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Research Article

Modeling Analysis of Improved Minimum Safe Following Distance under Internet of Vehicles

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The development of the Internet of vehicles technology can improve the communication between vehicles, thereby changing the driving behavior of drivers. Therefore, the traditional safe-following model cannot accurately describe the driving behavior and needs to be improved accordingly. First, two key parameters (i.e., drivers' reaction sensitivity and road friction coefficient) are obtained through a comprehensive comparative analysis of influencing factors on the Internet of vehicles environment. And the calculation methods of these two parameters are proposed by using the multilevel comprehensive weighted evaluation method and the BP neural network. Then, these two key parameters are used to improve the traditional minimum safety distance model for adapting to driving behavior under the Internet of vehicles environment. Finally, through setting up simulation experiments and comparative analysis, the relationship between different influencing factors and the minimum safe following distance is obtained, and the influence degree of different influencing factors is sorted. The most important factor affecting car-following safety is the drivers' characteristics. It can provide strong theoretical support for the safe driving assistance system of vehicles.

1. Introduction

The investigation of lots of traffic accidents indicates that the rear-end accident takes up a relatively high proportion and is one of the main traffic accidents. The studies suggested that the rear-end accident is mainly affected by drivers' characteristics, the acceleration/deceleration performance of vehicles, road condition, and weather situation [1–4]. The influence degree of the four types of factors is different.

Jiang and Yu established a highway antitailing model based on a radial basis function neural network by using traditional algorithms [5]. Nevertheless, the model is mainly applied to highways, and the influencing factors considered are relatively single. Based on the drivers' characteristics (e.g., driving age and gender), Xia established a fuzzy inference system to determine different drivers' response times and proposed an improved safe car-following model [3]. Peng derived the modified Korteweg-de Vries (mKdV) equation to describe the traffic behavior near the critical point by using linear stability theory and proposed an improved car-following (MCF) model based on the full velocity difference (FVD) model and considering multiple information inputs from preceding vehicles [6, 7]. Wilson and Ward suggested that all vehicle car-following models should be tested for stability to ensure improved performance [8]. Tan and Huang [9] proposed a cooperative collision warning system for vehicle-to-vehicle based on DGPS. However, the safety distance algorithm does not consider the drivers' driving characteristics and actual road conditions; thus, the practical application of the warning system is low. Luo et al. [10, 11] proposed an improved vehicle rear-end collision model by considering the driver types and multiple factors on the traditional driving environment.

With the emergence and development of the Internet of vehicles technology, the driver can obtain more information around in time, and the accuracy of the information is high.

It has a greater auxiliary effect on driving behavior and can effectively reduce the occurrence of traffic accidents, especially vehicle rear-end accidents. Sun et al. [12], Wang et al. [13], Hua et al. [14], and Monteil et al. [15] comprehensively consider the drivers' comprehensive grasp of driving data of the vehicle ahead in the vehicle-to-vehicle interconnection environment, and some improved models have been established. Wang et al. [13] not only considers the influence of the vehicle ahead on the car-following safety but also considers the influence of the secondary leading car and lane-changing behavior, and then, a combined car-following and lane-changing model considering dual leading vehicles is proposed. Ge et al. [16] consider that the rear neighboring vehicles have a certain urging effect on the target vehicle, and the target vehicle will also pay attention to the distance between the rear neighboring vehicle and itself in order to avoid collisions between vehicles. Through analysis and verification, an extended OV model based on backward observation is proposed. The research results show that considering the rearview effect of the rear vehicle can significantly enhance the stability of traffic flow. Gu [17] corresponded to the research objectives in the development stage of the Internet of vehicles with adaptive cruise technology (ACC) and cooperative adaptive cruise technology (CACC) and proposed the multimode, multiobjective, and multilevel car-following models of different development stages.

The driver can comprehensively obtain the road and other surrounding vehicles' information in the Internet of vehicles environment. Thus, the influence of external factors on driving safety becomes weaker. However, some subjective factors will still have an important impact on driving safety. Through comprehensive analysis and comparison, we obtained that the drivers' reaction sensitivity and the road surface have a greater impact on car-following safety. Thus, this paper sets up the estimation method of these two parameters and then improves the classical minimum car-following distance model by using them. The improved car-following model can be more in line with the driving behavior in the Internet of vehicles environment and can better provide assistance for car-following driving. At the same time, the influence degree of different influencing factors obtained by simulation comparison can provide strong support for vehicle-assisted driving decision-making.

2. Analysis of Factors Affecting the Car-Following Safety

From the analysis of the traffic operation system, the factors affecting driving safety can be divided into driver factors, vehicle factors, road factors, and traffic environment factors. There have been many relevant research reports on these factors. For example, the classic safe following distance model mainly focuses on the research of the minimum safety distance between the target vehicle and the leading vehicle during the following process. When the target vehicle brakes after a series of reactions and operational delays, a certain safety distance can be maintained with the front vehicle, and no vehicle rear-end collisions will occur. Under the environment of the vehicle network, the drivers can perceive the information of surrounding vehicles and the traffic environment in time. Thus, the influence of many objective factors has been reduced. By analyzing the existing research literature, two key parameters that affect the minimum safety distance can be obtained as follows: drivers' reaction sensitivity and road friction coefficient. The reaction sensitivity of the driver can be measured by the reaction time. And the factors affecting the two key parameters will be analyzed as follows.

2.1. Drivers' Reaction Sensitivity

2.1.1. Analysis of Influencing Factors. The factors affecting the drivers' driving reaction sensitivity can be divided into drivers' characteristics, traffic conditions, and environmental factors.

(1) Driver's characteristics: the investigation of many accidents shows that more than 80% of traffic accidents are caused directly or indirectly due to drivers [18]. Thus, the driver's characteristic is the main factor affecting the driving safety and can be divided into gender, age, driving experience, and physiological status. According to the survey, male and female drivers have different abilities to identify and judge traffic conditions and respond to sudden accidents. In general, the drivers' reaction sensitivity slows down with age [19]. The more experienced in driving, and the more mature in the treatment of various sudden traffic conditions. When the driver has a good mental state, the perception of road traffic information is accurate [20].

(2) Traffic condition: traffic condition is also an important external factor affecting car-following safety. It can be subdivided into the road feature and the car-following status, which has a great influence on driving behavior. First, the reasonable design of road alignment from three-dimensional (3D) angles (i.e., horizontal, vertical, and cross section) can provide suitable driving conditions and improve the safety of driving. On the contrary, the unreasonable design will cause the vehicle to run unsteadily or even lead to traffic accidents. Second, the car-following status affects the drivers' driving psychology and increases driving difficulty, thereby affecting the safety of driving.

(3) Environmental factors: for the environmental factors, the factors affecting the drivers' reaction sensitivity are driving period and weather characteristics. In accordance with traffic accident statistics, the accident-prone time periods are concentrated at noon and at early morning. During the two time periods, the physiological activities should be in a sleepy state. Under the limited lighting conditions at night, the drivers' visual perception range is reduced, and the field of view is narrowed. In

addition, the bad weather affects the drivers' reaction sensitivity and driving operation, thereby adversely affecting driving safety.

To sum up, various factors affecting the driving reaction sensitivity are analyzed. We use the reaction time to quantify the drivers' reaction sensitivity, and the calculation method of reaction time will be introduced as follows.

2.1.2. Calculation Method of Reaction Time

(1) Hierarchical Classification of Influencing Factors. According to the above analysis of influencing factors, a three-level evaluation system of drivers' reaction sensitivity (expressed by reaction time) was established. The goal of each layer is one of the three factors analyzed in the previous section. The factor set of the first-level layer contains three factors: driver characteristics, traffic conditions, and environmental factors. The first factor set of the second-level layer contains four factors: gender, age, driving experience, and physical state. The second factor set of the second-level layer contains two factors: road feature and car-following status. The third factor set of the second-level layer contains two factors: driving period and weather.

The evaluation and classification of different influencing factors on the second-level factor set are shown in Table 1.

(2) Weight Determination of Indicators. The weight set of the first-level factor is set to S, which contains three members: S_1, S_2, and S_3. The weight set of the second-level factor subset is set to $S_i = \{s_{i1}, s_{i2}, \ldots\ldots, s_{it}\}$, $i = 1, 2, 3$.

(1) Evaluation score of the hierarchical factors: the influence degree of the various factors on the second level is scored, as shown in Table 2.

(2) Calculation of the weight coefficient: the weight coefficient of each influencing factor is expressed as $w_1, w_2, \ldots w_i$, and their quantity relationship is $\sum_{i=1}^{n} w_i = 1$.

Matrix D can be obtained by comparing the above weight coefficients [21].

$$S = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix}. \quad (1)$$

The weight vector $w = (\beta_1, \beta_2, \beta_3, \ldots\ldots, \beta_n)^T$ is used to right multiplying matrix D, and the characteristic equation of matrix D can be expressed as

$$Dw = \lambda w, \quad (2)$$

where w is a vector combined with a weight factor β_i for each influencing factor and λ is the characteristic value of matrix D. The various influencing factors are compared in pairs. The elements d_{ij} in matrix D are used as an indicator to measure the relative importance of influencing factors Y_i. Thus, the relative importance value can be obtained according to the value of d_{ij}. The values of d_{ij} are 1, 2, 3, 4, 5, 6, 7, 8, and 9. The more the value of d_{ij}, the more important that d_i has than d_j.

We tested the consistency of the paired comparison matrix composed of the above impact indicators and found that the consistency ratio (CR) is less than 0.1, which shows that the judgment matrix passes the consistency test [21, 22]. Then, the weight values of the influencing factors at all levels are obtained, as detailed in Table 2.

(3) Calculation of drivers' reaction sensitivity: the evaluation score of each index at the first level can be obtained in accordance with the influence evaluation score of the corresponding factors at the second level. The calculation expression is

$$D_i = \sum\nolimits_{i=1}^{n} Y_i w_i. \quad (3)$$

(4) Score determination of the evaluation system: the evaluation score R of the driver reaction evaluation system can be obtained according to the evaluation score at the first level. The calculation expression is

$$R = \sum\nolimits_{i=1}^{3} D_i w_i. \quad (4)$$

2.2. Road Friction Coefficient

2.2.1. Analysis of Influencing Factors. The existing research literature shows that the factors affecting the road friction coefficient are mainly road characteristics, tire type, and force.

(1) Road Characteristics. Roads with different characteristics have different road friction coefficients, and the driving comfort of vehicles driving on them is also different. The influencing factors mainly include the road roughness and wet/dry degree. According to the literature [22–24], the relationship between the road friction coefficient and road type is shown in Table 3.

(2) Tire Type and Force. In addition to supporting the body weight of the car, the tire can transmit road condition information to the body. Existing researchers have proposed a tire model to describe the relationship between tire force and tire motion parameters, that is, the relationship between tire input and output during vehicle driving under different road conditions. A commonly used tire model consists of a drive force module, a slip angle module, a slip rate module, and a tire force module. The tire force module consists of lateral force and lateral velocity, longitudinal force and longitudinal velocity, return torque, and yaw velocity [25].

Table 1: Evaluation and classification of different influencing factors.

Factors	Classification and evaluation		
Gender (I)	Male (80–100)		Female (70–90)
Age (I)	18–30 (80–100)	30–50 (70–80)	50–70 (60–70)
Driving experience (I)	>10 years (80–100)	6–10 years (70–80)	1–5 years (60–70)
Physical state (I)	Normal (80–100)	Fatigue (70–80)	Illness (60–70)
Road feature (II)	Normal road (80–100)	Monotonous road (70–80)	Sharp-tend road (60–70)
Car-following status (II)	Free flow (80–100)	Normal following (70–80)	Emergency following (60–70)
Driving period (III)	Others (80–100)	12 a.m.–14 p.m. (70–80)	22 p.m.–6 a.m. (60–70)
Weather (III)	Sunny (80–100)	Rain (70–80)	Fog (60–70)

Table 2: Weight values of influencing factors.

1st level	Driver characteristics				Traffic condition		Environment factors	
Weight	0.40				0.29		0.31	
2nd level	Gender	Age	Driving experience	Physiological state	Road feature	Following status	Driving time	Weather
Weight	0.19	0.26	0.28	0.27	0.45	0.55	0.40	0.60

Table 3: Friction coefficients of four types of roads.

No.	Road type	Range of variation	Set value
1	Dry asphalt	(0.80, 0.95]	0.91
2	Wet asphalt	(0.61, 0.75]	0.71
3	Snow pavement	(0.20, 0.27]	0.24
4	Ice surface	(0, 0.10]	0.10

The longitudinal force, lateral force, and vertical force generated in the process of tire contact with the ground have an important effect on the stability of the vehicle. If these three forces can be coordinated and controlled during driving, the driving smoothness and safety can be improved.

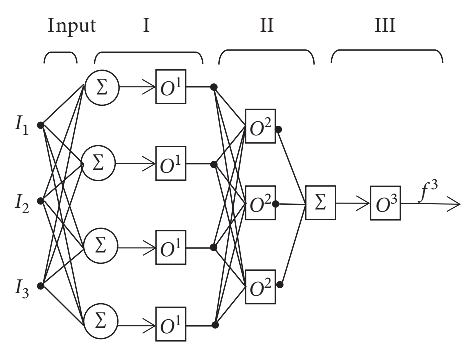

Figure 1: Neural network structure.

2.2.2. Estimation Method. The road friction coefficient is a key factor affecting the car-following safety and is mainly influenced by road surface condition, vehicle speed, and vehicle tire type. In accordance with our previous research results, the neural network can be used to calculate the road friction coefficient. This method is used to establish a network structure with the input for road characteristics, tire pressure, vehicle speed, and the output for friction coefficient, as shown in Figure 1. A detailed description can be found in the literature [10].

In general, the texture of tires can be divided into three categories, ordinary pattern, cross-country pattern, and mixed pattern. Thus, the input has three parameters in this network structure which are road characteristics, tire pressure, and vehicle speed. And the output is the friction coefficients of each tire type. The BP neural network structure adopts a three-layer structure, that is, an input layer, two hidden layers, and an output layer. The input layer contains three layers of input. The first and second layers have four neurons and three neurons, respectively, and the output layer has a single output, as shown in Figure 1. The training data come from 120 experimental samples under two road surfaces (asphalt and cement concrete), different weather, and different driving speed.

The log-sig, tan-sig, and purelin functions are chosen for the input transfer function of each layer, respectively, as follows [25–28]:

$$O^1(x) = \frac{1}{1+e^{-x}}, O^2(x) = \frac{2}{1+e^{-2x}} - 1, O^3(x) = x. \quad (5)$$

The relationship between input and output function is

$$a^3 = O^3\left\{\omega^3 O^2\left[\omega^2 O^1\left(\omega^1 I + d^1\right) + d^2\right] + d^3\right\}, \quad (6)$$

where $I_i \geq 0\,(i = 1, 2, 3)$ is an input parameter, O^i is the output result of the ith layer, and ω^j, d^j denote the weight matrix and an offset value vector at $j\,(j = 1, 2, 3)$ layer. When $j = 3$, the layer represents an output layer and f^3 is the output parameter.

3. Safe Following Distance Model Establishment

3.1. Existing Car-Following Distance Model. While the vehicle is running, the rear vehicle (vehicle B) should maintain a proper following distance from the front vehicle (vehicle A) to ensure the following safety and to prevent the occurrence of rear-end collisions during driving. The following relationship between the front and rear vehicles can be divided into three situations through the experimental investigation and analysis, and the specific models are described as follows [10, 11]. The car-following process is shown in Figure 2.

(1) Stationary State of the Front Vehicle. When the front vehicle is in a stationary state, the minimum following distance S_T can be expressed as

$$S_T = S_B + d = v_B\left(t_r + \frac{t_s}{2}\right) + \frac{v_B^{\,2}}{2a_B} + d, \quad (7)$$

where S_T is the minimum safe following distance, S_B are the distances traveled by vehicle B, respectively, v_B and a_B are the driving speed and braking deceleration of vehicle B, t_r is the sum of drivers' reaction time and brake coordination time, t_s is braking deceleration increase time, and d is the safety distance (2–5 m).

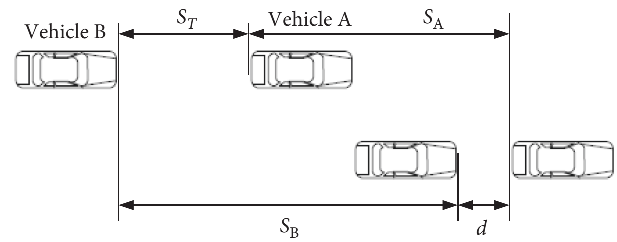

Figure 2: Car-following process.

(2) Constant Speed State of the Front Vehicle. When the relative speed of the two vehicles is small or large, the required minimum distance is different; thus, the safe following distance S_T can be expressed as

$$S_T = \begin{cases} v'\left(t_r + t_s\right) - \dfrac{\left(a_B t_s^2\right)}{6 + d} & I \\ v'\left(\dfrac{t_r + t_s}{2}\right) + \dfrac{v'}{\left(2a_B\right) + d} & II \end{cases}, \quad (8)$$

where v' is the relative speed of two vehicles, case I denotes that the value of v' is small, case II denotes that the value of v' is large.

(3) Uniform deceleration state of the front vehicle. There are three situations: the speed of the front vehicle is less than that of the rear vehicle, the speed of the front vehicle equals that of the rear vehicle, and the speed of the front vehicle is larger than that of the rear vehicle. For three different driving situations, the minimum safety distance models are different.

$$S_T = \begin{cases} v_B t_r + v' t_s/2 + v_B^2/\left(2a_B\right) - v_A^2/\left(2a_A\right) + d\mathrm{I} \\ v_B t_r + v_B^2/\left(2a_B\right) - v_A^2/\left(2a_A\right) + d\mathrm{II} \\ v_B\left(t_r + t_s\right) - \left(2v_B v' + v_A^2\right)/\left(2a_A\right) + v_B^2/\left(2a_B\right) - v_A t_s/2 + d\mathrm{III} \end{cases}, \quad (9)$$

where v_A is the driving speed of the front vehicle, a_A is the braking deceleration of the front vehicle. Case I denotes that the speed of the front vehicle is less than that of the rear vehicle, Case II denotes that the speed of the front vehicle equals that of the rear vehicle, and Case I denotes that the speed of the front vehicle is larger than that of the rear vehicle.

3.2. Improved Minimum Safe Following Distance Model. According to the motion characteristics of the vehicle, the brake acceleration of vehicles has the following relationship with the road friction coefficient.

$$a_{\max} \leq \mu g, \quad (10)$$

where $a_A = a_B = a_{max} = \mu g$. The value of μ_A is the same as that of μ_B, can be denoted as μ, which is used to correct the acceleration. Then, the calculation expression of the correction factor of drivers' reaction time is calculated as $\sqrt{75/R}$.

According to the literature [28, 29], the value of drivers' braking reaction time is 1.25 s, and under normal driving conditions, the value of the minimum safety distance is 2.5 m. Therefore, the corrected reaction time is $1.25P$, and the minimum safety distance is $2.5P$. The above-corrected parameters are substituted into the traditional safe vehicle following the distance model, and the improved models can be obtained as follows.

(1) Stationary state of the front vehicle:

$$S_T = v_B\left(1.25P + \frac{t_s}{2}\right) + \frac{v_B^2}{2\mu_B g} + 2.5P = v_B\left(1.25P + \frac{t_s}{2}\right) + \frac{v_B^2}{2\mu g} + 2.5P. \quad (11)$$

(2) Constant speed state of the front vehicle:

(a). The large relative speed:

$$S_T = v'\left(1.25P + t_s\right) - \frac{\mu_B g t_s^2}{6} + 2.5P = v'\left(1.25P + t_s\right) - \frac{\mu g t_s^2}{6} + 2.5P. \quad (12)$$

(b) The small relative speed:

$$S_T = v'\left(1.25P + \frac{t_s}{2}\right) + \frac{v'}{2\mu_B g} + 2.5P = v'\left(1.25P + \frac{t_s}{2}\right) + \frac{v'}{2\mu g} + 2.5P. \quad (13)$$

(3) Uniform deceleration state of the front vehicle:

(a) The speed of the front vehicle is less than that of the rear vehicle:

$$S_T = 1.25v_B P + v'\frac{t_s}{2} + \frac{v_B^2}{2\mu_B g} - \frac{v_A^2}{2\mu_A g} + 2.5P = 1.25v_B P + v'\frac{t_s}{2} + \frac{v_B^2 - v_A^2}{2\mu g} + 2.5P. \quad (14)$$

(b) The speed of the front vehicle equals that of the rear vehicle:

$$S_T = 1.25v_B P + \frac{v_B^2}{2\mu_B g} - \frac{v_A^2}{2\mu_A g} + 2.5P = 1.25v_B P + \frac{v_B^2 - v_A^2}{2\mu g} + 2.5P. \quad (15)$$

(c) The speed of the front vehicle is larger than that of the rear vehicle:

$$S_T = v_B\left(1.25P + t_s\right) - \frac{2v_B v' + v_A^2 - v_B^2}{2\mu g} - \frac{v_A t_s}{2} + 2.5P. \quad (16)$$

4. Simulation and Analysis of the Improved Models

In this study, three different driving states of the front vehicle (i.e., stationary state, uniform state, and uniform deceleration state) are defined according to the actual driving situation. Five different driving conditions (see Table 4) are set according to the previous analysis of influencing factors. 100 experienced experts are selected to score according to the scoring rule of each factor set in Table 1 and then take the average value. The values in brackets in Table 4 are the evaluation scores of factors.

Assuming that the front vehicle and the rear vehicle are vehicle A and vehicle B, respectively (the same as in the following), and the two vehicles are driving in the same direction in the same lane. The values of some parameters are set as follows: $t_s = 0.12$ s, $\mu = 0.70$, $g = 9.8$ m/s^2, $t_r = 1.25P$, $d_{\min} = 2.5P$.

The simulation of five representative situations is conducted to observe the effect of the drivers' brake reaction time on the safe car-following in five conditions. The total score R of the brake reaction time is calculated by using formulae (3) and (4). The weight coefficients of the various factors affecting the drivers' brake reaction time can be obtained from Table 4. After a comprehensive weighting evaluation, the total score value R and correction factor P of the drivers' reaction braking time are obtained. The calculation results can be found in Table 5.

4.1. Stationary State of the Front Vehicle. The first driving state is that the state of the front vehicle A is in the stationary, the speed of vehicle B is set within the range of 60–62 km/h, and the minimum safety distance of five cases can be obtained in accordance with the formula (11), as shown in Figure 3.

Table 4: Simulation parameters of different scenarios.

Influencing factors		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Driver characteristics	Gender (Y_1)	Male (80)	Female (60)	Male (80)	Male (80)	Female (60)
	Age (Y_2)	18–30 years old (85)	50–70 years old (60)	18–30 years old (85)	18–30 years old (85)	50–70 years old (60)
	Driving years (Y_3)	1–5 years (60)	>15 years (85)	1–5 years (60)	1–5 years (60)	>15 years (85)
	Psychology (Y_4)	Normal (85)	Disease (60)	Normal (85)	Normal (85)	Disease (60)
Traffic environment	Road feature (Y_5)	Normal road (85)	Normal road (85)	Sharp bend (60)	Normal road (85)	Sharp bend (60)
	Traffic density (Y_6)	Free flow (85)	Free flow (85)	Emergency follow (60)	Free flow (85)	Emergency follow (60)
Environment factors	Driving period (Y_7)	12 : 00–14 : 00 (75)	12 : 00–14 : 00 (75)	12 : 00–14 : 00 (75)	23 : 00–6:00 (60)	23 : 00–6:00 (60)
	Weather (Y_8)	Sunny (85)	Sunny (85)	Sunny (85)	High fog (60)	High fog (60)

Table 5: Weighted evaluations of different cases.

Parameters	Case 1	Case 2	Case 3	Case 4	Case 5
D_1	66.25	77.80	77.80	66.25	77.80
D_2	60.00	85.00	60.00	85.00	85.00
D_3	60.00	60.00	81.20	81.20	81.20
R	62.500	74.370	73.692	76.322	80.942
P	1.095445	1.004227	1.008836	0.991301	0.962595

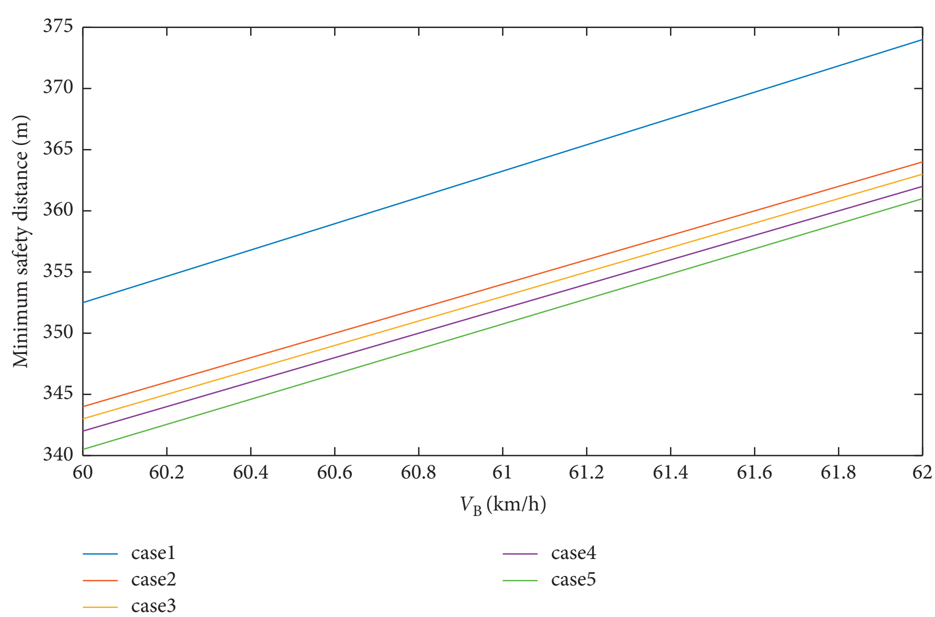

Figure 3: Minimum safety distance under the stationary state of the front vehicle.

As shown in Figure 3, the minimum safety distance has a linear increase in relation to the speed of vehicle B. When the speed of vehicle B ranges from 60 to 62 km/h, the variation range of the minimum safety distance is 340–375 m. It indicates that the value of the minimum distance increases by at least 35 m when the speed of vehicle B increases by 2 km/h. By comparing the safe following distance under five different driving conditions, the influence degree of various factors on the following distance can be obtained, the driver characteristics have the greatest impact, and the environmental condition and road characteristics have mostly the same influence degree.

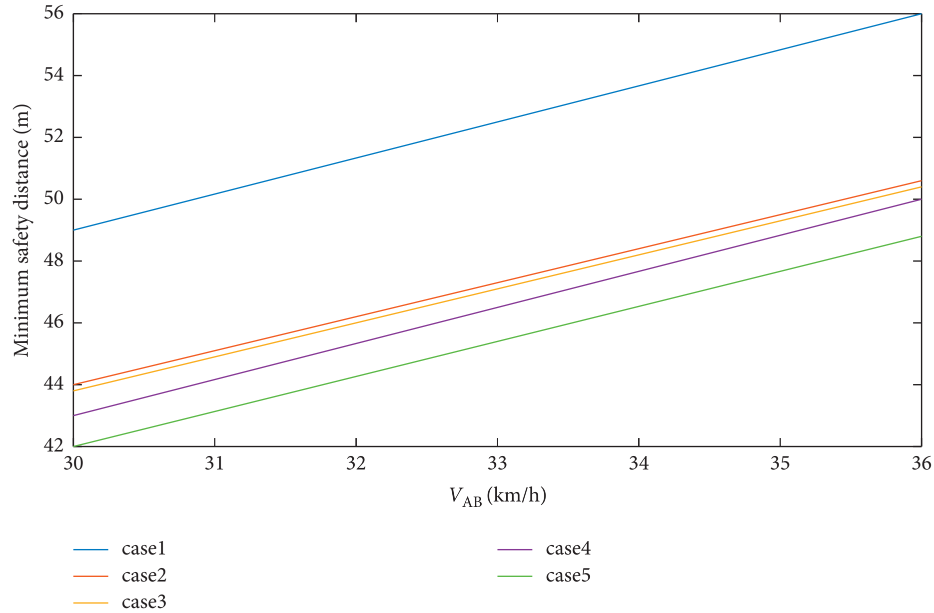

Figure 4: Minimum safety distances under constant speed state of the front vehicle (v' is large).

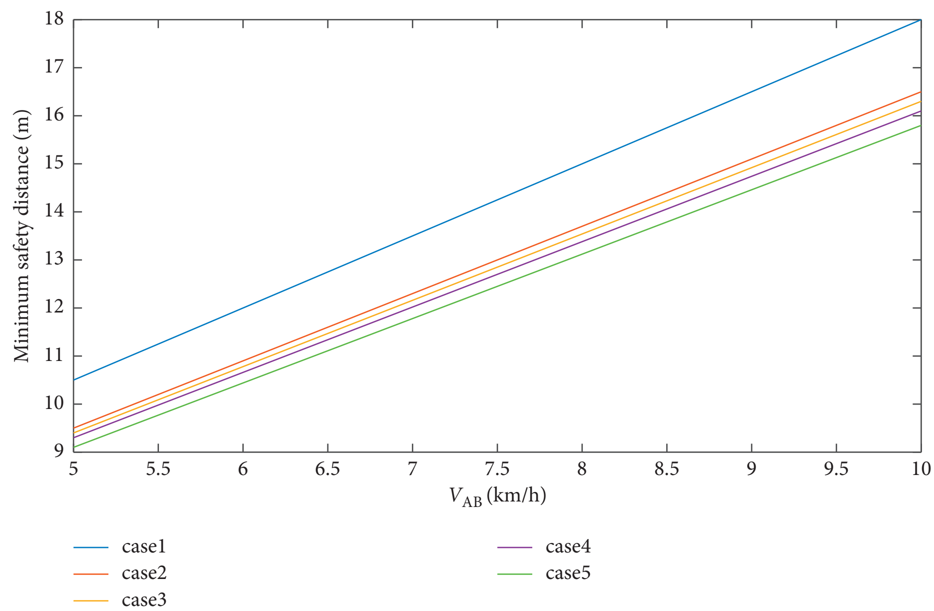

Figure 5: Minimum safety distances under constant speed state of the front vehicle (v' is small).

4.2. Constant Speed State of the Front Vehicle. When the front vehicle drives at a constant speed, there are two cases according to the speed relations between the front vehicle and the rear vehicle. The changing analysis of the minimum safety distance under five different driving conditions is conducted when the speed of the front vehicle drives by 50 km/h.

4.2.1. Relative Speed of Two Vehicles Is Large. When the speed of the rear vehicle is 80–85 km/h, then the relative speed of the two vehicles is 30–35 km/h, it belongs to the case where the relative speed between two vehicles is large. The changing of the minimum safety distance in this state can be obtained in accordance with formula (12), as shown in Figure 4.

4.2.2. Relative Speed of Two Vehicles Is Small. When the speed of vehicle B is 55–65 km/h, then the relative speed of the two vehicles is 5–10 km/h, it belongs to the case where the relative speed between two vehicles is small. The changing of the minimum safety distance in this state can be

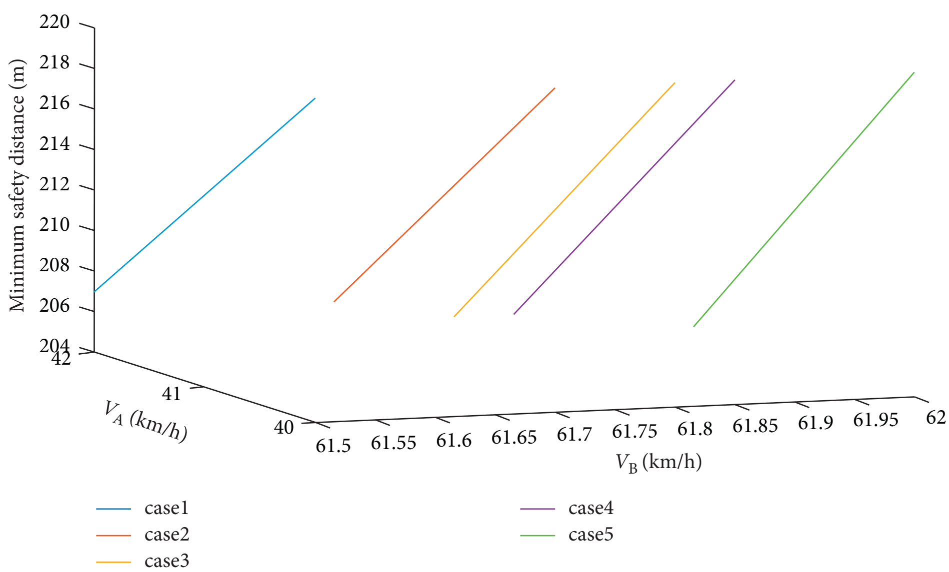

Figure 6: Minimum safety distance under uniform deceleration state of the front vehicle ($V_A < V_B$).

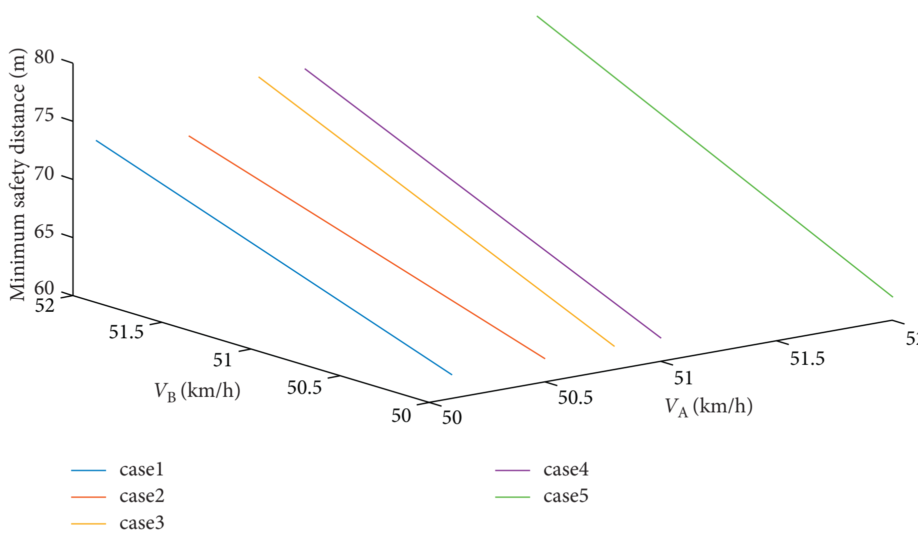

Figure 7: Minimum safety distance under uniform deceleration state of the front vehicle ($V_A = V_B$).

obtained in accordance with formula (13), as shown in Figure 5.

As can be seen from Figures 4 and 5, the minimum safety distance of case 1 is the maximum, and that of case 5 is the minimum. The changing of the minimum safety distance in the five cases is almost the same. Compare Figures 4 and 5 when the driving condition is not good, the minimum safety distance is less than 15 m at a relative speed of 8 km/h. However, the minimum safety distance is almost triple (about 50 m) at a relative speed of 32 km/h. Thus, the required safety distance is big enough to ensure car-following safety. When the relative speed of two vehicles is relatively small, then the three factors (drivers' own condition, environment condition, and road characteristics) have mostly the same degree of influence. And the drivers' own conditions have a slightly great degree of influence. When the relative speed of two vehicles is large, the order of influence degree of three factors on safe following distance from small to large is drivers' own condition, environmental condition, and road characteristics.

4.3. Uniform Deceleration State of the Front Vehicle. When the front vehicle drives at a uniform deceleration, there are three cases according to the speed relations between vehicle A and vehicle B. The changing analysis of the minimum safety distance under five different driving conditions is conducted.

4.3.1. The Speed of the Front Vehicle Is Less Than That of the Rear Vehicle. When the speed of the front vehicle is 40–42 km/h, and the speed of the rear vehicle is 60–62 km/h. The minimum safety distance of five cases can be obtained in accordance with formula (14), as shown in Figure 6.

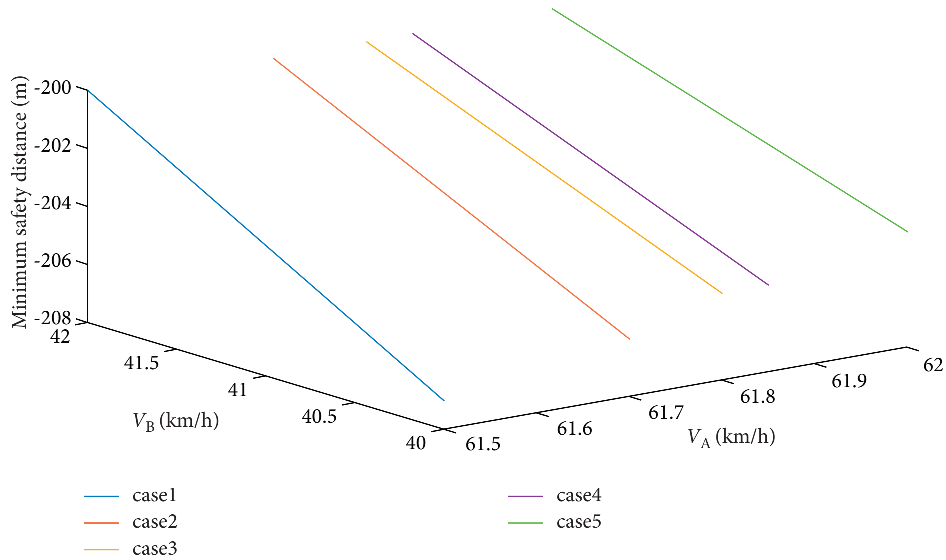

FIGURE 8: Minimum safety distance under uniform deceleration state of the front vehicle ($V_A > V_B$).

4.3.2. The Speed of the Front Vehicle Equals That of the Rear Vehicle. When the speed of both the front vehicle and the rear vehicle is 50–52 km/h, the minimum safety distance of five cases can be obtained in accordance with formula (15), as shown in Figure 7.

4.3.3. The Speed of Front Vehicle Is Larger Than That of the Rear Vehicle. In the third following situation of vehicle A in a uniform deceleration state, when the speed of vehicle A is 60–62 km/h, and the speed of vehicle B is 40–42 km/h, the minimum safety distance of five cases can be obtained in accordance with formula (16), as shown in Figure 8.

As can be seen from Figures 6 to 8, the minimum safety distance increases as the speed of vehicle A (or vehicle B) increases. By comparing the changing of the minimum safety distance under uniform deceleration of vehicle A, some conclusions can be get: (1) the minimum safety distance is the maximum when the speed of vehicle A is less than that of vehicle B and is the minimum when the speed of vehicle A speed equals that of vehicle B. (2) The drivers' characteristics are the most important factor affecting the braking reaction time. The road characteristics and environmental conditions have similar and weak influence. When the speed of vehicle A equals that of vehicle B, the influence of environmental condition is slightly greater than that of road characteristics. (3) In summary, when vehicle A is in a uniform deceleration state, the influence degree of the factors can be sorted: drivers' characteristics, environmental conditions, and road characteristics. The influence degree of the environmental condition is slightly greater than that of road characteristics under certain special conditions.

5. Conclusions

The communication between vehicles in the Internet of Vehicles environment has a great impact on car-following behavior. In order to establish a model that can better describe the car-following behavior in the Internet of Vehicles environment, this paper selects drivers' response time and road friction coefficient as the research objects according to the analysis of safety influencing factors under the environment of Internet of Vehicles and uses these two parameters to improve the traditional minimum safety distance model. Then, the simulation and analysis of the improved car-following distance models are conducted. The required safe following distance of five different cases was compared and analyzed. The following conclusions can be obtained under the three different driving states of the leading vehicle (vehicle A).

(1) With the increase of vehicle speed, the minimum safe following distance increases correspondingly. When the vehicle speed is relatively high, the safe following distance required should be increased even more when the vehicle speed increases by 1 km/h.

(2) In the same driving state of the leading vehicle A, the safe following distance required by case 5 is the smallest, and that required by situation 1 is the largest by comparing five different driving states.

(3) The three factors affecting the safe car-following can be sorted in accordance with the influence degree on the minimum safety distance from large to small are drivers' characteristics, environmental conditions, and road characteristics. The influence degree of the environmental condition is slightly greater than that of the road characteristics. However, the influence degree of the two factors can be regarded as approximately the same in most driving conditions.

The improved models established in this paper can better describe the driving behavior in the Internet of Vehicles environment and provide guidance for vehicle safety following. The ranking of the influence degree of the influencing factors can provide better theoretical support for the vehicle safe driving assistance system.

Data Availability

All data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] L. H. Xu, Q. Luo, J. W. Wu, and Y. Huang, "Study of car-following model based on minimum safety distance," *Journal of Highway and Transportation Research and Development*, vol. 27, no. 10, pp. 95–100, 2010.

[2] H. Hao, W. Ma, and H. Xu, "A fuzzy logic-based multi-agent car-following model," *Transportation Research Part C: Emerging Technologies*, vol. 69, pp. 477–496, 2016.

[3] D. H. Xia, *Research of Automobile Anti-collision Safety Distance Model Based on Characteristics of the Driver.*Master's Thesis, Liaoning University of Technology, Jinzhou, 2016.

[4] Z. Z. Yuan, K. He, and Y. Yang, "A roadway safety sustainable approach: modeling for real-time traffic crash with limited data and its reliability verification," *Journal of Advanced Transportation*, vol. 2022, Article ID 1570521, 2022.

[5] N. H. Jiang and J. G. Yu, "Study on rear-end avoidance model of highway based on neural network," *Forest Engineering*, vol. 26, no. 5, pp. 60–62, 2010.

[6] G. Peng and D. Sun, "A dynamical model of car-following with the consideration of the multiple information of preceding cars," *Physics Letters A*, vol. 374, no. 15, pp. 1694–1698, 2010.

[7] G. H. Peng, "A new car-following model with the consideration of driver's anticipation effect of the traffic interruption probability," *Chinese Physics B*, vol. 29, no. 8, pp. 393–399, 2020.

[8] R. E. Wilson and J. A. Ward, "Car-following models: fifty years of linear stability analysis - a mathematical perspective," *Transportation Planning and Technology*, vol. 34, no. 1, pp. 3–18, 2011.

[9] H. S. Tan and J. Huang, "DGPS-based vehicle-to-vehicle cooperative collision warning: engineering feasibility viewpoints," *IEEE Transactions on Intelligent Transportation Systems*, vol. 7, no. 4, pp. 415–428, 2006.

[10] Q. Luo, X. Chen, J. Yuan, X. Zang, J. Yang, and J. Chen, "Study and simulation analysis of vehicle rear-end collision model considering driver types," *Journal of Advanced Transportation*, vol. 2020, pp. 1–11, 2020.

[11] Q. Luo, X. Zang, J. Yuan, X. Chen, J. Yang, and S. Wu, "Research of vehicle rear-end collision model considering multiple factors," *Mathematical Problems in Engineering*, vol. 2020, pp. 1–11, 2020.

[12] D. H. Sun, T. Zhou, W. H. Liu, and Z. L. Jiang, "Feedback control car following model considering the comprehensive information of the nearest front vehicle," *Journal of Physics*, vol. 2013, no. 17, pp. 81–87, 2013.

[13] H. Wang, Z. Q. Liu, Z. X. Zhang, Y. Li, and W. Wang, "Joint model of car following and lane changing considering double leading vehicles," *Journal of Southeast University (Natural Science Edition)*, vol. 5, pp. 985–989, 2015.

[14] X. D. Hua, W. Wang, and H. Wang, "Traffic flow following model considering vehicle to vehicle interconnection communication technology," *Journal of Physics*, vol. 1, pp. 52–63, 2016.

[15] J. Monteil, R. Billot, J. Sau, and N.-E. El Faouzi, "Linear and weakly nonlinear stability analyses of cooperative car-following models," *IEEE Transactions on Intelligent Transportation Systems*, vol. 15, no. 5, pp. 2001–2013, 2014.

[16] H. X. Ge, Y. Cu, and R. J. Cheng, "Feedback control car following model considering front and rear vehicle effects," *Journal of Physics*, vol. 11, pp. 103–109, 2014.

[17] H. Y. Gu, *Research on Expressway Vehicle Following Model and Simulation under the Environment of Vehicle Networking*, Doctoral dissertation of Southeast University, China, 2017.

[18] A. C. Figueira and A. P. C. Larocca, "Analysis of the factors influencing overtaking in two-lane highways: a driving simulator study," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 69, pp. 38–48, 2020.

[19] J. Yu, *Research on Vehicle Anti-collision Safety Distance Algorithm Based on Driver Characteristics*, Dalian University of technology, China, 2018.

[20] H. Zheng, Y. Qin, and Z. Du, "Analysis of Driving Behavior Characteristics in the Transition of Yellow Light," in *Proceedings of the 20th COTA International Conference of Transportation Professionals*, Xi'an, China, December 2020.

[21] F. Seghir, "FDMOABC: fuzzy Discrete Multi-Objective Artificial Bee Colony approach for solving the non-deterministic QoS-driven web service composition problem," *Expert Systems with Applications*, vol. 167, no. 3, p. 114413, 2021.

[22] X. Chen, S. Wu, C. Shi et al., "Sensing data supported traffic flow prediction via denoising schemes and ann: a comparison," *IEEE Sensors Journal*, vol. 20, pp. 14317–14328, 2020.

[23] Y. Yang, Z. Z. Yuan, J. Y. Li, and Y. H. Wang, "Multi-mode public transit OD prediction and scheduling model," *Advances in Transportation Studies*, vol. 3, pp. 133–146, 2018.

[24] Y. Yang, K. He, Z. Z. Yuan, Y. h. Yin, and M. z. Guo, "Identification of dynamic traffic crash risk for cross-area freeways based on statistical and machine learning methods," *Physica A: Statistical Mechanics and Its Applications*, vol. 595, p. 127083, 2022.

[25] Q. Chang, S. X. Sun, Y. C. Zhao, and R. Gong, "Multi condition safety distance model based on pavement adhesion coefficient estimation," *Journal of Chongqing University of Technology (NATURAL SCIENCE)*, vol. 32, no. 12, pp. 46–53, 2018.

[26] W. Li, H. Li, K. Xu, Z. Huang, K. Li, and H. Du, "Estimation of vehicle dynamic parameters based on the two-stage estimation method," *Sensors*, vol. 21, no. 11, p. 3711, 2021.

[27] X. Chen, H. Chen, Y. Yang et al., "Traffic flow prediction by an ensemble framework with data denoising and deep learning model," *Physica A: Statistical Mechanics and Its Applications*, vol. 565, p. 125574, 2021.

[28] Y. Yang, Z. Z. Yuan, D. Y. Sun, and X. L. Wen, "Analysis of the factors influencing highway crash risk in different regional types based on improved Apriori algorithm," *Advances in Transportation Studies*, vol. 49, pp. 165–178, 2019.

[29] C. Zhai and W. Wu, "A continuous traffic flow model considering predictive headway variation and preceding vehicle's taillight effect," *Physica A: Statistical Mechanics and Its Applications*, vol. 584, 2021.