Analysis of Rear-End Collision Accident of Urban Traffic Based on Safety Pre-Warning Algorithm

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Analysis of rear-end collision accident of urban traffic based on safety pre-warning algorithm

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Abstract:

With the increase of per capita car ownership, traffic accidents frequently occur, in which rear-end collision accounts for 30% to 40% of the total accidents; thus, rear-end collision has become the primary factor of traffic environment deterioration. Therefore, how to improve road traffic safety and reduce the probability of rear-end collision has become a major social concern. In this study, based on the safety pre-warning algorithm, a vehicle collision model was built, and a vehicle anti-collision warning system was established. The calculation was performed based on the sample data to obtain the prediction value of vehicle collision time under different driving speeds, so as to provide drivers with effective response time and reduce the casualties and property losses caused by a vehicle collision. The experimental results showed that the accuracy rate of the pre-warning reached 80% when the speed was regarded as a variable, and the simulation results showed that the early pre-warning or delayed pre-warning rate was very low, and the timeliness rate reached 89%, which enables drivers to react quickly in the appropriate time and effectively reduces the risk of vehicle rear-end collision.

Keywords: early warning algorithm; rear-end collision; safe collision time

1. Introduction

With the increase of automobile production and ownership, traffic problem has become the basic problem of the city. Rear-end collision accident is the most common traffic problem and the biggest loss problem. At present, due to the imperfection of the vehicle warning system, drivers often can not respond in the first time, resulting in the loss of life and property. Therefore, it is necessary to study the analysis and early warning of rear-end collision. Scholars at home and abroad have put forward their views on this. Lee and Abdel-Aty [1] used the generalized estimation equation with negative binomial link function to model the rear-end collision frequency at signalized intersections and found that there was a high correlation between longitudinal or spatial related rear-end collisions. Hendricks et al. [2] applied the seven-step collision problem analysis method to the rear-end collision and defined and explained the countermeasure action by the front end analysis of the rear-end crash. Based on the artificial immune mechanism, Yi et al. [3] put forward an early warning model to identify and determine the trend caused by abnormal vehicle state, which is a theoretical basis for the safe operation and management of highway tunnel group. Huang et al. [4] studied and simulated the dynamic response of the human body in the vehicle with rear-end collision and established the nonlinear mathematical model of the human body and restraint system. They complied the motion equation of the model by using the Kane equation and the multi-body dynamic analysis program developed by Houston and found that the model was in good agreement. This study used the vehicle speed based safety pre-warning algorithm and simulated the effectiveness of the anti-collision system through data calculation and simulation, especially the response to the early and late pre-warning triggered under the change of speed per hour, so as to quantify the impact of warning on collision through safety benefit measures and ensure the accuracy and timeliness of the system.

2. Safety pre-warning system

2.1 Rear-end collision

Rear-end collision is a kind of straight-line collision in the state of car following. It refers to the situation that the head of one vehicle collides with the tail of another vehicle [5], as shown in Figure 1.

$\angle 1$ is denoted as θ_1, and $\angle 2$ is denoted as θ_2, representing the angle between the connecting line of the central coordinates of the front and rear vehicles and the driving direction of the vehicle respectively; v_1 represents the speed of the rear vehicle, v_2 represents the speed of the front vehicle; d represents the distance between the central position of the two vehicles; K refers to the transverse distance of the two vehicles. Only when the transverse distance between the two vehicles is smaller than the width of the car body, i.e., $K \geq \left|d \sin \theta_1\right|$, the rear-end collision between the two vehicles is possible. When $K \geq \left|d \sin \theta_1\right|$ is detected, the system needs to compare the time required for vehicle rear-end collision with time-to-collision (TTC) to determine whether there is a risk of rear-end collision. The rear-end collision of two vehicles can be active or passive. The time required for rear-end collision is assumed to be t. When rear-end collision occurs, i.e., the speed of the rear vehicle exceeds that of the front vehicle, and when $v_1 > v_2$ and $|\theta_1| < |\theta_2|$ are met, the time required for rear-end collision is:

$$t = 3.6 \times \left| d \times |\cos\theta_1| - 5 \right| / (v_1 - v_2)$$

.

2.2 Safety anti-collision

TTC is the shortest time required for a driver to know the danger and react to avoid collision [6]. In the process of driving, the calculation and processing module of the pre-warning system needs to calculate the reserved safety time in real time according to the vehicle status data returned by the detection instrument, then it can be compared with the time required for rear-end collision [7]. The smaller the TTC is, the greater the risk of rear-end collision is. The basic formula of TTC can be expressed as:

$$TTC = \frac{\mathrm{d} - L}{|V_{rear} - V_{front}|},$$

where L refers t o the length of the vehicle and V_{front} and V_{rear} are the real-time speed of the front and rear vehicles, respectively.

Considering that the acceleration of the vehicle is constant and the speed of the rear vehicle is higher than that of the front vehicle, then the acceleration of the front vehicle is expressed as a_{front}, and the acceleration of the rear vehicle is expressed as a_{rear} .

To simplify the calculation, let the relative speed between the front and rear vehicles ($\left|V_{rear} - V_{front}\right|$) be V_{rel}, let the relative acceleration ($\left|a_{rear} - a_{front}\right|$) be a_{rel}, let TTC = t_0, and the safe stopping distance is assumed to be s.

Considering the real-time motion state of the front vehicle, it is assumed that the front vehicle still has the speed when the rear-end collision accident occurs, i.e., $\Delta = V_{rel}{}^2 + 2a_{rel}d \geq 0$, the two vehicles may rear-end. Under this condition, when the front vehicle runs at a constant speed, i.e., $a_{front} = 0$, and $V_{front}t_0 + (d-s) > V_{rear}t_0 + \frac{1}{2}a_{rear}t_0^2$, the rear-end collision will not happen; when the rear vehicle runs at a constant speed, i.e., a_{rear}=0,

$$TTC = t_0 = \frac{d-s}{V_{rel}} .$$

When the rear vehicle has acceleration, i.e., $a_{rear} \neq 0$,

$$TTC = t_0 = \frac{-V_{rel} + \sqrt{V_{rel}^2 + 2a_{rear}(d-s)}}{a_{rear}}.$$

It is assumed that the front vehicle no longer has speed at the time of rear-end collision, i.e., the front vehicle completely stops it stops. When $(d-s) > V_{rear}t_0 + \frac{1}{2}a_{rear}t_0^2$ is satisfied, the collision will not happen. When the rear vehicle runs at a constant speed, i..e, a_{rear}=0,

$$TTC = t_0 = \frac{d-s}{V_{rear}}.$$

When the rear vehicle has acceleration, i.e. $a_{rear} \neq 0$,

$$TTC = t_0 = \frac{-V_{rear} + \sqrt{V_{rear}^2 + 2a_{rear}(d-s)}}{a_{rear}}.$$

2.3 Structure of the pre-warning algorithm system

The comparison between the time of vehicle rear-end collision and TTC showed that when TTC is smaller than the time required for rear-end collision, the collision will not occur; on the contrary, when TTC is larger than or equal to the time required for rear-end collision, there is a risk of rear-end collision. Therefore, the pre-warning system should be connected with the detection equipment to transmit the real-time information of the vehicle in the process of driving to the database, especially the speed of the vehicle and the distance and angle with the vehicle ahead [8]. The calculation module calculates the rear-end collision time and TTC, respectively, and transmits the judgment result to the processing center. If there is a risk, the driver shall be warned in time by sending out visual or auditory signals [9] to remind the driver to slow down; if the risk is removed, then the signal is canceled. The structure of the pre-warning algorithm system is shown in Figure 2.

3. Experiment

3.1 Experimental methods

The analysis of the virtual rear-end collision experiment and the construction of components, such as road network, vehicle, and signal lamp, was realized by MATLAB computer simulation software [10]. The intersection was selected as the virtual center section, and the finite element model and Computer-Aided Design (CAD) model of the basic vehicle parts were input [11]. SANTANA model was selected as the simulated vehicle as the alarm time of the model was relatively moderate. In the construction of the internal security pre-warning system, VanetMobisim that is the generation tool of moving node trajectory was adopted to establish a V2V communication scene and compile the OTCL simulation script. After the vehicle simulation rear-end collision model was built, the calculation was performed by Pam-Crush software, and the result was output. Ten experienced drivers with little difference in driving years were recruited for manual assessment.

3.2 System pre-test

In the actual process, considering the cost, it is impossible to make the vehicle really present the violent collision scene of a rear-end collision. Therefore, to ensure the scientificity of the experiment, it is necessary to carry out a pre-test on the pre-warning system. The length, width, and height of the vehicle body, which was used in the experiment was 4.5 m, 2 m, and 1.7 m, respectively. All vehicles were under the same road condition. The safe stopping distance of the vehicle was 3 m. Firstly, the rear-end collision time and TTC were calculated manually by the formula, and whether there was a risk of rear-end collision was determined based on the calculation result. Then the feasibility of the pre-warning system was detected by comparing it with the actual response of the pre-warning alarm. Five groups of data were randomly selected for the pretest. The test results are shown in Table 1.

Table 1 Pre-test results

	Speed of the front vehicle (km/h)	Speed of the rear vehicle (km/h)	Acceleration of the front vehicle (km/ s^2)	Acceleration of the rear vehicle (m/ s^2)	Distance between two vehicles (m)	$\sin\theta_1$	$\cos\theta_1$	Time required for rear-end collision t(s)	TTC (s)	Rear-end collision hazard judgment	Whether the pre-warning alarm sounds
The 1st grou	30	40	6	8	15	sin175	cos175	1.26	1	Safe	No

p											
The 2nd group	40	55	6	6	10	sin10	cos10	1.75	1.9	Danger	Yes
The 3rd group	52	64	7	8.5	7	sin15	cos15	0.79	1.56	Danger	Yes
The 4th group	59	68	6.5	7.5	5	sin160	cos160	0.5	1.52	Danger	Yes
The 5th group	42	53	7	9	9	sin12	cos12	4.45	1.83	Safe	No

Note: 1 km/h = 0.28 m/s

In Table 1, the comparison of the time required for rear-end collision and TTC showed that the rear-end collision accidents in the first group and fifth group would not occur, and the pre-warning system signal did not ring; however, in the 2^{nd}, 3^{rd} and 4^{th} group, TTC > t, thus the risk was assessed as dangerous, and the pre-warning system was required to timely prompt the driver to decelerate and brake, and all three alarms sounded. The alarm response was correct in the test of the five groups of data, which showed that the pre-warning system was feasible. After passing the pre-test, the next experiment was carried out.

3.3 Experimental results

3.3.1 Pre-warning accuracy

The simulation vehicles were randomly divided into three groups, including low speed group, medium speed group and high speed group, with five vehicles in each group. The vehicles were controlled to run at a low speed (10 ~ 20 km/s), moderate speed (30 ~ 40 km/s) and high speed (50 ~ 60 km/s) respectively. The time when the two vehicles touched and the time when the pre-warning signal of the vehicle interior warning system sounded were observed and recorded. The correct alarm and false alarm of the pre-warning system in the case of signal display and the correct avoidance and alarm failure in the case of no signal display were recorded. Two different collision results of this experiment were set in the simulation system in advance. The collision group and the non-collision group were repeated five times under the same conditions, 75 times in each case, and finally, 150 times of pre-warning data were obtained in total. The simulation results of the accuracy of the safety pre-warning algorithm are shown in Table 2.

Table 2 Simulation results of the accuracy of the security pre-warning algorithm

Rear vehicle	FRONT VEHICLE	COLLISION		NO COLLISION	
		Pre-warning	No pre-warning	Pre-warning	No pre-warning
LOW SPEED	Low speed	75	0	1	74
MODERATE SPEED	Moderate speed	70	5	2	73

HIGH SPEED	High speed	62	8	15	55
FALSE ALARM RATE			11%		
MISSING ALARM RATE			9%		
ACCURACY RATE			80%		

Note: the false alarm rate = the sum of pre-warning times in the case of no collision/total times; the missing alarm rate = the sum of the times of no pre-warning in the case of collision/total times; the accuracy rate = the sum of the times of pre-warning in the case of collision + the sum of the times of no pre-warning in the case of no collision/total times.

It was seen from Table 1 that the safety pre-warning algorithm system that took speed as the main benchmark was accurate in predicting the risk of vehicles at the low speed, followed by vehicles at a moderate speed. Due to the large centrifugal force of the high-speed vehicle, the coefficient of the friction with the ground was relatively reduced, thus the pre-warning algorithm had a large error, leading to the alarm in the case of no collision or no alarm in the case of collision in the high speed group; the frequency of false alarm and missing alarm in the high speed group was the highest. Also, the false alarm rate and missing alarm rate of vehicles at all speeds were controlled at a low level, 11%, and 9%, respectively, and the accuracy rate of vehicles at the low speed was nearly 100%. The results showed that the safety system based on the pre-warning algorithm could accurately calculate and compare the difference between the rear-end collision time and TTC, judge the risk of rear-end collision at the first time, and feed back to the driver. The real-time reminding and controlling of the driving speed can greatly improve the safety of the driving process.

3.4.2 Timeliness rate of pre-warning

Under the same conditions of the simulation experiment on the accuracy of the safety pre-warning algorithm, ten real drivers were asked to evaluate the rear-end collision time of low speed, medium speed, and high speed groups, respectively. The output module of the simulation system was controlled by the real drivers assigned to each group. According to their experience, the time required for rear-end collision was estimated, and then each driver submitted the demand for braking response in the simulation system according to their own judgment. The time of the braking reaction of the divers was recorded. Starting from the moment of the occurrence of the braking action, 0 ~ 2 s was the pre-braking stage, 2 ~ 4 s was the braking stage, and 4 ~ 6 s was the post-braking stage. The alarm of the pre-warning system before, during, and after braking was observed. To avoid the influence of the individual driving inertia, the rotation system was adopted, and the test was repeated 5 times, 50 times each group. Finally, 150 groups of data were obtained. The timeliness rate of the safety pre-warning algorithm is shown in Table 3.

Table 3. The timeliness rate of the security pre-warning algorithm

FRONT VEHICLE	REAR VEHICLE	BEFORE BRAKING	DURING BRAKING	AFTER BRAKING
LOW SPEED	Low speed	0	50	0
MODERATE SPEED	Moderate speed	2	45	3
HIGH SPEED	High speed	4	37	8
EARLY RATE		4%		
DELAY RATE		7%		
TIMELINESS RATE		89%		

Note: early rate = the sum of times before braking/total times; delay rate = the sum of times after braking/total times; timeliness rate = the sum of times during braking/total times.

It was seen from Table 2 that the vehicles at the low speed had the lowest early and delay rates and the highest timeliness rate; the high speed group had an obvious fluctuation of appearance time of the safety pre-warning signal before and after braking, and the early and delayed alarm rates of the high speed group were 8% and 16% respectively, which were twice as high as the average values. Moreover, the frequency of time deviation after braking was relatively high, i.e., the delay rate of the pre-warning system was higher than the early rate. Overall, the safety pre-warning system maintained a timeliness rate of 89%, showed a high sensitivity in the judgment of the rear-end accident, and kept a good synchronization with the experienced drivers [12]. This study provides a proof for the efficient analysis and timely feedback of the safety pre-warning algorithm and also offers a more powerful guarantee for the application of the safety pre-warning system in the field of avoiding vehicle rear-end collision.

4. Discussion

(1) The driver should control the speed. It was seen from the experimental results of this study that the speed was the most direct and key factor affecting the probability of rear-end collision [13]. The simulation experiment also verified that there was still a deviation in the accuracy rate and timeliness rate in high-speed driving even when the pre-warning system was used for preventing rear-end collision. Therefore, only when the driver controls the speed carefully can the problem be solved fundamentally.

(2) The driver should regularly check whether the vehicle braking performance is good. If the braking performance deteriorates, the braking reaction will be slowed down, and the braking duration will be shortened, which will shorten the time before the occurrence of rear-end collision accidents and more likely to cause traffic accidents [14].

(3) The vehicle should keep a distance. According to the calculation results of the time required for rear-end collision, the smaller the distance between vehicles is, the less reaction time left for drivers is. Moreover, the close collision is more likely to increase the severity of the accident. When the speed is low, the distance with the front vehicle in the same lane should be appropriately shortened, but the minimum distance shall not be smaller than 50 m [15].

5. Conclusion

Focusing on the prevention of urban rear-end collision accidents, this study analyzed the influencing factors of rear-end collision accidents, proposed a safety pre-warning algorithm with running speed as the main variable, established a safety pre-warning system, and verified the accuracy and timeliness of the system in predicting the risk of rear-end collision accident by simulation experiments. The results showed that:

(1) vehicle speed was an important factor affecting the occurrence of rear-end collision;

(2) the safety pre-warning algorithm based pre-warning system had strong feasibility for the analysis and judgment of rear-end collision accidents, which was manifested in high accuracy and high timeliness rate;

(3) the application of the safety pre-warning algorithm has a good prospect in avoiding the rear-end collision accident in urban traffic, which is conducive to reduce the collision risk and ensure the personal safety and traffic safety to the greatest extent.

Declarations

Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The author declare that they have no competing interests.

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Authors' contributions

SZW studied the vehicle rear-end collision and collision pre-warning system and designed relevant experiments. Based on the vehicle anti-collision pre-warning system, WJL calculated the experimental results through the sample data. CYK participated the analysis of the anti-collision pre-warning method and analyzed the experimental results.

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Figure 1 The schematic diagram of rear-end collision

Figure 2 The working structure of the security pre-warning system

Figures

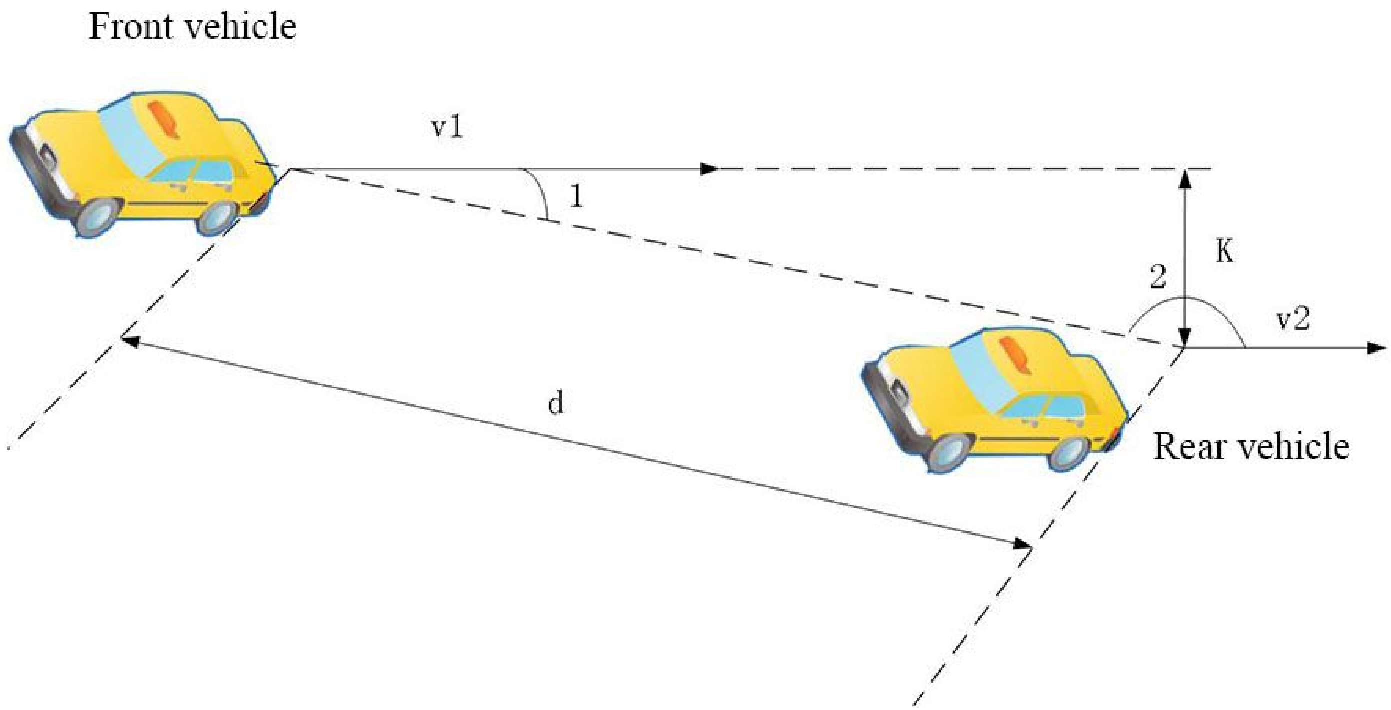

Figure 1

The schematic diagram of rear-end collision

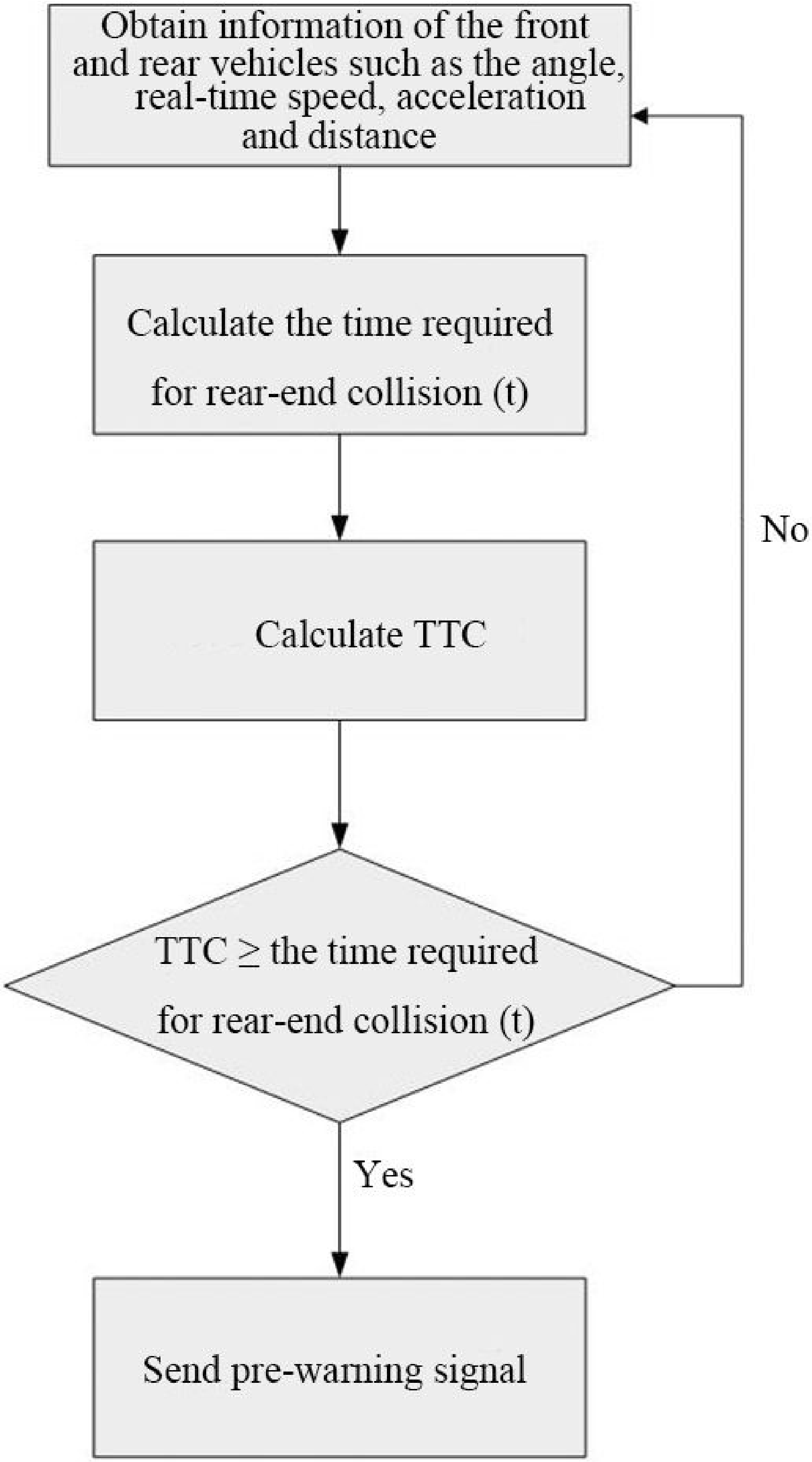

Figure 2

The working structure of the security pre-warning system