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An extended car-following model based on visual angle and backward looking effect

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ABSTRACT

By introducing driver's visual angle and backward looking effect into the full velocity difference model (FVDM), this paper proposes an extended car-following model. Through linear stability analysis and simulation analysis, the paper gets following conclusions: First of all, the neutral stability line of the extended model is asymmetry. Secondly, the stability of traffic flow is influenced by the width of the leading vehicle, the length of the following-car's head and the vertical distance from driver's eyes to vehicle's head. Thirdly, driver pay close attention to the rear vehicle can strengthen traffic flow, and driver's sensitivity of visual angle will influence the stability of traffic flow. Finally, the extended model can explain some complex nature of traffic phenomena and makes the car-following model more realistic.

1. Introduction

In recent years, the problems of traffic jam are becoming more and more serious. Traffic jam is described as a physical phenomena [1–8], and in order to reveal the essence of this phenomena, many traffic models have been put forward such as car-following model [9], cellular automaton (CA) model [10] and manipulator game model [11].

Through car-following models, many complex physical phenomena in traffic flow can be explained. According to earlier researches that each vehicle had an optimal velocity, Bando [12] proposed the optimal velocity model (OVM). The model can describe the process of traffic congestion successfully, but comparing with the measured data, unrealistic high acceleration and high deceleration often appear in this model; To solve this problem, Heling and Tilch [13] proposed a generation force model (GFM). In this model, the velocity difference is taken into account, and it effectively improves the problem in OVM; However, the two models still can't solve a problem: when the speed of leading vehicle is larger than the following vehicle, the following vehicle will not slow down even if the distance between two vehicles is less than the safe distance, and it is very dangerous. To overcome this problem, many works pay attention to the improvement of the OVM and GFM in order to make the model more realistic and efficient. Among these works, many factors have been considered, like velocity difference, safety distance, gravitational force and so on. In this process, Komada [14] thought about the influence of gravity on traffic flow, Tang [15] researched the influence of different road conditions on traffic flow, Ngoduy [16] thought about the effect of driver's behavior on the formation and dissipation of traffic flow instabilities, Zhou [17] used nonlinear analysis to research the optimal velocity difference model with reaction-time delay. On the basis of previous achievements, Jiang

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et al. [18] proposed a full velocity difference model (FVDM). The experimental results of this model indicated that FVDM can describe the phase transition of traffic flow and predict changes of traffic condition. Based on the FVDM, scholars had conducted a number of researches: Yuan and Hua [19] got modified Koteweg-deVries (mKdV) equation by making use of nonlinear analysis, and they used this equation to describe the phenomena of traffic jam. Zhao [20] proposed the full velocity and acceleration difference model (FVADM), and the acceleration difference was considered into the FVDM which made the stable region of traffic flow became larger.

To sum up, most of the researches pay much attention to the vehicles' factors, but the factor of driver's visual angle is not taken into account. Some scholars also put forward some improvements: Sun [21] considered the influence of rear car's message, and proposed an extended car-following model. Jin et al. [22] also proposed a car-following model which took the visual angle as a reference quantity, and they found that the width of leading car had a great influence on the stability of traffic flow; Li et al. [23] estimated the safety level of the vehicle by capturing the change rate of driver's visual angle; Based on the previous studies, considering the visual angle of driver and the backward visual effect, this paper proposes an extended car-following model. Though linear analysis, some suggestions are proposed in order to keep the traffic flow stability and avoid traffic jams.

2. Model

In 2001, Jiang et al. proposed the FVDM on the basis of previous study, the model can be used to explain the traffic flow problems such as traffic congestion realistically, so it was widely used.

The model control equation is:

$$\frac{d^2x_n(t)}{dt^2} = a\left[V(\Delta x_n(t)) - \frac{dx_n(t)}{dt}\right] + \lambda\Delta v_n(t) \tag{1}$$

where $\Delta x_n(t) = x_{n+1}(t) - x_n(t)$, which denotes the displacement difference between the $(n+1)$th and the nth vehicles; $\Delta v_n(t) = v_{n+1}(t) - v_n(t)$, which denotes the velocity difference between the $(n+1)$th and the nth vehicles; a denotes driver's distance sensitivity coefficient. In fact, it is impossible for vehicle to regress in the process of advancing, so this paper takes $a > 0$; λ is the sensitivity coefficient of driver to speed difference; $V(\Delta x_n(t))$ is optimal velocity function.

In 2012, Sun [21] proposed an extended model which considered driver's backward looking as the major factor in traffic flow.

The model control equation is:

$$\frac{d^2x_n(t)}{dt^2} = a[(1-p)V_F(\Delta x_n(t)) + p(V_B(\Delta x_{n-1}(t)) - v_n(t)] + \lambda\Delta v_n(t) \tag{2}$$

where p denotes the probability of driver to pay attention to the information of rear vehicle; $V_F(\Delta x_n(t))$ and $V_B(\Delta x_{n-1}(t))$ are the optimal velocity function of the $(n+1)$th and nth vehicle. When $p = 1$, the model only considers the effects of previous vehicle information, so it becomes the FVDM.

Driver's visual angle is also an important factor which influences the stability of traffic flow [24]. The driver's visual angle is influenced by many factors, such as the distance of vehicles, the length of vehicle's head, the height of driver's eyes. Fig. 1 is a schematic diagram, which shows the connection between driver's visual angle and the above factors.

In Fig. 1, h is the vertical height between driver's eyes and the head of nth vehicle, l_n is the length of nth vehicle, w is the width of $(n+1)$th vehicle, L_{n+1} is the length of $(n+1)$th vehicle, θ is driver's visual angle.

It is worth noting that the Fig. 1 may be not practical when the distance between the following and leading vehicle is large, because in this case, the driver may not be able to see the leading vehicle. However, in general, the driver will subconsciously speed up the car when he does not see any vehicle ahead, so the impact of this process on traffic flow is relatively small. What's more, if the driver can't see any vehicle ahead, it means the traffic is pretty good at this moment. So this paper will not consider the process which drivers can't see any vehicle ahead.

In Fig. 1, the visual angle $\theta_n$of driver can be deduced as:

$$\tan\frac{\theta_n(t)}{2} = \frac{wl_n}{2\sqrt{(l_n^2 + h^2)}(\Delta x_n(t) - L_{n+1} + l_n)} \tag{3}$$

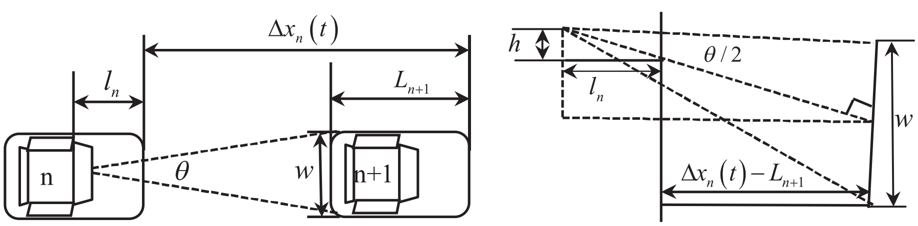

Fig. 1. Schematic diagram of driver's visual angle.