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Original Article

Space Based Longitudinal Car Following Safety Field Model for Vehicles and its Auxiliary Decision-Making and Traffic System Self-Regulation Methods

Deng Hao

School of Navigation, Wuhan University of Technology, Wuhan 430063, China

***Corresponding Author: Deng Hao**

Abstract:
Using the car following model safety distance and mathematical methods, based on the concept of driving risk field, space occupation, and human factor initiative, a complete new traffic safety field model has been successfully established. It also has the ability to self adjust based on speed, and explores the quantitative reflection of road risk based on the safety distance that represents various complex traffic environment factors, as well as the adaptive ability of the model to this safety distance and its complex traffic environment. Use Matlab to simulate, validate, and improve the model. This model can assist human drivers in driving vehicles, optimize transportation systems, enhance their adaptive and self regulating capabilities, guide the movement of connected autonomous vehicles, and ensure safety to a certain extent in the event of unexpected network interruptions. Therefore, this model has great application prospects, especially in the current context of the development of intelligent transportation systems and autonomous driving in the transportation field. This longitudinal model can also be extended to various directions and all things, reflecting the traffic environment in detail. In other words, leveraging the widely applicable properties of the potential field model can also generate stronger effectiveness.

Keywords: Car following model; Safe distance; Safety field; Self regulating; Human initiative

1. Introduction

In existing transportation theories, some focus on studying the safety of a vehicle, some consider road traffic conditions based on traffic flow, and some conduct model research on local areas or specific problems, such as intersections, lane changes, etc. The reason for this situation is largely due to the complexity of the road traffic environment and the massive amount of data. Not only is there a wide variety, large volume, and complex sources of road data, but further research is still needed on the use of traffic data**1**. The research conducted by combining cutting-edge new technologies such as big data and artificial intelligence is increasingly valued in the field of transportation. At the same time, the rapid development of new generation information technology, especially artificial intelligence, big data, cloud computing and other technologies, has provided strong technical support for the development of intelligent transportation and promoted the construction of a new generation of intelligent transportation system**2**. However, as mentioned above, there are some shortcomings in road traffic theory. Firstly, digitalization and precision are insufficient. Currently, many studies are still based on empirical judgment for the complex environment of roads. In other words, complex road traffic has not been well expressed in mathematical logic language; Secondly, the overall integration and completeness are insufficient, and research is often limited to local areas and specific scenarios, with low generalization and insufficient coverage. On the contrary, fields such as big data and artificial intelligence require much higher levels of digitization than transportation. In order to adapt to and integrate these advanced technologies, it is necessary to promote the development of digital transportation.

On the other hand, although there are many mature theories on traffic safety, when driving, one can only rely on relevant theoretical knowledge and make vague empirical judgments based on their own perception, without a good and relatively accurate quantitative indicator to guide driving behavior. At the same time, there is less information transmission between vehicles, and they rely on their own perceptual experience to make judgments, which is relatively isolated. This is not conducive to overall collaborative response and the guarantee of system security. With the development of communication and computer technologies, vehicle road collaboration has been proposed, emphasizing the collaboration between "vehicles", "vehicles and roads", and "vehicles and people". Combined with Internet and Internet of Things technology, the vehicle road collaboration system has introduced the Internet of Vehicles technology (V2X). V2X covers a variety of interaction modes, including vehicle vehicle (V2V), vehicle road setting (V2I), vehicle Internet (V2N) and vehicle person (V2P) 3. In addition, human perception is far from sufficient for high-precision road safety. Human perception, especially line of sight, is easily affected by the environment and has significant errors. Advanced and high-precision perception devices such as radar and laser can be used to replace human perception,. Therefore, a suitable method for perceptual visualization, safety quantification, and decision-making assistance is also needed. This is the focus of the research.

At the same time, many existing traffic models still remain at the level of spatiotemporal and mathematical models, without effectively incorporating human factors into them. Traffic accidents are fundamentally caused by the imbalance of a system composed of human, vehicle, road, and environmental elements. The causes of traffic accidents can be divided into subjective and objective aspects, with human behavior being the most important factor**4**. Driving a car is a process that generally combines the driver's perception, judgment, and operational abilities, requiring the driver to adhere to his/her driving intentions and choose a series of operational behaviors that are most suitable for the current driving conditions. The behavior of drivers has a significant impact on the safety of vehicles**5**. Therefore, it is necessary to make the traffic model reflect human factors when establishing it.

The ability to self regulate and optimize is a crucial part of future smart transportation systems, equivalent to developing implicit system mechanisms to mitigate risks.

2. Research background

2.1 Overview of car following model and safety distance

In 1950, Dr. Herman **6** used dynamic methods to establish a car following model and proposed the car following theory. Pipes L A **7** proposed the car following theory in 1953. Afterwards, Kometani et al. **8**calculated the safe following distance using the front and rear vehicle speeds and proposed the first safe following distance model. Newell**9** first proposed a speed based single lane following model in 1961. Gipps proposed a model based on safe headway in 1980 **10**.

The vehicle following model characterizes the interaction relationship between adjacent vehicles in the same lane and the trend of driving state changes, and is one of the most basic micro driving behavior models **11**. Classic car following models include the Gazis Herman Ross model **12**, Safety Distance model **13**, Linear model **14**, PsychoPhysical model **15**, Fuzzy Logic based model**16**, etc. Nowadays, in the improvement and development of car following models, the nonlinear changes of the driving road surface have also been considered and valued. Fei et al.**17** proposed a new safety distance model considering the dynamic changes in adhesion coefficient during braking.

The 'safe distance' refers to the initial relative distance required for the rear vehicle to maintain a constant speed and avoid collision with the front vehicle by taking a certain level of braking measures.

2.2 Research ideas and methods based on driving risk field

Consider vehicles as occupying a certain amount of space, and consider their potential impact or accident capabilities as an influence. Space occupation and this influence or ability radiate outwards like waves. Driving risk, like all fields that spread in space, will change dynamically with traffic factors, and its variability is similar to the temporal and spatial changes of the field **18**. Vehicles radiate (safety impact diffusion or radiation) towards their surroundings, which is similar to a spatial material density. Assuming 1 represents occupied space, 0 represents unoccupied space, greater than 1 represents collision and compression, and less than 1 represents a virtual spatial occupation of the entity radiating towards the surroundings, it is used to evaluate distance and collision related safety. The safety status of vehicles can be reflected by their spatial occupancy characteristics. Assuming that the sin function is used to represent the radiation waves of a vehicle for a simple consideration, considering the characteristics of the vehicle itself, the spatial domain of each vehicle should be appropriately selected, that is, the width of its radiation range, as well as factors such as loading and speed. The range here is actually the safe distance. Due to its characteristics such as motion and shape, vehicles have different impacts in different directions. Therefore, it is necessary to find suitable function waveforms to represent the vehicle's occupation of space and the diffusion of its impact.

The research on displacement safety field originated from the trajectory planning method for mobile robots based on the concept of artificial potential field proposed by Khatib **19**. By extending the safety distance model, a safety field model that can quantitatively evaluate driving safety can be obtained**20**. Wang Jianqiang**21** et al**Error! Reference source not found.** proposed the theory of driving safety field (a virtual force method based on field theory), which is very effective for traffic safety planning and has been widely applied in autonomous driving risk assessment and decision planning. This model overcomes the shortcomings of traditional methods in dealing with complex traffic situations and defines a risk quantification index based on the field of driving safety, namely the Driving Safety Index (DSI) **22**. Due to its strong real-time nature and abundant traffic information, the driving risk field can be used to describe the comprehensive driving risks in complex scenarios, and is easy to use for decision-making and control **23**. Combining classic car following models with mathematical methods can generate greater utility. Since the proposal of the driving safety field, it has been improved and developed by combining other models and methods. Zheng et al. **24** treated the motion of vehicles on the road as a force field and used a Hidden Markov Model (HMM) to predict the driver's steering intention. Li Linheng et al. **25** introduced acceleration parameters to establish a safe potential field car following model. Li et al. **26** constructed a new driving safety field model by combining the effects of acceleration and heading angle on driving risk, which dynamically adjusts the potential field with the vehicle's motion to more accurately reflect the actual driving risk under various motion states. Ma et al. **27** improved the driving safety field model by considering the specific driving characteristics of highway weaving areas. Han et al. Error! Reference source not found. proposed a new spatiotemporal risk field (STRF), which fills the gap of existing research that can only obtain instantaneous safety fields by describing dynamic driving risks from the perspective of spatiotemporal coupling.

The driving risk field is a theory and method based on risk, using virtual force and potential field methods, and reflecting various risk factors, with good generalization and generalization properties. However, the risk is relatively virtualized, which is a judgment and prediction of future unsafe situations, and cannot adapt well to the physical space of roads, and cannot reflect the characteristics of spatial entities well. To this end, from another perspective - spatial occupancy, virtual methods are also used for diffusion to establish a car following distance safety field model that better reflects the characteristics of spatial entities.

The driving risk field is established by establishing a field strength formula. To establish a car following model and a safety field model, it can also be implemented based on space through mathematical design of function waveforms.

3. Model Building

3.1 Space and motion characteristics of vehicles and roads

The main motion of a vehicle is forward and backward movement and lane changing, and the frequency of forward movement is obviously higher than that of backward movement. The vehicle is basically symmetrical in shape and motion. The speed of vehicle movement refers to the speed at which the space occupied by the vehicle changes or its position moves.

Considering the longitudinal motion from front to back and upward, assuming the minimum safe distance between the two vehicles is d, classify the safety conditions of the vehicles and determine the boundary point. Consider the minimum safe distance as the boundary point between safe and unsafe, and the collision as the boundary point between non accident and accident.

Assuming A is a set of vehicle boundary points and q (spatial density) is 1, due to practical errors and safety requirements, the boundary is expanded outward by a small distance a. Also, since the areas near each corner of the vehicle are actually inaccessible to other vehicles, if simplification is needed, they can be simplified as rectangular boundaries.

3.2 Preliminary design of longitudinal waveform based on the minimum safe distance, dynamic changes, and human factor initiative of the car following model

Ignore the car itself and analyze it as a particle.

The initiative of human factors in accidents: Under the constraints of safe traffic rules, the cause of accidents is often the active violation or negligence of one driver towards the rules. Therefore, in traffic, the initiative of human factors is the key source of accidents and the focus of traffic safety planning.

The strength of this initiative can be understood as the impact and significance of its actions.

3.2.1 Allocation of Safety Distance between Two Vehicles

Without knowing the environment or spatial background, based on the classical concept of space, the higher the speed, the longer the space experienced in the same time, and the greater the possibility and danger of active destruction, which is proportional to the speed, that is:

$$X = \mathrm{v} \cdot \mathrm{t} \qquad (1)$$

Where t is constant and X is the distance traveled.

During the following process of the two vehicles, the actual indicator of the accident becomes relative distance, and the change in relative distance is caused by relative speed.

Assuming that car A follows car B, and the distance between cars A and B is unknown, and both cars are moving in the same direction, the accident is directly proportional to the relative speed Va $_{\mathrm{Vb}=\Delta\,\mathrm{V}}$.

Consider variable speed:

$$\mathrm{V}_a' = \mathrm{V}_{a0} + \mathrm{at};\ \mathrm{V}_b' = \mathrm{V}_{b0} + \mathrm{bt} \qquad (2)$$

Among them, t represents the time elapsed during the speed change process, $_{\mathrm{Va0}}$ and $_{\mathrm{Vb0}}$ are the initial velocities of car a and car b, Va 'and Vb' are the velocities of car a and car b after time t, and a and b are the accelerations of car a and car b. When the car undergoes variable acceleration motion, the accelerations a and b change over time:

$$\mathrm{a} = \mathrm{f(t)}; \mathrm{b} = \mathrm{f(t)} \qquad (3)$$

$$\mathrm{V}_a' = \mathrm{V}_{a0} + \int \mathrm{adt};\ \mathrm{V}_b' = \mathrm{V}_{b0} + \int \mathrm{bdt} \qquad (4)$$

At the final moment:

$$\Delta\mathrm{V}{=}\mathrm{V}_a' - \mathrm{V}_b'{=}\ \mathrm{V}_{a0} - \mathrm{V}_{b0} + \int(\mathrm{a} - \mathrm{b})\mathrm{dt} \qquad (5)$$

$$\Delta\mathrm{V}_0{=}\ \mathrm{V}_{a0} - \mathrm{V}_{b0} \qquad (6)$$

Where ΔV is the speed difference between the two vehicles at the last moment, ΔV_0 is the initial speed difference between the two vehicles.

According to the previous text, in the case where the distance between a and b is unknown, the accident risk is proportional to ΔV

Accumulate the accident risk, i.e. relative speed, within time t:

$$\int \Delta V dt=\int (V_a' - V_b')dt=\int [V_{a0} - V_{b0} + \int (a-b)dt]dt=\int \Delta V_0 dt + \iint (a-b)dtdt \qquad (7)$$

At each moment, relative velocity causes a change in relative distance, and the accumulated relative velocity results in the change in relative distance over time t. If the distance between two vehicles decreases to 0 at the end of the moment, a collision occurs, and the contribution to the change in relative distance is the contribution to the accident.

So at the final moment, the contribution of each part to the change in relative distance or the decrease in relative distance to 0, i.e. the occurrence of collision, is:

$$\begin{gathered}\text{A's contribution: } \iint (a)(dt)^2 \\ \text{B's contribution: } \iint (-b)(dt)^2 \\ \text{Initial (relative velocity) contribution:} \int \Delta V_0 dt\end{gathered} \qquad (8)$$

Among them, for accidents, car A has a positive gain and car B has a negative gain, which means that car A's positive acceleration promotes the occurrence of accidents, while car B's positive acceleration escapes the occurrence of accidents.

The above is the contribution of the accident at the last moment, but in the case where the specific moment of the accident is unknown, the contribution of each part of the accident at each moment can be accumulated within time t

$$\begin{aligned}&\text{A's contribution: } \iiint (a)(dt)^3 \\ &\text{B's contribution: } \iiint (-b)(dt)^3 \\ &\text{Initial (relative velocity) contribution:} \iint \Delta V_0 \ (dt)^2\end{aligned} \qquad (9)$$

In reality, accidents are a concept of continuous time, and accidents are actually the continuation and consequences of collisions. Therefore, it is necessary to attribute the small time period Δ t of the collision to describe the source of the accident well, and Δ t may to some extent exceed the moment of collision.

The source or contribution of accidents here refers to the responsibility and source for changes in relative distance, which is different from the human responsibility for traffic accidents. In traffic accidents, it is a personnel responsibility related to property and losses.

After having a good attribution, we can proceed with spatial allocation. Assuming that the minimum safe distance between cars a and b is d, Δ_{V0} and the distance between cars a and b are unknown.

Absolute safety situation: Δ V is always less than or equal to 0 at any time.

Among them, 0 is the least safe and serves as the boundary point for the trend of safety changes. That is to say, when ΔV<0, the system changes towards a safe direction. ΔV>0, the event changed in a dangerous direction, ΔV=0 The security status of the system remains unchanged. The size of ΔV reflects the speed of the trend of change.

The allocation results for each part of the safety distance are based on the proportion of contribution:

$$\begin{aligned}&\text{A}: \iiint (a)(dt)^3 \ / \ [\iiint (a)(dt)^3 + \iiint (-b)(dt)^3 + \iint \Delta V_0 \ (dt)^2] \\ &\text{B}: \iiint (-b)(dt)^3 \ / [\iiint (a)(dt)^3 + \iiint (-b)(dt)^3 + \iint \Delta V_0 \ (dt)^2] \\ &\text{Initial:} \iint \Delta V_0 \ (dt)^2 \ / [\iiint (a)(dt)^3 + \iiint (-b)(dt)^3 + \iint \Delta V_0 \ (dt)^2]\end{aligned} \qquad (10)$$

The safety distance allocated to the initial part is the required initial safety distance accumulated and left over from all times before time zero. Allocate the initial safe distance to two vehicles according to formula (6):

$$A:[\iiint(\mathrm{a})(\mathrm{dt})^3+\iint(\mathrm{V_{a0}})(\mathrm{dt})^2]\ /\ [\iiint(\mathrm{a})(\mathrm{dt})^3+\iiint(-\mathrm{b})(\mathrm{dt})^3+\iint\Delta V_0\,(dt)^2] \qquad (11)$$

$$B:[\iiint(-b)(dt)^3+\iint(-\mathrm{V_{b0}})\,(\mathrm{dt})^2\,]\ /\ [\iiint(a)(dt)^3+\iiint(-b)(dt)^3+\iint\Delta V_0\,(dt)^2]$$

The sum of the triple integral of acceleration and the double integral of velocity of a vehicle within a certain period of time can be defined as its action during that time, and the external allocation of safety distance is based on the action. Use the letter $\mathrm{A_a}$ to represent the action of car $_\mathrm{a}$:

$$A_a=\iiint(\mathrm{a})(\mathrm{dt})^3+\iint(\mathrm{V_{a0}})(\mathrm{dt})^2 \qquad (12)$$

b> At 0:00, the allocation received by car B may be negative, indicating that in this situation, car B is resisting the accident to some extent by accelerating and escaping from the impact of car A.

Therefore, for a car, it can be assigned a safe distance from the front and rear vehicles to obtain its own safety zone. For safety reasons, the safety areas of each vehicle cannot overlap, that is, a safe distance must be ensured.

3.2.2 Allocation of safety distance between the front and rear of bicycles

According to formula (1), in the case of unknown surrounding environment, the risk of accidents is proportional to the distance experienced, and for the same time, the distance experienced is proportional to the speed.

When the speed is 0 and the initiative at the beginning and end is 0, the safety domain should be symmetrical and evenly distributed, that is:

$$L_a=L_f=L/2 \qquad (13)$$

Among them, L is the total safety distance obtained by assigning safety distances to the vehicle and the front and rear vehicles respectively (the initial safety distance is not assigned to the vehicle), while $_\mathrm{La}$ and $_\mathrm{Lf}$ are the safety distances obtained by reassigning the internal safety distance of the vehicle to the rear and front vehicles respectively.

When the safety distance between the front and rear is not redistributed, the safety distance between the front and rear is exactly the safety distance obtained by allocating the contribution of the relative distance change based on the speed and acceleration of a vehicle adjacent to that direction. Establish a model to allow the vehicle to virtually move or deviate within its own safety zone based on its own speed. When the speed is 0, it is located at the midpoint of the safety zone. When the speed in a certain direction tends towards positive infinity, it is precisely located at the boundary of its safety zone in that direction. In this way, when the speed in a certain direction is too high, the car gets closer to the boundary of the safety zone in that direction, and the driver realizes the need to slow down by observing the corresponding visual interface. Therefore, the speed of the vehicle is represented using its virtual offset relative to the midpoint within its own safety domain. Meanwhile, the change in speed is a reflection of the driver's active operation, which means that the virtual offset indirectly reflects the driver's operability or initiative through speed.

Under the premise of formula (11), it is also necessary to ensure that when the velocity in a certain direction approaches positive infinity, the safe distance in that direction approaches 0.

Using an exponential function, with the forward direction of the vehicle as the positive direction of velocity, the internal safety distance is allocated as follows:

$$\Delta L = (L/2) \cdot e^{-1/v}$$
$$L_a = (L/2) \cdot (1-e^{-1/v})$$
$$L_f = (L/2) \cdot (1+e^{-1/v}) \qquad (14)$$

Among them, ΔL is the modulus of the difference in safe distance between the front and rear directions, and e is a relatively gentle value set arbitrarily, which can be adjusted later.

Here, speed is used for allocation. In fact, when the speed is not constant, the driving distance needs to be calculated using integration, which is the same as the external safety distance allocation above, and will not be repeated here.

3.2.3 Waveform Settings

Using F (x) to represent spatial density, with the car as the origin and the safety endpoint F (x)=0, attention should be paid to danger. Therefore, the closer to danger, the more accurate, and the faster the change, that is, the more obvious the change in safety factor. Therefore, when approaching the center, there is a drastic change. Using the exponential function again, we still use the x<0 part in ex, with the car as the center or origin, and compress it on La or Lf to construct the waveform:

$$x>0\text{时，} F(x)=e^{-(xk)/1}$$
$$x<0\text{时，} F(x)=e^{(xk)/1} \qquad (15)$$

When **l** and x are greater than 0, they are equal to L_f; when x is less than 0, they are equal to L_a, and k is a larger number that facilitates waveform adjustment.

In fact, it is impossible to compress zero to negative infinity to a finite length, but a large number can be used to make $e^{-|x|k}$ approach zero, and the value of k is therefore dependent on accuracy.

Here, a single base exponential constructor is used, where the waveform and its rate of change or slope at each point are related to e^k. In fact, regions can be further subdivided according to actual needs, and different e^k values can be used for each part to construct more complex function graphs. In this way, by selecting the e^k value, it meets the needs of complex practical environments.

If k is too small, it will cause large errors, and if k is too large, it will cause changes to be too concentrated, with no fluctuations in the boundary waveform, that is, the image response is not sensitive. When there is a clear response, it is already a highly dangerous situation.

In summary, the overall idea of the model is to obtain the security domain, allocate the first and last security domains, and display the waveform.

3.2.4 Model boundary points

When the distance between two vehicles is exactly equal to the minimum safe distance, which happens to be when the front and rear waveforms meet, and when the distance is less than the minimum safe distance, the spatial density accumulates or superimposes, resulting in peaks with values less than 1, indicating an unsafe situation.

The peak with a value of 2 represents the beginning of the collision, and afterwards, the collision compression will produce a peak exceeding 2.

4 .Scenario simulation and decision-making methods

4.1 Scene Description

Assuming that three vehicles, a, b, and c, are driving forward in the same lane in sequence, and cannot overtake on a single lane, and the three vehicles are accelerating at a constant speed, the safety domain of the middle vehicle b is studied. The speed unit is meters per second, and the acceleration unit is meters per second squared. Here, a relatively simple safety distance is used, assuming that the maximum acceleration of the three vehicles is 4 meters per second squared, which can be used for deceleration. The minimum safety distance is the forward distance traveled by the rear vehicle to reduce the relative normal speed to zero at the maximum relative deceleration. Assuming that only the rear vehicle responds during the emergency braking process, the acceleration and speed of the front vehicle remain constant, meaning that the front vehicle is unaware or unaware of the dangerous situation. The relative maximum deceleration is 4 meters per second squared plus the forward acceleration of the front vehicle. The default length of the car is 5 meters. Use MATLAB for numerical simulation.Using position as the horizontal axis and spatial occupancy integrity as the vertical axis.

In this simplified scenario, the safe distance depends on the relative speed. Note that when the relative velocity is negative, the safe distance is also negative. However, the negative value here does not mean that the distance can be safe even when it is negative, but rather a description of its inability to keep up with the property. In other words, in the case where the distance between two vehicles is unknown, a collision may occur when the relative speed of the rear vehicle to the front vehicle is greater than 0. When it is equal to 0, the speed is the same, and there will be no collision. The safe distance is 0, and when it is less than 0, there will be no collision and it will develop in the opposite direction of the collision, that is, far away. A negative safe distance is a reflection and measurement of this trend or safety. A positive relative speed indicates the need to use a safe distance for defense, while zero and negative values indicate no need for defense, or even opening up. The allocation of internal safety distance depends on the initial velocity and acceleration, which can simultaneously characterize safety and proactivity.

During simulation, the length of the vehicle body needs to be included, and the diffusion of the vehicle boundary is temporarily not done. However, in order to ensure safety, it is recommended to do some diffusion processing in real scenarios.

In reality, acceleration cannot change suddenly. To simplify the calculation, it is assumed that acceleration can change suddenly.

4.2 Scene Simulation

Scenario 1:

Table 1

Current speed at the moment	Current moment acceleration
10	1
20	2
30	3

The calculation result shows that for b, La=Lf=0, the plot is as follows:

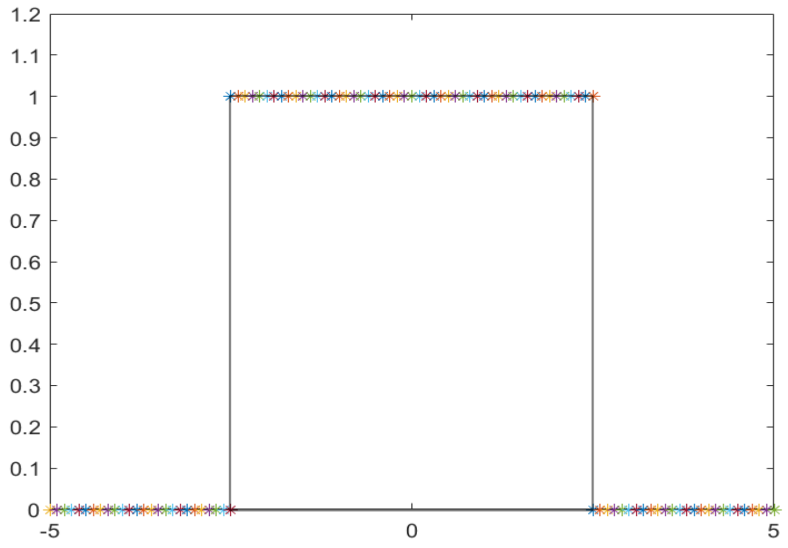

Figure 1 Scene 1

The rectangular area in the picture represents the safety domain and space occupation of vehicle B.

The safety field of vehicle B only has its own scope, and the explanation for this situation is that the initiative or destructiveness of vehicle B's impact on the front vehicle and escape from the rear vehicle cancel each other out. From the perspective of car B, it can be understood as passively accepting the collision between the front and rear cars.

In fact, speed is an intrinsic property that is related to the operator; Distance refers to external conditions. The method of establishing the model here integrates internal or human factors and external conditions.

In scenario 1, the distance between each vehicle is not provided. Assuming the distance is small enough, vehicle B will be collided. Since the safety distance between the front and rear of vehicle B is 0, its front and rear initiative will cancel each other out. Therefore, no matter how vehicle B reacts and operates, it will cause impact in one direction and escape in the other direction, sacrificing the safety of one party to protect the other, that is, avoiding one party and actively colliding with the other. Here, a more vivid expression of "offending" can be used. The result of vehicle B's reaction is that it must offend one party. Without knowing the distance between car B and the front and rear vehicles, car B should maintain its state and not make any changes, while notifying car A and car C to actively make adjustments. If the distance between the front and rear vehicles is known and there is a significant danger within a short period of time at the current distance, and the front and rear vehicles cannot cooperate with each other and are not aware of the dangerous situation of vehicle B, then the party with relatively less harm and loss can be chosen to offend, that is, "bullying the soft and fearing the hard", thereby reducing the loss of life and property.

Scenario 2:

Table 2

Current speed at the moment	Current moment acceleration
40	3
30	2
40	4

According to the previous text, attribution is actually an assessment and prediction of accidents and risks within time t. Therefore, the larger the selection of t, the wider the time range of evaluation; conversely, the smaller t, the shorter the time interval, and the higher the accuracy. T=1s is used in the simulation. K is temporarily set to 5. The calculation results are plotted as follows:

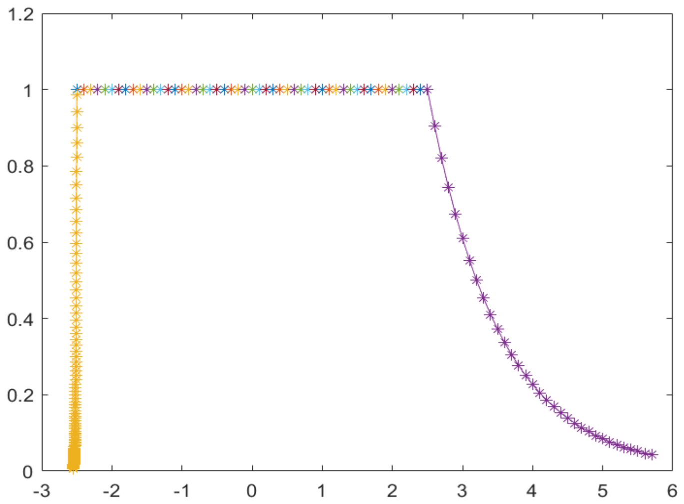

Figure 2 Scene 2

During the calculation process, it was found that the safe distance between car b and car a was negative, indicating a safe state between the two cars. It was also found that the contribution of car B was positive but its proportion was negative. In the end, car B was assigned a positive safety distance, while car A obtained a negative safety zone and even invaded the interior of car A. Similarly, the negative safety field of car A indicates that it is in a safe state. Since vehicle B still contributes positively to the accident, its contribution is positive. However, the total contribution is negative, indicating that the negative contribution of car A to the accident between car A and car B has overshadowed the positive contribution of car B, resulting in a negative total contribution to the accident between the two cars. This means that the accident will not occur and may even be too safe.

By comparing speed and acceleration, it can be concluded that car B does not have a risk of catching up with car A, but there is a risk of being caught up by car C.

The image display is actually a more appropriate allocation of security domains to one's own rule based on one's own initiative and mutual cooperation. A wider security domain in a certain direction indicates greater initiative and operational space in that direction.

From the image, it can be seen that the operating space in the rear of the vehicle is far less than that in the front, so avoiding the front vehicle from the rear is an ideal way of working on the road. On the other hand, when the rear safety zone is still relatively long, it means that there is still some operating space for self rescue, which can accelerate the further compression of the rear operating space and thus self rescue. If the rear operating space is almost zero, the difficulty of self rescue is relatively high, so it is advisable to notify the rear vehicle to change its own motion state as much as possible. That is to say, the farther away the operating space from the vehicle itself, the easier it is to be actively utilized. If you need to quantify the operable space, you can use the safety distance internal allocation ratio. On the other hand, the acceleration towards a certain direction can drive the internal allocation of the security domain to shift in the same direction, providing longer security domain requirements for that direction to suppress the harm of initiative. At the same time, it can reduce the security domain in the other direction and bring the invaded security domain back to an uninvolved state, that is, from an unsafe state to a safe state.

Due to the certain symmetry between the front and rear of the vehicle, the situation where the operating space is shifted backwards is similar.

The proactive decision-making here is actually based on equivalent substitution between the front and back security domains. If the front and back security domains are not equivalent, it can lead to biased or directional decisions. In fact, people, including drivers, often sit in the front of the vehicle, so forward safety is more important than backward safety. However, front and rear safety are considered equally important here.

5 .Quantification of Impact Capability and Standard Field

In scenario 2, taking k=5 will affect the image. Draw the following figure for k=1 and 20 respectively:

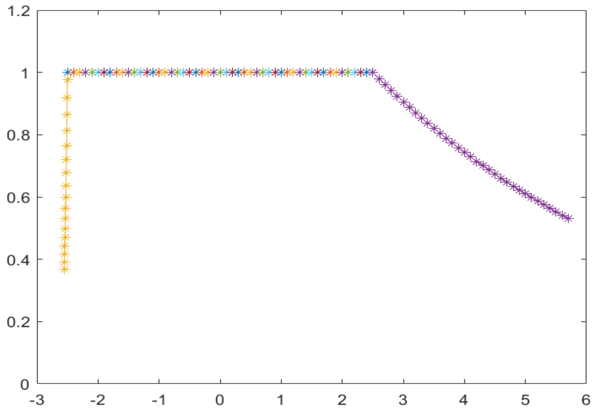

Figure 3: k=1

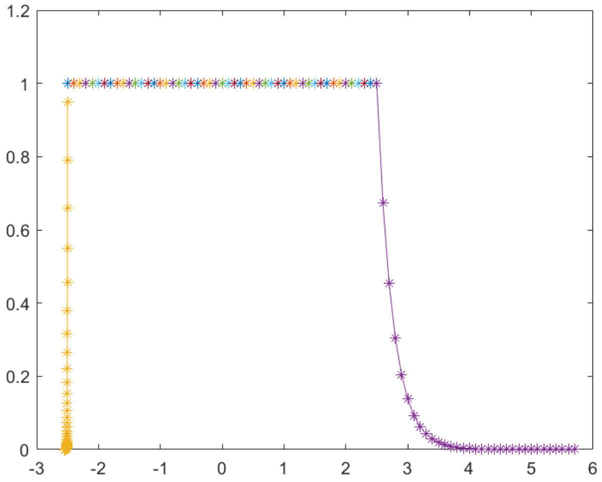

Figure 4: k=20

After comparison, it can be found that when the value of k is small, the height of the boundary in the security domain is still relatively high, which results in a large error and is not the desired model; At the same time, when the value of k is large, although the boundary height is low and the error is small, the waveform only changes significantly when approaching the vehicle, which makes the response to impact less sensitive.

Assuming B is the length of the vehicle. It was also found that e5≈148.4≈V·B=150. Using V · B instead of ek to redraw the image is as follows:

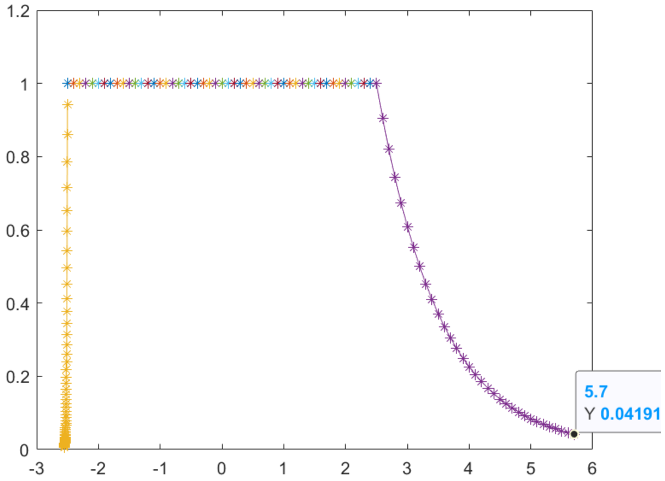

Figure 5 VB=150

It can be seen from the graph that the waveform basically meets the requirements, and the error is only a few percent, which is acceptable.

In fact, the driver indicates the space occupied by the vehicle, and the speed indicates the change in the vehicle's spatial position. It is preliminarily believed that a vehicle's impact capability is related to these two factors.

Furthermore, at each moment, the vehicle occupies the spatial width of the vehicle length, and the product of the vehicle length and speed is exactly the sum of the overlapping spaces occupied by the vehicle length at each moment in a unit time, without offsetting each other.

Assuming the spatial background is unknown, a car is placed in the unknown space, occupying a certain amount of space and destroying the original background. So at each moment, the width of the space occupied by the vehicle can represent its destructive power on the space. The accumulation of destructive force per unit time is a description of the destructive force of a moving vehicle.

However, under the condition of infinite randomness, where the spatial background changes relative to the previous moment at every moment, and the new background is also random and unknown, the product of speed and vehicle length can indeed represent its destructive power. However, in reality, traffic is a relatively safe state, which means that the ability or destructive power of vehicles to collide due to human factors, spatial continuity, and other reasons is not as great as described above, and is weakened. The space occupied by the vehicle in the previous moment is still occupied by the vehicle in the next moment. In a continuous space, the continuous impact of the vehicle on the same space in time should not be counted repeatedly. If the starting and ending points are ignored, the repeated calculation of space can be quantified as B divided by V, that is, each space is repeated B/V times. So dividing by B/V gives the car's impact capability V^2. However, this is only its ability to actively impact other cars, and the impact is mutual. That is to say, the other party will actively enter or collide with the already occupied space. The space occupied in the previous moment will still be occupied in the next moment. The previous moment is safe, but the next moment may be collided, which satisfies the condition of infinite random spatial background. Therefore, overall, the quantitative indicator of vehicle impact is still V multiplied by B. Based on this, the impact capability can be classified into active impact capability （V^2） and passive impact capability ($VB-V^2$). When B=V, the passive impact capability is 0; When B>V, it has passive impact capability; When B<V, it has the ability to avoid passive impacts in an infinite random space background.Every car here is hit and actively impacted, which actually doubles the impact, but the proportion of risks remains unchanged.

Multiplying V by B reflects its ability to withstand impact, and based on this, a risk field can be established. Just multiply the original waveform by VB.

Furthermore, formula (14) can be corrected:

$$\begin{aligned}&\text{If } x>0,\ F(x)=(VB)^{1-x/l}\\&\text{If } x<0,\ F(x)=(VB)^{1+x/l}\end{aligned}\qquad(16)$$

Risk field

$$\begin{aligned}&\text{If } x>0,\ F(x)=(VB)^{-x/l}\\&\text{If } x<0,\ F(x)=(VB)^{x/l}\end{aligned}\qquad(17)$$

Security Field

In fact, traffic risk is also known as the ability to withstand collisions, or VB. The risk field distinguishes individuals and can reflect the traffic environment and its risks in detail, while the safety field reflects safety and does not differentiate individuals, treating the safety of each individual as equally important. It can be considered that the safety field is the standardization of the risk field, that is, regardless of the VB or the level of risk, it is transformed into the completeness of space occupation. The space occupation at the vehicle body is 1, and the boundary space occupation of the safety field is 1/VB, that is, the risk at the boundary of the safety field in the risk field is 1. Meanwhile, both the risk field and the safety field adopt exponential diffusion attenuation. On the other hand, the risk field reflects risk, as well as danger or destructive power. The process of standardizing from risk field to safety field can also be considered as the proportion of risk retention with distance, that is, the retention of risk with distance is equivalent to its spatial occupation and diffusion.

At the same time, the risk here is a combination of self collision and being hit, with each other being doubled in collision and being hit, but the proportion of risk between individuals remains unchanged.

6. Quantitative method for single lane safety

status based on safety distance

In the stage of obtaining safety domain, based on the contribution of relative distance changes, the result is that the preceding vehicle obtains a negative proportion of safety distance, and the following vehicle obtains a positive proportion of safety distance.

Each car is chasing after the front car and escaping from the rear car, and the safety distance between cars is a description of the safety requirements or protection needed to prevent collisions between the two cars using space. Therefore, the safety distance between two cars is a reflection of the safety situation as the acceleration increases with speed. That is to say, at higher speeds, the safety situation becomes worse, that is, accidents are more likely to occur, and the safety distance is also larger.

The contribution of relative distance changes is the proportion of their respective influences.

The process of offsetting the positive and negative safety distances between the front and rear of a car is actually the result of multiplying the severity of the safety conditions or the size of the safety distance in each direction by their own proportion, and then adding them up.

Therefore, the sum of the safety distances at the beginning and end can be considered as the overall impact of one's own adverse safety conditions.

As can be seen from the above, the safety distance is a reflection of the adverse safety conditions. Therefore, the total safety distance of a section of road can also reflect the overall road safety conditions. By dividing it by the total number of vehicles, the average safety distance per vehicle can be obtained, which can reflect the average safety conditions of vehicles in the area where the vehicle is located.

However, the severity of road safety here is based on speed, which means that the higher the speed, the smaller the deceleration acceleration, and the worse the road safety situation. Conversely, the better. This is consistent with the general belief in reality that the slower the speed, the safer it is. The total safe distance of a road can be defined as the road safety environment index, which is more accurate than simply using speed to judge the road safety environment condition, because the safe distance can take into account various factors such as vehicle acceleration and road conditions.

Similarly, there is an average safe distance per vehicle and an average safe distance per meter. The average safe distance per vehicle can reflect the safety status of the number of vehicles, while the average safe distance per meter can reflect the safety status of the road length. The safety distance per meter for each vehicle is a reflection of the overall safety situation based on the number of vehicles and road length. They are all calculated by dividing the total safe distance of a section of road by the corresponding indicators.

The speed based road safety environment index is far from sufficient to reflect the road safety situation. The environmental index describes basic factors such as speed, acceleration, road surface, and braking related to safe distance, similar to describing the environment. The environmental index is actually the shortest total safety distance required to ensure safety, or the minimum environmental requirement, or survival requirement. In addition to the minimum environmental requirements, road safety also needs to consider the gap between the actual conditions and the environment or requirements, which can be reflected to some extent by dividing by the road length or number of vehicles. The conductor is also a worthy consideration among them. The total length of the road should be reduced as much as possible by the length of the vehicle.

The overall response may often mask extreme individual situations. It is feasible to use the above quantitative indicators with a certain road length in a relatively safe and stable overall situation, but the shorter the road length, the more accurate it is. For roads, individual accidents and unsafe conditions should be captured and reported as much as possible.

Based on the principle that safety distance equals risk, and safety distance equals protection, this unifies protection and risk. By re understanding the model, the contribution to relative distance is equal to one's own risk sharing. The redistribution of internal front end safety distance is based on transferring a small amount of front-end risk to the back-end through speed transfer. Each vehicle does this to ensure that the safety distance at the rear end is greater than zero when it is unsafe or L is not zero, playing a certain protective role.

From a risk perspective, the larger the safety distance, the greater the risk or danger. When considering only speed and acceleration, regardless of the road environment, the higher the relative forward speed of the rear vehicle compared to the front vehicle, the smaller the relative forward deceleration, which is consistent with the previous discussion on safety environment.

Note that the safety domain of a car only represents the risk based on one's own initiative and responsibility, and the responsibility here is also based on the contribution to the relative distance.

7 .The result of internal safety distance reallocation and its self optimization effect

According to formula (13), the offset ΔL= （L/2）·e-1/v.

Since the safety distance is calculated using the safety distance formula, the subsequent work only involves redistribution, so the total safety distance on a road remains unchanged. However, through internal redistribution, the distribution of the total safety distance among vehicles will change.

Based on the large scenario described in 3.1, consider the three vehicle following model, assuming that the driver always approaches the designed safety distance model or uses the safety field model to guide driving during the driving process.

By calculation, it can be concluded that:

$$\mathbf{d}_{ab}{}' - \mathbf{d}_{ab} = \frac{1+e^{-1/v}}{2}\cdot \mathbf{d}_{b-} + \frac{e^{-1/v}-1}{2}\cdot \mathbf{d}_{b+} \qquad (18)$$
$$d_{bc}{}' - d_{bc} = \frac{1-e^{-1/v}}{2}\cdot d_{b+} - \frac{e^{-1/v}+1}{2}\cdot d_{b-}$$

Among them, d_{ab} and $d_{ab}{}'$ are the safety distances between vehicles a and b before and after internal redistribution, d_{bc} and $d_{bc}{}'$ are the safety distances between vehicles b and c before and after internal redistribution, and d_{b+} and d_{b-} are the front and rear safety distances before and after internal redistribution of vehicles b.

Based on the actions defined in the previous text, we can also derive:

$$d_{b+} = A_b/(A_b-A_a)\cdot d_{ab} \qquad (19)$$
$$d_{b-} = -A_b/(A_c-A_b)\cdot d_{bc}$$

Consider a more general scenario, where vehicle B pursues the preceding vehicle and escapes from the following vehicle; The positive safety distance is greater than 0 and the negative safety distance is less than 0. It was found that in this situation, a portion of the safety distance between cars A and B was internally redistributed and increased to between cars B and C. Moreover, this situation is common unless:

$$\frac{1+e^{-1/v}}{2}\cdot d_{b-} + \frac{e^{-1/v}-1}{2}\cdot d_{b+} = 0 \qquad (20)$$

In the general case considered above, assuming that the absolute values of $d_{b+}$and d_{b-} are equal, it will be found through calculation that before reassignment, the front and rear safety distances of car b are exactly opposite to each other. After reassignment, the front and rear safety distances of car b are exactly 0, which means that the initiative of the car before impact and the car after escape cancel each other out. Assuming that each driver is approaching the redistributed safety distance until the system stabilizes, it is necessary to ensure that all vehicles in the system are at a constant speed and acceleration, even if the total safety distance approaches 0, that is, the total risk approaches 0. At this point, based on the same state of each vehicle, it can be inferred that the actions of each vehicle (as defined in 2.2.1) are the same, equivalent to relative stillness. The safe distance between every two vehicles is also zero. Therefore, the model controls the vehicles in the system to move towards a direction of relative stillness, but does not control the distance between vehicles. That is to say, as long as there is a difference in speed, there will be fluctuations and the system will be in a dynamic equilibrium state. All vehicles are in a relative stationary state with constant speed and equal acceleration, moving together relative to the road surface. In a relatively safe single lane following traffic system where all drivers use the safety field model and no traffic accidents occur, assuming that the speed is in the positive direction and the safety distance between the two vehicles is positive, then each vehicle transfers the safety distance from the preceding vehicle to the safety distance from the following vehicle, that is, transferring the front-end risk to the back-end as mentioned above.

According to formula (18), ignoring all safety distances, i.e. keeping all safety distances constant, if the speed increases, the value of $d_{ab}' - d_{ab}$ will also increase. In the general case mentioned above, if the value is less than zero, an increase means that its modulus decreases. That is to say, the amount of safe distance that the vehicle carries from the front end to the rear end decreases, which will cause the front safety distance to increase relative to low-speed vehicles. This will make it easier for the front safety field to overlap, and the driver will have to widen the safety distance between the front and rear vehicles, requiring deceleration; Similarly, the front end of low-speed vehicles is relatively less likely to overlap with safety areas, so you can confidently increase speed. Only when the previous stable situation is reached, the state of all vehicles will not adjust. At this time, if a vehicle actively changes its state, it will push the entire system state to change. Therefore, the system is in a dynamic equilibrium state and constantly pursues a stable state, that is, the interior of the vehicle is relatively stationary.

For ease of understanding, space can be imagined as longitudinal waves, with high density at the peak representing compression and high danger, and can be reflected to the driver. The driver's reaction promotes a reasonable distribution of safety distance and risk.

For a transportation system, it can be seen as a transformation from the relatively stationary stable state mentioned above, which means that the cause of traffic accidents is the instability of the transportation system and excessive compression of local space.

Based on the principle that safety distance equals risk, it is ensured that the number of vehicles deployed in a certain space will not excessively compress the space and ensure safety. That is, each vehicle can obtain the space it needs for safety or survival, and there will be no danger under the condition of thorough sharing. The cause of accidents is unreasonable space allocation or local compression caused by unstable or uneven systems. Therefore, promoting equal spatial distribution and risk sharing can improve the stability of the transportation system, thereby enhancing its safety. Based on this method, the risk of equal distribution will eventually return to zero, which means that due to the driver's initiative, the uniform distribution or safety status of the transportation system will be changed, resulting in danger. The risk is actually generated by the driver's operation, and can also be eliminated through the driver's operation.

There is no doubt that e in formula (18) controls the span and speed of the traffic system's self-regulation. If the span is too large, collisions are more likely, and if the span is too small, the self-regulation speed may be too slow or even ineffective. Therefore, more detailed research is needed on the self-regulation process.

In fact, these can be seen from the internal allocation in 2.2.2. The vehicle moves forward, and before the internal redistribution, the front safety distance is positive and the rear safety distance is negative. The final redistribution requirement is that when the total safety field is not zero, the front and rear safety distances are both positive. From this, it can be seen that the safety distance between the front two vehicles is transferred to the rear two vehicles, and the transfer generally occurs to each vehicle. The higher the speed, the more proportion of the safety distance is placed in the forward direction. Until the forward speed is infinitely positive, the safety field belongs entirely to the front end. That is to say, the higher the speed, the smaller the ability to transfer the safety distance to the rear end. That is to say, the higher the speed, the more protective the front safety distance is, making it easier for the front end to overlap in the safety field and forcing the driver to slow down by pulling back the front and rear distance.

The real self-regulation process is much more complex than what was mentioned earlier.

Constant speed and equal acceleration, stationary as a whole, only moving together relative to the road surface, this is the ideal operating state of the transportation system. The total safe distance and risk are both zero. The existence of a safe distance is to protect against danger. Without a safe distance, it means there is no danger. In the safety distance, factors such as road surface and pedestrians can be included. By incorporating these factors into the development of safety distance, the model can actively adapt to safety distances and real traffic environments that contain various factors due to its self optimization ability. Of course, the potential field is not limited to only one vertical direction. Similarly, the field is not limited to safety and vehicles.

The biggest challenge of the current model is the insufficient consideration of actual distance. The control of self regulating rate is currently the biggest challenge for the model.

8 .Conclusion and Outlook

This article establishes a new potential field model based on space, and at the same time, it has adaptive capability based on constant velocity control and detailed reflection of safe distance on road environment. Compared to the reflection of the potential field of the virtual force method on the interaction relationship between objects, this potential field model has a better real-time reflection of the spatial state. The potential field models established by the two methods must be unified in the end, and their interrelationships and unified methods need to be further studied. In addition, it is necessary to strengthen the control of distance and the modeling of stationary objects. One of the suitable applications of potential field models is in the field of autonomous driving.

The spatial potential field model has guiding significance for autonomous driving. When accuracy is not sufficient for high safety, it is possible to consider using a potential field model, fuzzy boundaries, and spatial potential field transformation, so that the individual space in the potential field occupies more than the real individuals. At the same time, the height of the potential field represents the height of the risk, and the height difference of the potential field represents the risk difference. The safest requirement is to minimize the height, that is, minimize the risk. In this way, in the visualized risk potential field, the risk can be measured and calculated through height, and the route can be planned, requiring the total risk or total height to be minimized. For autonomous driving, objects can be roughly perceived through visual models, radar, lasers, etc., and values can be set to simulate human intuition. The size of the object can be slightly overestimated, and the potential field of the surrounding environment can be established. By simplifying the potential field environment of the real environment, autonomous driving can be guided, which will greatly reduce the amount and difficulty of thinking and calculation. It can even make cars no longer rely on the calculation of network level models, and locally carry models to guide autonomous driving. This has great practical significance and may have significant applications in fields such as autonomous driving. On the other hand, based on the idea that space occupation equals risk, for stationary objects, their size should be directly transformed into potential field entities, and a distinction and transformation should be made between stationary and moving fields. At the same time, the potential field should be able to extend infinitely, which will result in individuals accumulating a certain original height in the potential field. This can ignore the field height outside the safety domain of individual individuals, or ignore the part of the potential field extension process that is less than a certain height.

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