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The influence of the non-motor vehicles for the car-following model considering traffic jerk[☆]

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HIGHLIGHTS

- We consider the influence of the non-motor vehicles and traffic jerk for the car-following model.
- We use the control method to analyze the stability of the improved model and obtain some results.
- The feedback control signal is added into the improved model and the stability condition is obtained.
- Numerical simulations are conducted to show the results for the stability of the model with and without control signal.

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ABSTRACT

The influence of the non-motor vehicles and traffic jerk is considered for the car-following model in this paper. The control method is used to analyze the stability of the model. A control signal which is the velocity difference between the target vehicle and the following vehicle is added into the model and the stability condition is obtained. Numerical simulation is used to display the results for the stability of the model with and without control signal.

1. Introduction

In recent years, the traffic congestion has become more and more serious. Many methods have been used to analyze and solve the traffic jam [1–12].

The car-following model which was presented by Newell in 1961 [2] is a model to describe how vehicles follow one another on the road. The linear stability method and the nonlinear analysis method have been used to research the density wave for car-following model and a lot of research results have been obtained [13–15]. Recently, the application of control method in the coupled map car-following model is investigated widespread [16–18], but according to car-following model, the results are few [19,20].

As we know, there are many non-motor vehicles on urban and country roads without isolation belts. Those non-motor vehicles will influence the proceeding and the following vehicles. So, the influence of the non-motor vehicles should be taken

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into account. At the same time, because of the influence of the non-motor vehicles, the vehicles may produce a sudden change in acceleration which is called jerk. Therefore, the influence of jerk also should be included in the car-following model.

In this paper, we present the dynamic model to describe the influence of non-motor vehicles for the car-following model considering traffic jerk. In Section 2, the car-following model with consideration of the influence of the non-motor vehicles and traffic jerk on the road without isolation belts is given. In Section 3, a control signal is added into the model and the control method is used to analyze the stability conditions. In Section 4, numerical simulations are carried out and conclusions are given in Section 5.

2. Improved car-following model and its stability analysis

2.1. Improved car-following model

Based on the car-following model, considering the influence of non-motor vehicles and traffic jerk, the improved car-following model is put forward as follows:

$$\frac{d^2x_n(t)}{dt^2}=a[V^{op}(\Delta x_n(t))+\kappa(p\overline{V}^{op}(\Delta\bar{x}_n(t))+q\overline{V}^{op}(\Delta\tilde{x}_n(t)))-v_n(t)]-\lambda j_n(t) \tag{1}$$

where $x_n(t)$ and $v_n(t)$ are the position and velocity of the nth vehicle; $\Delta x_n(t)=x_{n+1}(t)-x_n(t)$ is the headway distance between the nth and its preceding vehicle; $\Delta\bar{x}_n(t)$ and $\Delta\tilde{x}_n(t)$ are the lateral and longitudinal distances between the nth vehicle and non-motor vehicles; κ is the influence coefficient between vehicle and non-motor vehicle; p and q $(p+q=1)$ are the reaction coefficients of lateral and longitudinal distances; a is the sensitivity of the driver and $V^{op}(\Delta x_n(t))$ is the optimal velocity (OV) function; λ is the jerk parameter; $j_n(t)$ is the derivative of acceleration with respect to the nth vehicle at time t. The OV function $V^{op}(\Delta x_n(t))$ and traffic jerk $j_n(t)$ are given as follows:

$$V^{op}(\Delta x_n(t))=\frac{v_{\max}}{2}[\tanh(\Delta x_n(t)-h_c)+\tanh(h_c)] \tag{2}$$

$$\overline{V}^{op}(\Delta\bar{x}_n(t))=\begin{cases}0, & \Delta\bar{x}_n(t)\geq d_1\\ \dfrac{v_{\max}}{2}[\tanh(\Delta\bar{x}_n(t)-d_1)+\tanh(d_1)], & 0\leq\Delta\bar{x}_n(t)\leq d_1\end{cases} \tag{3}$$

$$\overline{V}^{op}(\Delta\tilde{x}_n(t))=\begin{cases}0, & \Delta\tilde{x}_n(t)\geq d_2\\ \dfrac{v_{\max}}{2}[\tanh(\Delta\tilde{x}_n(t)-d_2)+\tanh(d_2)], & 0\leq\Delta\tilde{x}_n(t)\leq d_2\end{cases} \tag{4}$$

$$j_n(t)=\lim\nolimits_{\tau\to 1}\frac{a_n(t)-a_n(t-\tau)}{\tau}=\frac{dv_n(t)}{dt}-\frac{dv_n(t-1)}{dt} \tag{5}$$

where $v_{\max}$ is the maximum velocity; h_c is the safe headway distance between consecutive vehicles; d_1 and d_2 are the lateral and longitudinal safety distances between vehicles and non-motor vehicles.

The OV function $V^{op}(\Delta x_n(t))$ means that as $\Delta x_n\to\infty$, $V^{op}(\Delta x_n(t))\to v_{\max}$, there is no influence between the target vehicle and its preceding vehicle and the target vehicle runs at maximum speed and as $\Delta x_n\to 0$, $V^{op}(\Delta x_n(t))\to 0$, there is on collision between the target vehicle and its preceding vehicle. The OV function $\bar{V}^{op}(\Delta\bar{x}_n(t))$ means that when the lateral distance between the target vehicle and the lateral non-motor vehicle $\Delta\bar{x}_n(t)\geq d_1$, the lateral non-motor vehicles have no effect on the target vehicle and when $0\leq\Delta\bar{x}_n(t)<d_1$, the lateral non-motor vehicles will affect the motion of the target vehicle and when $\Delta\bar{x}_n(t)\to 0$, $\bar{V}^{op}(\Delta x_n(t))\to 0$ to avoid a collision between the target vehicle and the lateral non-motor one. The OV function $\tilde{V}^{op}(\Delta\tilde{x}_n(t))$ means that when the longitudinal distance between the target vehicle and the longitudinal non-motor vehicle $\Delta\tilde{x}_n(t)\geq d_2$, the longitudinal non-motor vehicles have no effect on the target vehicle and when $0\leq\Delta\tilde{x}_n(t)<d_2$, the longitudinal non-motor vehicles affect the motion of the target vehicle and when $\Delta\tilde{x}_n(t)\to 0$, $\tilde{V}^{op}(\Delta x_n(t))\to 0$ to avoid a collision between the target vehicle and the longitudinal non-motor one.

2.2. Stability analysis

The dynamical equation is given as follows:

$$\begin{cases}\dfrac{dv_n(t)}{dt}=a[V^{op}(y_n(t))+\kappa(p\overline{V}^{op}(\bar{y}_n(t))+q\overline{V}^{op}(\tilde{y}_n(t)))-v_n(t)]-\lambda j_n(t)\\ \dfrac{dy_n(t)}{dt}=v_{n+1}(t)-v_n(t)\\ j_n(t)=\dfrac{dv_n(t)}{dt}-\dfrac{dv_n(t-1)}{dt}\end{cases} \tag{6}$$

where $y_n(t)=\Delta x_n(t)$, $\bar{y}_n(t)=\Delta\bar{x}_n(t)$, $\tilde{y}_n(t)=\Delta\tilde{x}_n(t)$.