A Dynamic Risk Assessment Method for Vehicles at Intersections Considering Imminent and Collision Risks

Siman Wu [1], Pengrui Li [1], Miaomiao Liu [1, *], Doudou Liu [1], Shengrui Wei [1], Mingyue Zhu [1], Xiaochen Liu [1] , Hui Deng [2]

[1] School of Transportation Science and Engineering, Beihang University, Beijing 102200, China;

[2] China Telecom System Integration Co. Ltd, Beijing 100000, China

Abstract. Most of the traditional dynamic risk assessment methods for vehicles use parameters such as distance and speed to describe the current motion relationship between a traveling vehicle and surrounding objects, which cannot well describe the risk associated with potential future collisions of multidirectional traffic participants at intersections. To better describe the collision possibilities of moving vehicles and surrounding objects in an intersection, this study proposes a dynamic risk assessment method for vehicles considering imminent and collision risks. Firstly, the imminent risk is calculated based on the positional relationship between the surrounding objects and the target vehicle and the speed of the target vehicle, which characterizes the movement trend of the surrounding objects and the target vehicle; the trajectories of the surrounding objects and the target vehicle are predicted, and the collision risk is calculated, which characterizes the possibility of collision between the surrounding objects and the target vehicle. Then, the conflict time between the surrounding objects and the target vehicle is calculated, and the imminent risk and collision risk are selected; finally, the risks posed by other environmental elements to which the target vehicle is exposed are combined to determine the overall risk faced by the vehicle in real-time. This information can serve as a robust foundation for issuing safety warnings and making assisted driving decisions. In terms of experimental validation, the braking events were screened using the actual intersection data in Suzhou, and the distributional differences of the risks were examined using statistical methods, it was found that the differences in the risk levels before and after braking were significant at the 0.1% confidence level, which indicated that the model could accurately measure the driving risks of the vehicles, and the validity of the model was verified.

Keywords: driving risk estimation; imminent risk; collision risk; driving safety .

1. Introduction

Road intersections as a key node of road traffic, traffic conditions are intertwined and changeable, intricate and complex, it is difficult for drivers to perceive all the potential risks in the surrounding environment, and it is easy to misjudge the current safety conditions of vehicles driving, and it is more likely to have traffic accidents. Therefore, accurate vehicle risk assessment is of great significance in avoiding traffic accidents, safeguarding people's lives and property, and improving the safety level of intersections.

Existing methods for vehicle operational risk assessment can be categorized into two types: with and without collision detection[1]. Collision detection refers to a certain degree of prediction of the trajectory and relative position of the target vehicle and the surrounding vehicles based on the dynamics model, based on which the possibility of collision between the target vehicle and the surrounding vehicles is judged as the basis for risk assessment. Examples include Time to Collision (TTC)[2], as well as Modified Time-to-Collision (MTTC)[3], which is derived based on TTC, and Time Exposed Time-to-collision (TET)[4]. Due to the ability of this method to quickly assess the risk of the current situation, many scholars have deepened their research: KIM et al. based on a fifth-order polynomial and introduced target lane detection to predict the motion trajectories of surrounding vehicles to achieve accurate TTC prediction over a longer time horizon[5]. LEE et al. employed a constant acceleration model as a motion prediction model for surrounding vehicles to generate the Predictive Occupancy Map (POM) [6]. No-collision detection, i.e., the assessment method based on potential field theory, refers to the concept of potential field in physics, assuming that the elements in the environment can generate field strengths, and constructing risk fields for different environmental elements around the main vehicle to characterize the risk of the environmental elements for risk assessment, which can take into account the risk of the target vehicle caused by multiple environmental elements, and is more comprehensive. Wang et al. introduced a novel notion termed the "driving risk field," aimed at quantifying the level of risk associated with vehicle operation safety resulting from various factors within the human-vehicle-road interface [7]. Li et al. introduced a new driving risk indicator (PFI) for assessing the level of vehicle risk by constructing a potential field model that integrates the effects of various types of traffic information on driving risk[8]. Li et al. introduced the acceleration parameter to calculate the field strength based on the relative position and relative velocity[9].Kolekar et al. proposed the Driver Risk Field (DRF), which uses parabolas and multiple Gaussian functions in the longitudinal[10-11]

In the existing vehicle risk assessment methods, there are collision detection methods are mostly established for specific scenes, single environment elements, and high scene dependence, and do not apply to complex driving scenes with complex flow directions and multiple conflicts at intersections. Although the no-collision detection method comprehensively integrates multiple scene elements and provides a unified risk assessment of the intricate traffic environment, its model construction process solely accounts for the instantaneous states of environmental elements, such the position, velocity, and other pertinent parameters of the target vehicle, and can not portray the environmental elements and the target vehicle between the relative motion trend and the risk impact of potential conflicts, that is, as long as the surrounding moving objects and the target vehicle are far away from each other. Therefore, this study innovatively constructs a dynamic risk assessment method for vehicles at intersections considering impending and collision risks, which provides solid and reliable data support for the subsequent safety warning and assisted driving decisions.

2. Modeling Dynamic Travel Risks for Vehicles

2.1 Description of imminent risk

The imminent risk caused by the surrounding moving objects to the target vehicle has the following characteristics: 1) the larger the mass of the target vehicle and the surrounding moving objects, the larger the inertia, the longer it takes for the two to change their mutual movement trend from close to far away, and the greater the imminent risk caused by the moving object to the target vehicle; 2) motorized vehicles and moving objects moving in the direction of the greater the angle, the greater the relative speed, the movement of the object closer to the target vehicle, the greater the risk posed by the target vehicle, this risk due to the potential convergence of moving vehicles to the target vehicle is not a linear increase in the risk brought about by the movement of the vehicle is close to the target vehicle the greater the change in the trend of the movement of the vehicle is close to the target vehicle, the greater the speed of the imminent risk brought about by the increase in the speed of the present study using an exponential function to describe the This kind of change rule, so imminent risk is considered to be linearly correlated with the speed of the target vehicle, the specific model is as follows:

$$E_{app-veh} = \frac{m_{host} \times R \times e^{-\cos\theta} \times |v_{host}^{t}|}{d} \tag{1}$$

where m_{host} and m_n are the weights of the target vehicle and the surrounding moving objects, respectively, R is the mass correction coefficient of the surrounding moving objects, v_{host}^{t} is the traveling speed of the target vehicle, respectively, d is the relative distance between the target vehicle and the moving objects at risk of collision, and θ is the angle between the moving object and the target vehicle's direction of motion, and the mass correction coefficient is determined as follows:

$$R = \rho^2 \times (v_{host}^t \times v_n^t)^\mu \qquad （2）$$

Coefficients to be determined for ρ and μ. To specifically determine the values of ρ and μ, traffic accident data were used to represent the effect of speed on driving risk, and existing studies[12] have yielded a value of ρ of 1.566×10^{-14} and a value of μ of 6.687.

Description of collision risk

The collision risk caused by the moving object to the target vehicle has the following characteristics: l) the greater the mass of the target vehicle and the moving object, the greater the potential collision damage, and the greater the collision risk caused by the moving object to the target vehicle; 2) according to the formula of kinetic energy damage during the collision, the damage caused by the object's velocity increases during the collision, and the maximum value of the velocity in the moving object between the target vehicle and the moving object with the risk of collision is selected to describe the potential collision damage, the specific model is as follows:

$$E_{col-veh} = m_{host} \times m_n \times R \times exp\left(-\frac{d^2}{2(v)^2}\right) \qquad (3)$$

where m_{host} and m_n are the weights of the target vehicle and the surrounding moving objects, respectively, R is the mass correction factor of the surrounding moving objects, i.e., Equation (2), v is the larger value of v_{host}^t of the target vehicle and v_n^t of the surrounding vehicles, and d is the relative distance between the target vehicle and the moving objects that are at risk of collision.

3. Selection and Overlay of Vehicle Risk

Calculation of the time of conflict

Assuming that the moving object maintains the current speed and direction, and the target vehicle maintains the current speed and yaw rate, the motion trajectories of the moving object and the target vehicle are calculated respectively for a certain period, and if there is an overlap in the spatiotemporal trajectories of the target vehicle and the surrounding moving objects, the overlap point is a potential collision point, and the conflict time is calculated:

$$\mathrm{T} = \min\left\{\frac{D_{host}}{v_{host}^t}, \frac{D_n}{v_n^t}\right\} \qquad (4)$$

Where T is the conflict time, D_{host} and D_n are the distances between the target vehicle and the surrounding moving objects and the potential collision point, v_{host}^t and v_n^t are the velocities of the target vehicle and the surrounding moving objects, and the shorter time for the two to reach the potential collision point is taken as the conflict time.

If the driver perceives the risk and initiates braking actions, enabling the target vehicle to halt before reaching the potential conflict point, the risk posed by the object to the target vehicle is deemed an imminent risk. Conversely, if the object's risk to the target vehicle persists with braking intervention, it is categorized as a collision risk. The decision rules are outlined as follows:

$$\lambda_i = \begin{cases} \text{imminent risk}, T > t \\ \text{Collision risk}, T < t \end{cases} \qquad (5)$$

$$\mathrm{t} = t_0 + \frac{v_0}{a} \qquad (6)$$

where t is the critical time, a is the deceleration of the target vehicle, v_0 is the vehicle speed limit of the specific roadway, and t_0 is the driver reaction time.

Calculation of the risk of the target vehicle

Based on the establishment of the imminent risk field and the collision risk field, each of them selects the maximum value of the risk caused by the surrounding moving objects to the target vehicle, to obtain the two kinds of risk values of the target vehicle and risk pooling; when the collision risk exists, the target vehicle's risk is the collision risk, and when only the imminent risk exists, the target vehicle's risk is the imminent risk.

$$Risk = \begin{cases} \left\{Risk_{i,col}\right\}_{t=t_0}^{\Delta t} \\ \left\{Risk_{i,app}\right\}_{t=t_0}^{\Delta t} \end{cases}$$

where $\mathrm{Risk}_{\mathrm{i,col}}$ is the maximum value of collision risk faced by the target vehicle, $\mathrm{Risk}_{\mathrm{i,app}}$ is the maximum value of imminent risk faced by the target vehicle.

4. Model Validation and Analysis

Real data were used to validate the risk assessment model, and the experimental data were obtained from the intersection in Suzhou. In this study, a camera was used to record moving vehicles on December 1, 2023, and a total of 14,192,233 data were tested through the intersection scenario, which contained the complete trajectory data of 1,820 motor vehicles located at the intersection. Define the braking event: the driver, after a long period of acceleration or driving at a constant speed, suddenly takes braking measures at a certain moment, and the size of the vehicle deceleration is greater than 1m/s2. According to the data of the vehicle state, analyze the frequency distribution of the risk of the vehicle 1s before emergency braking and 1s after braking. If the risk of 1s after braking is smaller than the risk of 1s before braking, it means that the driver thinks that there is a safety hazard in the vehicle before braking to make a response, and the risk of the vehicle after braking becomes smaller, which reduces the safety hazard, and it is considered that the risk assessment model is effective.

Currently, the time indicator TTC (Time to Collision) is widely used in collision warning systems, and Hirst and Graham report that a TTC value of 4 seconds can be used to differentiate between a driver unintentionally getting into a hazardous situation versus a situation where the driver maintains control[13]. Figure 3 shows the histogram of the TTC model crash risk probability. In pursuit of precise test outcomes, both the Kolmogorov-Smirnov Z-method and the Mann-Whitney U-method were employed. Notably, the results derived from these methods exhibited significant disparities at a confidence level of 0.1%, the probability of collision risk of the pre-braking TTC model was significantly greater than the probability of collision risk of the post-braking TTC model. Similar to the previous approach, the histogram depicting the probability distribution of collision risk for this model is illustrated in Figure 4.

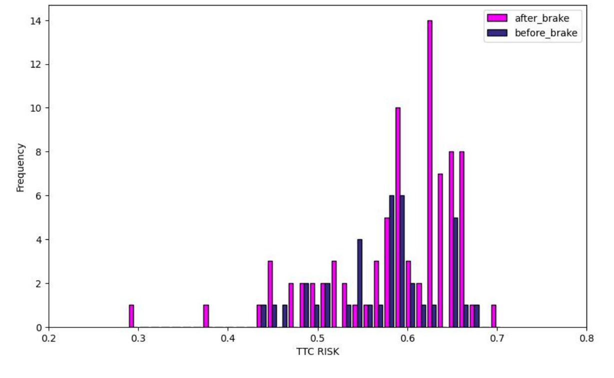

Figure 3 TTC Model

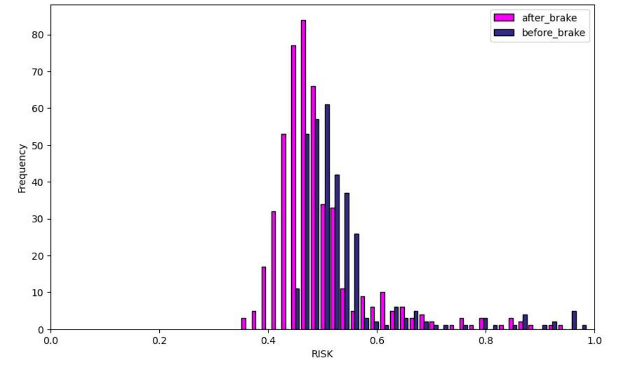

Figure 3 Our Model

Figure 5 shows the change of each risk in the braking event, the red risk curve represented by the TTC model rises only when other vehicles are closer to its own vehicle, this model, by considering the potential collision points of other vehicles and its own vehicle in advance, the orange risk curve represented by the collision risk rises before braking, suggesting that the risk exists, and the blue curve represented by the imminent risk maintains a higher level in a longer period, indicating that other vehicles still have an imminent trend with their own vehicles. In contrast, the present model is more sensitive to vehicles with conflicting trajectories, showing the advantages of the present model in assessing driving risk in intersection scenarios.

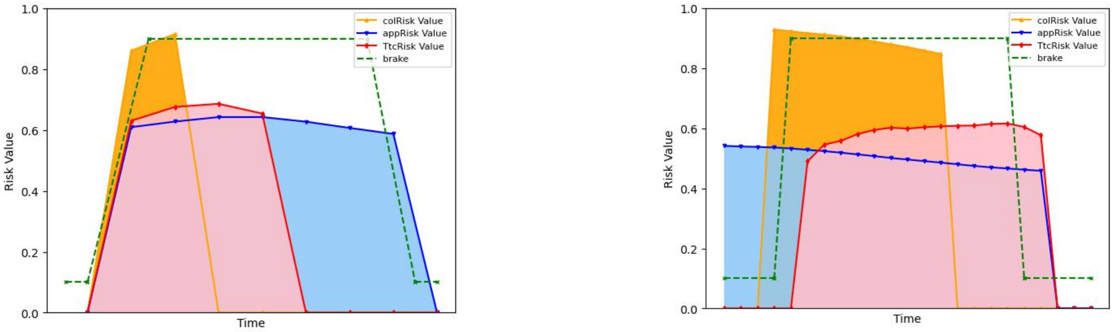

Figure 5. Value-at-risk changes in the two models during braking

5. Conclusion

This study summarizes the current research status of vehicle operation risk assessment methods at home and abroad, based on which it proposes a dynamic risk assessment method for vehicles at intersections considering imminent and collision risks.The main research work and results of this study focus on the following areas:

(1)This study proposes a dynamic risk assessment method for vehicles considering imminent risk and collision risk: considering the overlapping of the future trajectory of the moving objects and the trajectory of the target vehicle, the risk generated by the moving object is categorized into imminent risk and collision risk, and the risk field model is established respectively, which better describes the change rule of the risk of the target vehicle and the surrounding moving objects with the existence of potential conflict.

（2）This study utilizes actual data to test the rationality and validity of the model. Through the scrutiny of braking occurrences utilizing real-world intersection data, disparities in risk levels before and after braking events emerge, thus validating the efficacy of the risk model.

In the future, it is necessary to continue to collect more intersection vehicle operation data and environmental information, to improve and refine the risk field model, and to propose corresponding early warning methods or develop corresponding early warning systems based on the improved model, with a view to applying the present model to the actual vehicle early warning system and to improve the safety of vehicle operation.

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