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Optimization and Simulation of the Minimum Safety Distance of Car Following Model

Yin Xiaoqing, Liu Peiji, Zou Xiaodong and Liu Xiang
State Key Lab of Mechanical Transmission, Chongqing University, 40044, Chongqing, China

Abstract: To solve the problem that the common safety distance models cannot simultaneously take into account of warning distance and traffic efficiency, an optimized model of minimum safety distance of car following was established, which considered 12 situations of car following. The new model which had the additional analysis of the leading vehicle in uniform deceleration condition and canceled the ideal assumptions that the velocity of vehicle brake in driver response decision stage and operation stages is uniform, included 7 dangerous situations when the leading vehicle in uniform speed, uniform deceleration and emergency braking driving states. The Matlab simulation indicated that the optimized model got a smaller warning distance in common situations and got a longer warning distance in extremely dangerous situations. The optimized model, not only ensured traffic safety and improved the traffic efficiency.

Key words: Warning distance, safety distance model, traffic efficiency, automotive collision avoidance

INTRODUCTION

At present, automobile traffic safety is the major topics to be solved in the intelligent transportation system. With the development of active safety warning related technologies, automotive safety warning research makes great progress (Zhang and Zheng, 2010). Active safety warning system is based on the motion relationship of the workshop to judge how dangerous and take the corresponding warning measure (Kim *et al*., 2007; Dong *et al*., 2011). Among them, the determination of safety distance model is the key to warning system for research. Based on the braking process of kinematics analysis of safety (Tang, 2005) to ensure the vehicle driving safety, did not consider the factor of road traffic efficiency and the determined safety distance is longer, warning too frequently. The safety distance model based on the time interval (Hou *et al*., 2005) to ensure that the road traffic efficiency, has a smaller relative speed between vehicles to modeling, does not take into account a greater relative speed between vehicles, it cannot ensure the driving safety in the case of dangerous situation (Tian *et al*., 2009; Wang *et al*., 2012). In order to overcome the defects of the model, the thesis (Luo and Xu, 2010) based on the braking process is put forward which is based on the minimum safety distance of car following model, considers the several motion state of vehicles and vehicle acceleration gradual process, solves the problem that before adding velocity mutation model, Combines the efficiency of traffic safety and road traffic. But it only considers the leading vehicle stationary and uniform velocity states, does not reflect the actual movement of all cases. Therefore, on the basis of this study, the thesis added the leading vehicle in deceleration state to the safety distance analysis; In particular, the following car reaction stages of decision making and operating brake vehicles at the uniform state of ideal assumptions was cancelled.

BRAKING DISANCE ANALYSIS

In the safety distance model based on interval, interval is the difference between the times of adjacent vehicles respectively go through the same specified point, when vehicles are driven with a certain relative speed, the front vehicle and rear vehicle will have a certain linear relationship with the vehicle speed. The safety distance model on the basis of the relationship:

$$d^* = v_0 t_d - S_0 \tag{1}$$

where, d^* is the early-warning distance; t_d is the brake lag time, usually $t_d = (1.2\sim2.0)$ s; v_0 is the speed of rear vehicle before braking; S_0 is the safety distance between vehicles after stopped, usually $S_0 = 2\sim5$ m.

In the safety distance model based on kinematics analysis of braking process, the car's braking process is divided into four stages: the reaction of driver stage t_1; the braking system operator responding and brake eliminating clearance stage t_2; the braking deceleration of

Corresponding Author: Yin Xiaoqing, State Key Lab of Mechanical Transmission, Chongqing University, 40044, Chongqing, China

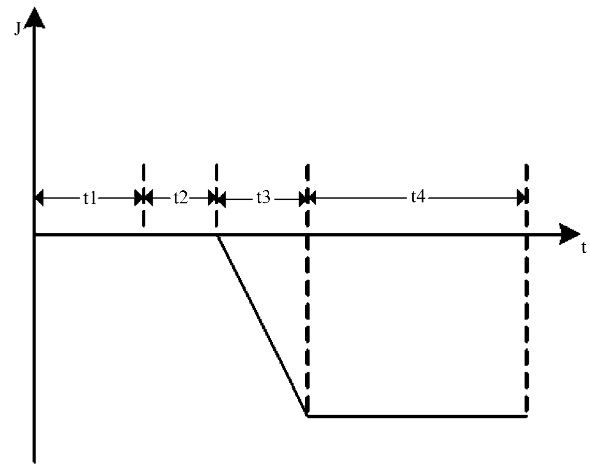

Fig. 1: Acceleration curve in brake process when the vehicle is uniform speed

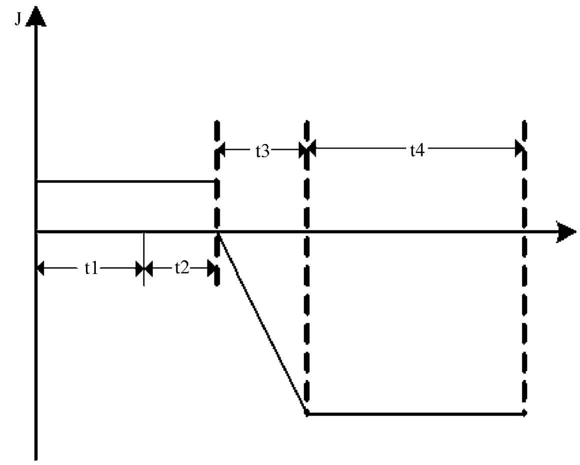

Fig. 2: Acceleration curve in brake process of automobiles when the vehicle uniformly accelerated

growth stage t_3; the brake continuous stage t_4. Assuming that vehicle is in uniform during the driver reaction time t_1 and brake coordination time t_2.The vehicle acceleration of retarded or braking process changes over time as illustrated in Fig. 1.

Braking distance formula (Luo and Xu, 2010):

$$S_i = V_{i0}\left(t_1 + t_2 + \frac{t_s}{2}\right) + \frac{V_{i0}^2}{2J_{imax}} - \frac{1}{24}J_{imax}t_3^2 \tag{2}$$

where, V_{i0} is the initial velocity of vehicle i; J_i is initial acceleration of vehicle i; J_{imax} is the biggest braking acceleration of vehicle i.

In fact, at the beginning of braking, vehicle should be uniformly retarded motion, constant speed or in a uniformly accelerated motion, so the acceleration of uniformly retarded motion and uniformly accelerated motion in braking process changes over time as illustrated in Fig. 2-3.

Compared to the Eq. 2, 3 has considered the uniformly accelerated (retarded) motion and constant speed motion. The derivation process is omitted:

$$S_i = \begin{cases} \dfrac{V_{i2}^2 - V_{i0}^2}{2J_i} + V_{i2}\dfrac{t_s}{2} + \dfrac{V_{i2}^2}{2J_{imax}} - \dfrac{1}{24}J_{imax}t_3^2 & J_i \neq 0 \\ V_{i0}\left(t_1 + t_2 + \dfrac{t_s}{2}\right) + \dfrac{V_{i0}^2}{2J_{imax}} - \dfrac{1}{24}J_{imax}t_3^2 & J_i \end{cases} \tag{3}$$

Where:

$$V_{i2} = V_{i0} + J_i(t_1 + t_2)$$

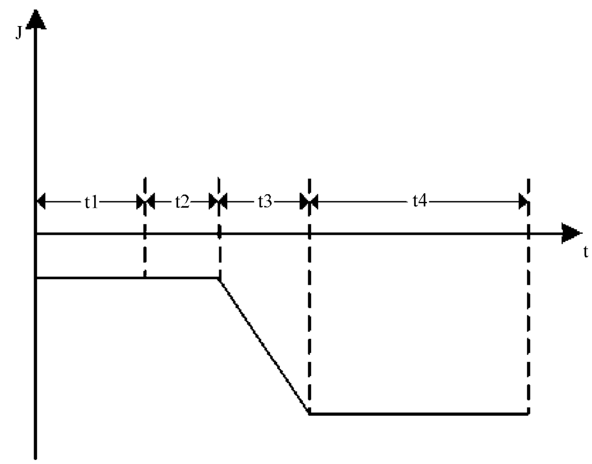

Fig. 3: Acceleration curve in brake process of automobiles when the vehicle uniformly retarded

SECURITY RISK ANALYSIS OF VEHICLE

As illustrated in Fig. 4, adjacent vehicles head the same direction, the front vehicle is "a", the rear car "b". where, d is the real-time vehicle distance; V_{a0} is the relative speed. $\Delta V = V_{b0} - V_{a0}$.When $\Delta V \leq 0$, d increases constantly, if d>d*,it is safe. When $\Delta V > 0$, d decreases constantly, if d<d*,it exists safety hazards. Tab.1 presents the safety relationship.

Table 1 shows that, during the process of two cars following, if the front vehicle is acceleration, the possibility of collision is low even none. If the front vehicle is uniform motion, deceleration or emergency

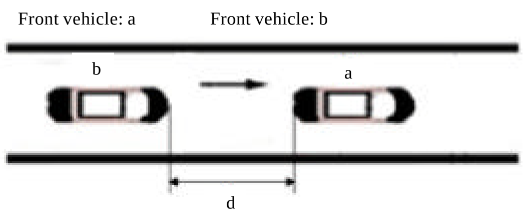

Fig. 4: Vehicle relationship simulation map

Table 1: Vehicle safety hazards analysis

Front vehicle (a)	Rear vehicle (b)	Risk level
Acceleration	Deceleration	Safe
	Uniform motion	Safe
	Acceleration	Relatively safe
Uniform speed	Deceleration	Safe
	Uniform speed	Relatively safe
	Acceleration	Dangerous
Deceleration	Deceleration	Dangerous
	Uniform speed	Dangerous
	Acceleration	Especially dangerous
Emergency braking	Deceleration	Especially dangerous
	Uniform speed	
	Acceleration	

braking, it has serious safety hazards. Especially, it is the most dangerous when the front vehicle is emergency braking or deceleration while the rear vehicle is acceleration.

SAFETY DISTANCE MODEL

Based on the kinematics analysis of the braking process, the safety distance model is (Zheng, 2002):

$$d^* = S_b - S_a + S_0 \tag{4}$$

And S_b is the total braking distance of vehicle-b. S_a is the braking distance of vehicle-a among t_3 and t_4.

S_b is based on the Eq. 3. S_a Is just considered in the braking deceleration of growth stage t_3 and the brake continuous stage t_4.Then:

$$S_a = \frac{t_3}{2} V_{a0} + \frac{V_{a0}^2}{2J_{amax}} - \frac{1}{24} J_{amax} t_3^2 \tag{5}$$

According to Table 1, combined 7 dangerous situations when the front vehicle in uniform speed, uniform deceleration and emergency braking driving states, the specific safety distance model can get in following analysis.

Front vehicle in uniform speed and the rear in uniform acceleration driving states while the rear vehicle gets a bigger velocity than the front: In this situation, the rear vehicle has to slow down to less than or equal to the leading vehicle speed to beyond danger. Hence, among (t_1+t_2), the rear vehicle accelerated continuously from the initial speed of V_{b0} to V_{b1} with the uniform acceleration J_{b0}. Hence, $V_{b1} = V_b + J_{b0}(t_1+t_2)$. In this period, the distance of the rear vehicle running:

$$S_{b1} = \frac{\left(V_{b1}^2 - V_{b0}^2\right)}{2J_{b0}}$$

In the period of t_3, the acceleration of the rear vehicle will be in the mutation and growth state. Due to the smaller values of the state, just omit the effects from the period of t_3 brings. Hence, in the period of t_3, the rear vehicle decelerated continuously from V_{b1} to V_{a0} with the uniform deceleration J_{b1} and the needed time is V_{b1}-V_{a0}/J_{b1}, the distance of the rear vehicle running:

$$S_{b2} = \frac{\left(V_{b1}^2 - V_{a0}^2\right)}{2J_{b1}}$$

In the period of:

$$\left(t_1 + t_2 + \frac{V_{b1} - V_{a0}}{J_{b1}}\right)$$

the distance of the front vehicle running:

$$S_a = V_{a0}\left(t_1 + t_2 + \frac{V_{b1} - V_{a0}}{J_{b1}}\right)$$

So, the safety distance model in this situation can be got:

$$\begin{aligned} d^* &= S_{b1} + S_{b2} - S_a + S_0 \\ &= \frac{\left(V_{b1}^2 - V_{b0}^2\right)}{2J_{b0}} + \frac{\left(V_{b1}^2 - V_{a0}^2\right)}{2J_{b1}} - V_{a0}\left(t_1 + t_2 + \frac{V_{b1} - V_{a0}}{J_{b1}}\right) + S_0 \end{aligned} \tag{6}$$

Front vehicle in uniform deceleration driving state while the rear vehicle gets a bigger velocity than the ahead: In this situation, the rear vehicle also has to slow down to less than or equal to the leading vehicle speed to beyond danger. Taking into account the vehicle deceleration state mutation probability, the behavior of escape from danger situation is simplified as the car braking process. The total braking distance of vehicle-b is the same as the Eq. 3. In the period of ($t_1+t_2+t_3+t_4$), the front vehicle decelerated continuously from V_{a0} to V_{a1} with the uniform deceleration J_{a0} and $Va1 = V_{a0} - J_{a0}(t_1+t_2+t_3+t_4)$, the distance of the front vehicle running:

$$S_a = \frac{V_{b0}^2 - V_{a1}^2}{2J_a}$$

Hence, the safety distance model in this situation can be got:

$$d^* = S_b - S_a + S_0 = S_b - \frac{V_{b0}^2 - V_{a1}^2}{2J_a} + S_0 \qquad (7)$$

Front vehicle emergency braking: In this situation, the distance of the later vehicle running can get from the Eq. 3 and the distance of the leading vehicle running can get from the Eq. 5. Hence, the safety distance model in this situation is the same as the Eq. 4.

SIMULATION AND ANALYSIS

By using MATLAB simulation platform, the 7 kinds of dangerous driving conditions of safety distance optimization model (the equation 3, 5, 6, 7) had been simulated. Under the same condition, this optimization model had been compared with the common model: One based on interval (Eq. 1), another based on kinematics analysis of braking process, S_0 = 2 m, t_1 = 0.8 sec, t_2 = 0.2 sec, t_3 = 0.25 sec (Hakkanen and Summala, 2001).

According to Fig. 5, under the dangerous situation of the front vehicle in uniform speed state and the rear vehicle in acceleration state, the actually warming distance is much smaller than the two common models'.

According to Fig. 6a-c, under the dangerous situation of the front vehicle in uniform speed, uniform deceleration and uniform acceleration driving states, the actually warming distance is also much smaller than the two common models'.

According to Fig.7a-b, under the dangerous situation of the front vehicle in emergency braking state, if the rear vehicle accelerates uniformly, the actually warming distance is much longer than the two common models'. If

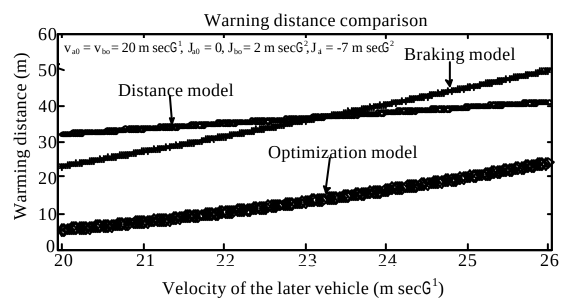

Fig. 5: Vehicle-a in uniform speed state

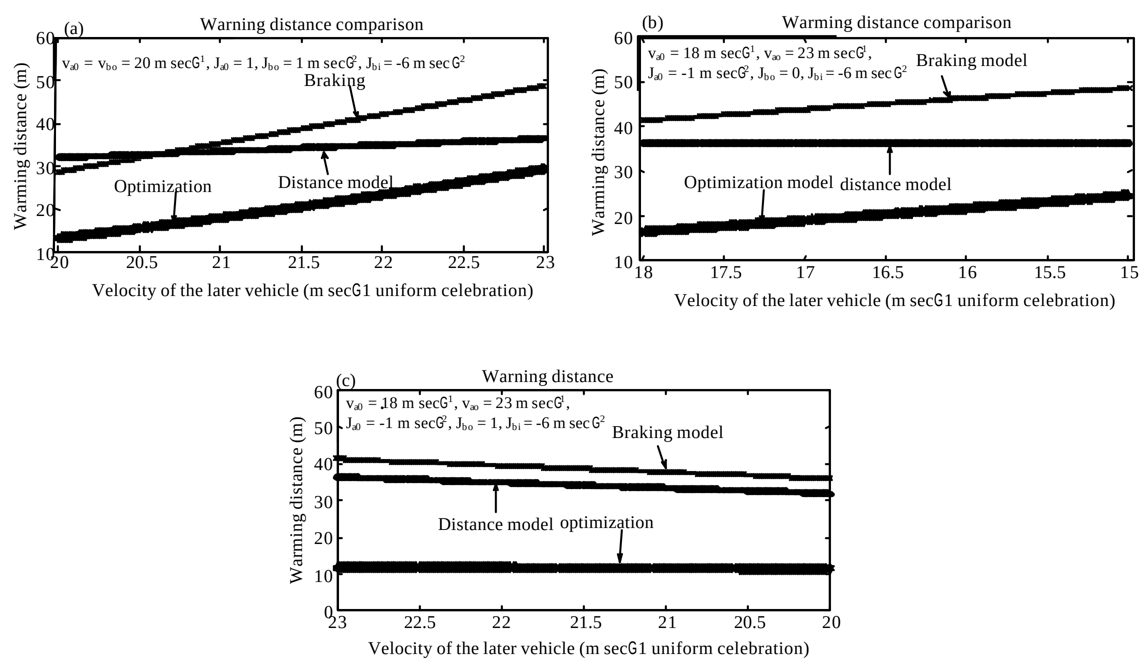

Fig. 6(a-c): (a) Vehicle-a decelerates uniformly and vehicle-b accelerates uniformly, (b) Vehicle-a decelerates uniformly and vehicle-b uniform speed and (c) Vehicle-a and vehicle-b decelerates uniformly

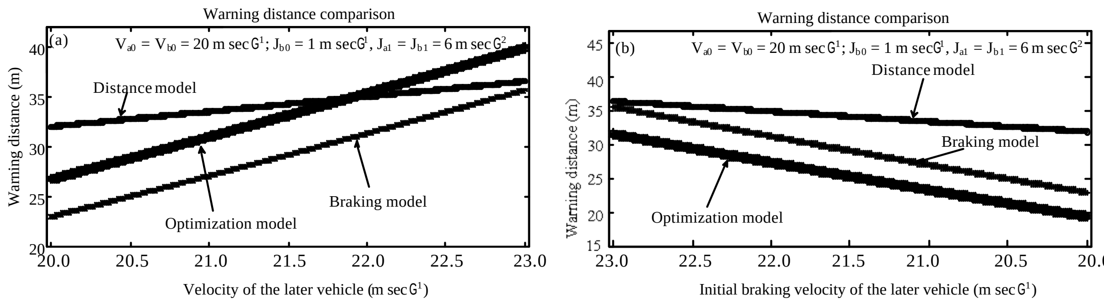

Fig. 7(a-b): (a) Vehicle-a emergency braking and vehicle-b accelerates uniformly and (b) Vehicle-a emergency braking and vehicle-b decelerates uniformly

the later vehicle decelerates uniformly, the actually warming distance is much smaller than the two common models'.

CONCLUSION

By comparing the simulation optimization model with the other two models of early warning distance, in the seven kinds of dangerous driving conditions, six circumstances get the smaller distance in the optimization model. Only if the vehicle ahead when the car is under accelerated after the emergency brake, the optimization model of early warning distance is bigger. Therefore, the optimization model of early warning distance in six cases of schedule is small and has high efficiency transportation; and we also pay specially attention to the vehicle brake the car accelerated high dangerous situation,so driving is safer.

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