) < q_{l,n_l}(t) \tag{5}$$

$$b_{l,n_l}(t) > h^b_l \tag{6}$$

where Eqs. (4)–(5) are incentive criteria for the lane-changing decision, and Eq. (6) is the security criterion. $b_{l,n_l}(t)$ is the distance between the vehicle n_l in lane l and the closest vehicle in the neighbor lane behind this vehicle. h^f_l is the safety distance in lane l. h^b_l is the safety distance in the neighbor lane.