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An improved car-following model considering the influence of space gap to the response

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HIGHLIGHTS

- Point out that the response of drivers is influenced by the space gap.
- Capture the asymmetry between deceleration and acceleration.
- Explain why the asymmetry exists in the car-following behavior.
- Improve the FVD model and calibrate parameters.

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ABSTRACT

The Full velocity difference (FVD) model considers the velocity difference, but it cannot capture the acceleration/deceleration asymmetric characteristic. This paper points out that the response of drivers to the velocity difference is influenced by the space gap (which is the space headway minus the vehicle length), and improves the FVD model based on this view. The improved model indicates that the reason why the asymmetric characteristic exists in the car-following behavior is that the response of drivers to the velocity difference is in negative correlation to the space gap. Neutral stability curves of the improved model are asymmetry. And the stability analysis indicates that the visual angle model (one of the improved FVD models) is a special case of the improved model proposed in this paper. Results of numerical computer simulations confirm that the improved model can capture the asymmetric characteristic, and further indicate that the asymmetric characteristic is caused by the influence of space gap to the drivers' response. And finally, parameters of the improved car-following model are calibrated by real traffic flow data.

1. Introduction

Car-following models describe interactions of vehicles on the traffic stream [1]. It has decades of development since that the earliest car-following model was introduced by Pipes and Reusche [2,3]. The Gazis–Herman–Rothery (GHR) model probably is the most studied model, which is based on the framework of "*response* = *sensitivity* × *stimulus*". The GHR model assumes that the acceleration of the subject vehicle is influenced by the velocity difference from the preceding vehicle, space headway and the current velocity. The non-linear GHR model is defined as [4]:

$$a_n(t) = \alpha \frac{v_n(t)^{\beta}}{\Delta x_n(t-\tau_n)^{\gamma}} \Delta v_n(t-\tau_n) \quad (1)$$

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where, $a_n(t)$ is the acceleration rate of vehicle n at time t; $v_n(t)$ is the velocity of vehicle n at time t; $\Delta v_n(t-\tau_n)$ is the velocity difference between the subject vehicle n and the preceding vehicle $n-1$; $\Delta x_n(t-\tau_n)$ is the space headway between the subject vehicle n and the preceding vehicle $n-1$; α, β and γ are parameters; and τ_n denotes as the reaction time.

The optimal velocity (OV) model is another most universal car-following model which proposed by Bando [5] firstly. The OV model assumes that each vehicle has an optimal velocity and which depends on the space headway. The acceleration of the subject vehicle depends on the difference between the optimal velocity and the current velocity. The OV model can be defined as:

$$a_n(t) = \kappa\left[V(\Delta x_n(t)) - v_n(t)\right] \tag{2}$$

where, κ is the parameter; and the $V(\cdot)$ is the optimal velocity function which depends on the space headway $\Delta x_n(t)$. Helbing and Tilch [6]defined the optimal velocity function as:

$$V(\Delta x_n(t)) = V_1 + V_2 \tanh\left(C_1\left(\Delta x_n(t) - l_c\right) - C_2\right) \tag{3}$$

where parameters are calibrated as: $V_1 = 6.75$ m/s, $V_2 = 7.91$ m/s, $C_1 = 0.13\ \text{m}^{-1}$ and $C_2 = 1.57$, the $l_c = 5$ m is the length of vehicle.

The OV model can describe the stop-and-go traffic phenomenon, but it will produce unrealistic high acceleration and deceleration. Helbing and Tilch [6] introduce the Generalized Force (GF) model to address this issue, which add the velocity difference into OV model when the velocity of subject vehicle is higher than that of the preceding vehicle. And the GF model is given as:

$$a_n(t) = \kappa\left[V(\Delta x_n(t)) - v_n(t)\right] + \lambda H(-\Delta v_n(t))\Delta v_n(t) \tag{4}$$

where, $H(\cdot)$ is the Heaviside function; and λ is the sensitivity parameter. Jiang et al. [7] find that both positive and negative velocity differences influence the car-following behavior. And they extended the GF model to Full Velocity Difference (FVD) model considering both positive and negative velocity differences. The FVD model can be written as following:

$$a_n(t) = \kappa\left[V(\Delta x_n(t)) - v_n(t)\right] + \lambda\Delta v_n(t) \tag{5}$$

The FVD model is indifferent to acceleration and deceleration for that it uses a single parameter λ. But it is generally known that drivers behave differently during acceleration and deceleration. Thus, Gong et al. [8] introduce the Asymmetric Full Velocity Difference (AFVD) model which uses two parameters λ_1 and λ_2 to capture the acceleration/deceleration asymmetric characteristic. The AFVD model is written as:

$$a_n(t) = \kappa\left[V(\Delta x_n(t)) - v_n(t)\right] + \lambda_1 H(-\Delta v_n(t))\Delta v_n(t) + \lambda_2 H(\Delta v_n(t))\Delta v_n(t) \tag{6}$$

where $\lambda_1 > \lambda_1$ indicates that most drivers have greater deceleration than acceleration.

The FVD model considers the space headway, the velocity difference and the current velocity of subject vehicle. But the car-following behavior not only depends on these three factors, but also depends on other factors. Lenz et al. [9] consider multi-vehicle interactions in the OV model. Dihua Sun et al. [10] improved the FVD model by considering the average velocity of preceding vehicles group. Shaowei Yu et al. [11] extended the FVD model by considering the immediately ahead car's velocity difference. Shaowei Yu et al. [12] taken the factor of velocity fluctuation of preceding vehicle into the FVD model. Hua Kuang et al. [13] extended the FVD model by considering the average space headway of preceding vehicles group. Lantian Guo et al. [14] improved the FVD model by considering multiple preceding vehicles' velocity fluctuation feedback. Considering multiple preceding vehicles can increase the stability of the car-following model. Shaowei Yu et al. [15] found that considering relative velocity difference with memory in modeling CF behaviors and designing the advanced adaptive cruise control strategy could improve the stability and fuel economy of traffic flow. Shaowei Yu et al. [16] found that vehicular gap fluctuation had significant effects on the dynamic characteristics, fuel consumptions and exhaust emissions of traffic flow. Qi Xin et al. [17] put forward two new car-following models by taking constant time headway policy and variable time headway policy into optimal velocity function into the FVD model, separately.

The OV model, the FVD model and their extended models do not consider human factors. Sheng Jin et al. [18] modified the FVD model by replacing the space headway and velocity difference with the drivers' visual angle, and proposed the visual angle car-following model. The visual angle model is defined as:

$$a_n(t) = \kappa\left[V(\theta_n(t)) - v_n(t)\right] - \lambda\frac{d}{dt}\theta_n(t) \tag{7}$$

$$V(\theta_n(t)) = V_1 + V_2 \tanh\left(C_1\frac{w_{n-1}}{\theta_n(t)} - C_2\right) \tag{8}$$

where, w_{n-1} is the width of vehicle $n-1$; $\theta_n(t)$ is the visual angle of the driver in vehicle n at time t, which can be calculated approximately by following:

$$\theta_n(t) = \frac{w_{n-1}}{\Delta x_n(t) - l_{n-1}} \tag{9}$$

where, l_{n-1} is the length of vehicle $n-1$. The visual angle model does not use parameters λ_1 and λ_2, but it can capture the acceleration/deceleration asymmetric characteristic.