

Research Article

In Search of the Consequence Severity of Traffic Conflict

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Currently, many studies on the severity of traffic conflicts only considered the possibility of potential collisions but ignored the consequences severity of potential collisions. Aiming toward this defect, this study establishes a potential collision (serious conflict) consequences severity model on the basis of vehicle collision theory. Regional vehicles trajectory data and historical traffic accident data were obtained. The field data were brought into the conflict consequences severity model to calculate the conflict severity rate of each section under different TTC thresholds. For comparison, the traditional conflict rate of each section under different TTC thresholds that considered only the number of conflicts was also calculated. Results showed that the relationship between conflict severity rate and influencing factors was somehow different. The conflict severity rate seemed to have a higher correlation with accident rate and accident severity rate than conflict rate did. The TTC threshold value also affected the correlation between conflicts and accidents, with high and low TTC threshold indicating a lower correlation. The results showed that conflict severity rate that considered each single conflict consequence severity was a little better than the traditional conflict rate that considered only the numbers of conflicts in reflecting real risks as a new conflict evaluation indicator. The severity of traffic conflicts should consider two dimensions: the possibility and consequence of potential collisions. Based on this, we propose a new traffic safety evaluation method that takes into account the severity of the consequences of the conflict. More data and prediction models are needed to conduct more realistic and complex research in the future to ensure reliability of this new method.

1. Introduction

A common method for studying traffic safety is based on historical traffic accidents data. This method is logically rational and reliable, but it has some limitations: (a) Traffic accidents are random and accidental. If accident data are insufficient and do not meet statistical requirements, then the influencing factors on traffic accidents cannot be analyzed. Thus, drawing useful conclusions on traffic safety evaluation and improvement will be difficult [1–3]. (b) Accidents or serious traffic conflicts that do not cause serious consequences are often unrecorded. For example, Hauer and Hakkert [4] found that six percent of minor accidents are unrecorded. However, these minor accidents often contain substantial information. (c) The analysis of accident data can only be conducted after the occurrence of an accident. Aiming toward these shortcomings, some scholars proposed the concept of traffic conflict in the 1960s–70s [5, 6] and

developed the traffic conflict technique (TCT) [7]. With the TCT, substantial data can be observed before accidents occur. The technique has some statistical advantages, such as large sample size, short cycle, and small region [8]. The traffic conflict analysis method is also deemed as one of the promising research directions in the field of traffic safety [9].

At present, the traffic conflict measurement indicators that determine the severity of conflicts can be classified as spatial/temporal proximity (including distance, velocity, and time) and evasive action indicators. Time indicators, which combine the distance and velocity, are thus widely used. The most commonly used time indicators include TTC (time to collision) [10] and PET (postencroachment time) [11]. However, most of these indicators can only measure one aspect of conflict severity, that is, the possibility/proximity severity of traffic conflict to a collision, and they do not consider the consequence/outcome severity of potential collisions caused by conflicts [12]. The original Swedish TCT

only defined the severity of conflict as the possibility of an accident and did not consider casualties and property losses [13]. Low TTC/PET values represent a short time to collide and high possibility from conflict to collision. The same TTC/PET values represent the same possibility of collision. Nevertheless, a minor accident caused by small vehicles is obviously different from a serious accident leading to casualties caused by trucks even if their TTC/PET are same; thus the consequence severity of potential collisions should be considered.

Few studies have explored the consequence severity of traffic conflicts. Dutch Traffic Conflict Technique (DOC-TOR), subjective scoring with video recording, is used to evaluate severity. But the consistency and accuracy need to be improved. Evans [14] and Gabauer [15] found that a close relationship exists between the velocity difference and the severity of accident consequences. Therefore, many early studies used velocity difference as an indicator to describe the severity of conflict consequences. However, some works confirmed that the severity of accident consequences is also related to vehicle quality, collision angle, and other factors. Considering only the velocity difference is not enough [16]. As a result, many scholars began to comprehensively consider the physical motion parameters of vehicle (e.g., velocity and acceleration) in their calculation. For example, Bagdadi [17] considers the quality, velocity, and acceleration of vehicles. The theoretical research was valuable, but it needs accurate and continuous data on speed, acceleration, vehicle type, conflict type, collision angle, and vehicle quality before and after collision. Thus, existing studies lacked the support of actual data.

The severity of traffic conflicts should include two dimensions: the possibility of conflict to develop to collision and the severity of potential conflict consequences. However, the latter is neglected sometimes. In the study, theoretical and empirical studies are carried out to address the above problems. The paper comprises three parts. In the first part, a conflict consequence severity model is established. In the second part, data collection method and processing procedure are introduced. In the third part, conflict consequence severity model is verified to determine whether it is better than the traditional model which only considers the possibility of collisions by studying their correlation with historical accident data.

2. Potential Collision Consequences Severity Model

As mentioned above, the severity of traffic conflict includes the possibility and consequence of potential collisions. Distribution in terms of nearness to collisions [7] and pyramid hierarchy [18] shows that serious conflicts are closely related to collisions. Therefore, this paper assumes that, after a serious conflict occurs, no evasive action will be taken, and a conflict will certainly develop to a collision. After a vehicle collision, some kinetic energy is converted into destructive energy for vehicle deformation, which is used to reflect the severity of potential collision consequences in traffic conflicts. Apparently, the greater kinetic

energy is lost, the more serious collision consequences will be and the higher severity of the conflicts consequences will be.

Vehicles collide not only with other vehicles but also with road facilities, such as guardrails and central reservations. Therefore, in the study, collision contains two categories: potential collision under vehicle-vehicle conflict and potential collision under vehicle-road facility conflict. The process is as follows.

2.1. Potential Collision in Vehicle-Vehicle Conflict

2.1.1. Basic Principles and Hypotheses

- (1) Traffic conflict is defined as follows: When two users are close to each other within a certain time and space, a risk of collision exists if they do not change their motion. The difference between collisions and conflicts lies only in whether the driver has taken successful evasion action after conflicts happen. The evasion actions that drivers take are different in postconflict situations and are simplified. The worst effects are considered in the paper, that is, assuming that drivers do not take any evasion action after each serious conflict.
- (2) The conflict in the model is the serious conflict. The indicator for measuring conflict severity (collision possibility) in this study is TTC, which is defined as "the time required for two vehicles to collide if they continue at their present speeds on the same path" [10].
- (3) Vehicle collision is a process of momentum exchange. At the same time, the internal force caused by vehicle collision (acting force and reacting force produced by the collision) is considerably greater than the external force (such as friction force); thus, it can be treated approximately by the law of conservation of momentum.
- (4) Vehicle collision is also a process of energy exchange. During the process of vehicle collision, the light, heat, and sound energy produced by the collision are neglected. To simplify the analysis, this study assumes that a portion of the mechanical energy is converted to the deformation energy of the vehicle before and after the collision. In this study, deformation energy is defined as the destructive energy hidden in each traffic conflict.
- (5) Avoidance measures are not taken into account, and vehicle braking is not considered from the beginning of a serious traffic conflict to collision. Thus, only existing rolling resistance, which is extremely low, is neglected. As the time between the conflict and the collision is short usually, collision speed is similar to serious conflict speed.
- (6) The time from serious conflict to collision is extremely short, and avoidance measures are considered; thus, collision angle can be deemed approximate to the angle when serious conflict occurs.

- (7) Vehicles are defined as rigid bodies with mass in this study. Before and after collision, their mass, centroid position, wheelbase, moment of inertia, and other parameters do not change [19].
- (8) Vehicle height is not considered in vehicle collision, and no phenomenon in which a small vehicle goes under a truck or a truck goes on top of a small vehicle occurs. Vehicle collision only occurs in a plane space, that is, a two-dimensional collision model.
- (9) In this study, the object of data collection is a highway where no head-on collision occurs. Only rear-end and cross collisions are assumed. At the same time, a vehicle is simplified to a point with mass (centroid point) without considering its shape. The centroids of two vehicles are assumed to be in a straight line that coincides with the direction of the collision as the collision occurs. No change in angular momentum occurs.

2.1.2. Phase from Conflict to Collision. The period from conflict to collision is roughly divided into four phases. In the first phase, serious conflict happens between two vehicles. The speed of the vehicle ahead and that of the vehicle behind in one conflict are V_a and V_b , respectively. The angle is α ; as only rear-end conflict and cross conflict are considered, α is -90° to 90° . In the second phase, two vehicles are about to collide, and their deformation is about to begin. At the initial stage, the speeds of two vehicles are V_a and V_b (in hypothesis (5), they are approximately equal to the vehicle speed in serious conflict), and the angle is α (in hypothesis (6), it is approximately equal to the angle in serious conflict). In the third phase, two vehicles collide. The speed of the vehicle behind decreases, and the speed of the vehicle ahead increases. Moreover, the speeds of the two cars are the same V_i at a certain moment. During the period from the second phase to the current phase, a portion of the mechanical energy is converted into deformation energy. In the fourth phase, the speed of the vehicle behind continues to decrease to V'_a and the speed of the vehicle ahead continues to increase to V'_b . However, the two vehicles separate, and the deformation is over. The deformation starts during the period from the second to the third phase, which is the main goal of our research, as shown in Figure 1.

2.1.3. Computational Process. The current work is aimed at the period from the second phase to the fourth phase. During this period, the velocity change caused by collision causes some kinetic energy to be converted into deformation energy. The conversion satisfies the law of conservation of energy. For convenience, the velocity is converted to the X - and Y -axes. The details are as follows:

$$\frac{1}{2}M_a \cdot V_{aX}^2 = \frac{1}{2}M_a \cdot V_{iX}^2 + \frac{1}{2}M_b \cdot V_{iX}^2 + E_X, \quad (1)$$

$$\frac{1}{2}M_a \cdot V_{aY}^2 + \frac{1}{2}M_b \cdot V_b^2 = \frac{1}{2}M_a \cdot V_{iY}^2 + \frac{1}{2}M_b \cdot V_{iY}^2 + E_Y. \quad (2)$$

At the same time, the conversion also satisfies the law of conservation of momentum:

$$M_a \cdot V_{aX} = M_a \cdot V_{iX} + M_b \cdot V_{iX}, \quad (3)$$

$$M_a \cdot V_{aY} + M_b \cdot V_b = M_a \cdot V_{iY} + M_b \cdot V_{iY}, \quad (4)$$

where V_{aX} , V_{aY} , and V_b , respectively, represent the velocities of the vehicle behind (in the X - and Y -axes) and the vehicle ahead after a serious conflict, V_{iX} and V_{iY} , respectively, denote the velocities in the X - and Y -axes at an instant after the collision when the velocity is the same, M_a and M_b , respectively, represent the masses of the vehicles ahead and behind, and E_X and E_Y , respectively, denote the destructive energy (deformation energy) hidden in a traffic conflict in the X - and Y -axes.

The following can be obtained on the basis of Formulas (3) and (4):

$$V_{iX} = \frac{M_a \cdot V_{aX}}{M_a + M_b}, \quad (5)$$

$$V_{iY} = \frac{M_a \cdot V_{aY} + M_b \cdot V_b}{M_a + M_b}. \quad (6)$$

Substitute (5) and (6) into (1) and (2) to calculate

$$E_X = \frac{1}{2} \cdot \frac{M_a \cdot M_b}{M_a + M_b} \cdot V_{aX}^2, \quad (7)$$

$$E_Y = \frac{1}{2} \cdot \frac{M_a \cdot M_b}{M_a + M_b} \cdot [(V_{aX} - V_b)^2]. \quad (8)$$

According to the trigonometric relationship,

$$V_{aX} = V_a \sin \alpha, \quad V_{aY} = V_a \cos \alpha. \quad (9)$$

They are substituted into (7) and (8) to obtain

$$E_X = \frac{1}{2} \cdot \frac{M_a \cdot M_b}{M_a + M_b} \cdot [(V_a \sin \alpha)^2], \quad (10)$$

$$E_Y = \frac{1}{2} \cdot \frac{M_a \cdot M_b}{M_a + M_b} \cdot [(V_a \cos \alpha - V_b)^2]. \quad (11)$$

Finally,

$$E = E_X + E_Y = \frac{1}{2} \cdot \frac{M_a \cdot M_b}{M_a + M_b} \cdot [(V_a \sin \alpha)^2 + (V_a \cos \alpha - V_b)^2]. \quad (12)$$

2.2. Potential Collision in Vehicle-Road Facility Conflict

2.2.1. Basic Principles and Hypotheses

- (1) Vehicle-road facility conflict is defined as follows: When a vehicle and a road facility, such as a central reservations and guardrail, are close to each other within a certain time and space, a risk of collision exists if the vehicle does not change its motion state. The difference between accidents and conflicts lies only in whether the driver has taken successful evasion action after the conflict. Similarly, it is also

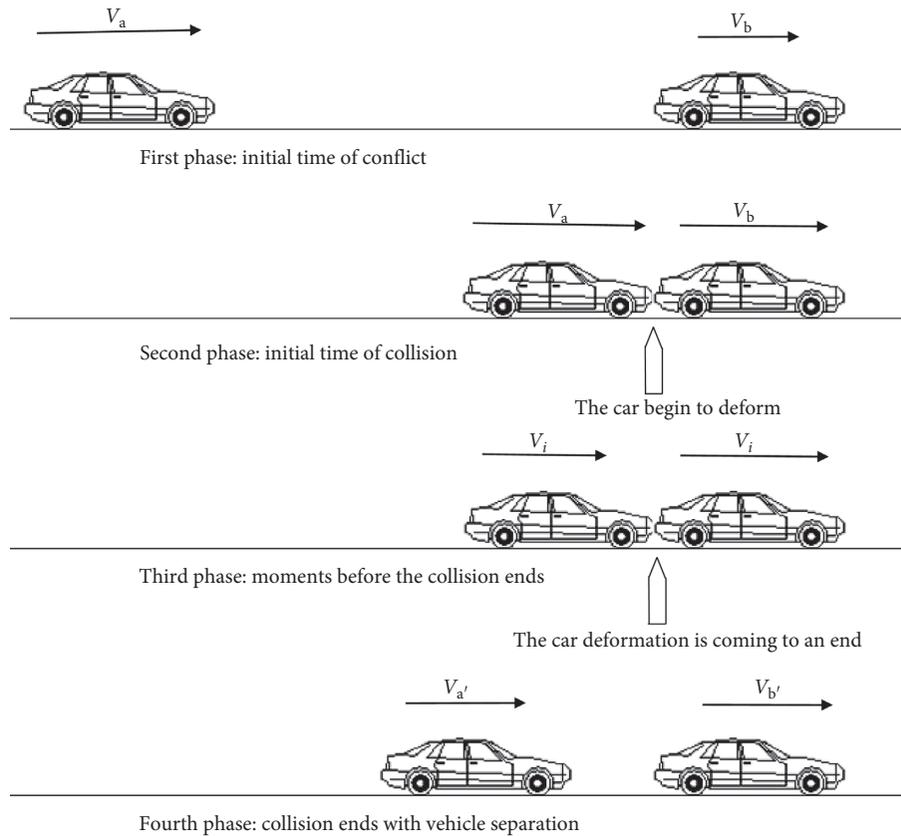


FIGURE 1: Schematic diagram of speed changing during vehicle collision.

simplified. The worst effects are considered here, that is, assuming that the drivers do not take any evasion action after each serious conflict.

- (2) When different types of vehicles collide with facilities, differences in velocity and energy after collisions are observed. The calculation is simplified by dividing collision into two categories: collision of trucks and facilities and collision of small or medium vehicles and facilities. The speed of small and medium vehicles is assumed to decrease to 0 after collision with facilities. By contrast, the speed of trucks is assumed to halve, but the driving direction is unchanged after collision with facilities; chain collision of the opposite lane is not considered here.
- (3) Other hypotheses are basically the same as those for vehicle-vehicle conflict.

2.2.2. Phase from Conflict to Collision

- (1) Collision of small and medium vehicles and road facilities. The period from conflict to collision of small and medium vehicles and facilities is roughly divided into four phases. In the first phase, serious conflict occurs between vehicles and facilities. The instant speed of the vehicles is V_a , and the collision angle is α . In the second phase, the small and medium vehicles collide with the facilities, and the

deformation of the vehicles is about to begin. At the initial stage of collision, the speed is V_a , and the angle is α (the initial collision velocity and angle are assumed to be approximate to the vehicle speed and angle in serious conflict, respectively). In the third phase, the vehicles collide with the facilities, and the speed of the small and medium vehicles decreases to 0; moreover, some of the mechanical energy is converted into deformation energy. In the fourth phase, small and medium vehicles may rebound, but the deformation is over. The deformation starts during the period from the second phase to the third phase, which is the main goal of our research, as shown in Figure 2.

- (2) Collision between trucks and road facilities. The period from conflict to collision between trucks and facilities is roughly divided into four phases. In the first phase, serious conflict occurs between vehicles and facilities. The instant speed of the vehicle is V_a , and the collision angle is α . In the second phase, the trucks collide with the facilities, and the deformation of the vehicles is about to begin. At the initial stage of collision, the speed is V_a , and the angle is α (the initial collision velocity and angle are assumed to be approximate to the vehicle speed and angle in serious conflict, respectively). In the third phase, the vehicles collide with the facilities, and some of the mechanical

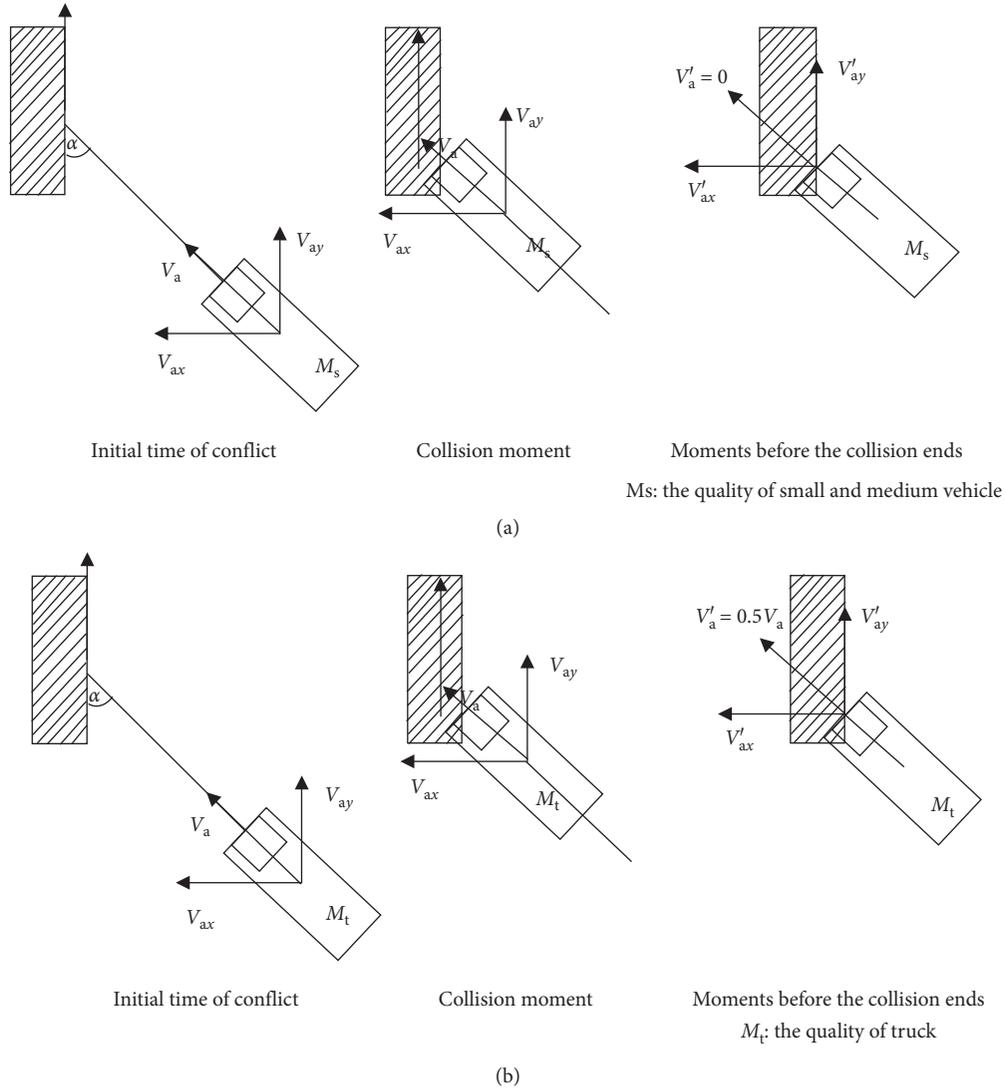


FIGURE 2: Schematic diagram of collision between vehicle and road facility (two categories).

energy is converted into deformation energy. The speed decreases to V'_a ($V'_a = 0.5V_a$). In the fourth phase, the trucks break free from the facilities to run continuously, but the deformation is over. The deformation starts during the period from the second phase to the third phase, which is the main goal of our research, as shown in Figure 2.

2.2.3. *Computational Process.* The research covers the period from the second to the third phase. During this period, the velocity change due to collision causes some kinetic energy to be converted into deformation energy. The conversion satisfies the law of conservation of energy. For convenience, velocity is converted into the X- and Y-axes. The details are shown as follows:

- (1) Collision between small and medium vehicles and facilities

$$\frac{1}{2}M_s V_{ax}^2 = E_X, \tag{13}$$

$$\frac{1}{2}M_s V_{ay}^2 = E_Y, \tag{14}$$

where V_{ax} and V_{ay} , respectively, represent the components of the velocities of small and medium vehicles in the X- and Y-axes before collision, M_s represents the mass of small and medium vehicles, and E_X and E_Y , respectively, denote the destructive energy (deformation energy) hidden in a traffic conflict (X-axis and Y-axis).

According to the trigonometric relation,

$$V_{ax} = V_a \sin \alpha \quad V_{ay} = V_a \cos \alpha. \tag{15}$$

Finally,

$$E = E_X + E_Y = \frac{1}{2}M_s V_a^2. \tag{16}$$

(2) Collision between trucks and facilities

$$\frac{1}{2}M_t V_{aX}^2 = E_X + \frac{1}{2}M_t V_{aX}'^2, \quad (17)$$

$$\frac{1}{2}M_t V_{aY}^2 = E_Y + \frac{1}{2}M_t V_{aY}'^2, \quad (18)$$

where V_{aX} and V_{aY} , respectively, represent the components of the velocities of trucks in the X - and Y -axes before collision, M_t refers to the mass of trucks, and E_X and E_Y , respectively, represent the destructive energy hidden in traffic collision in the X - and Y -axes.

According to the trigonometric relation,

$$V_{aX} = V_a \sin \alpha, \quad V_{aY} = V_a \cos \alpha. \quad (19)$$

Finally,

$$E = E_X + E_Y = \frac{3}{8}M_t V_a^2. \quad (20)$$

3. Data Collection Method and Processing

Comprising regional high-precision videos and historical traffic accident data, the data used in this work were mainly acquired using two methods. (1) Field conflict data were obtained by collecting high-precision videos of continuous vehicles using a UAV (unmanned aerial vehicle) hovering at a high altitude. Follow-ups were dealt with through the video recognition and the traffic conflict identification program. (2) The historical traffic accident data were mainly collected by traffic police and local highway administration bureau. (3) Some other data are processing and assumptions.

3.1. Conflict Data Collection

3.1.1. Location and Time. The video data collection location was the Jinan-Qingdao Highway in Shandong Province, China. The collection period was from August 20, 2017, to September 8, 2017. The collection times were from 9:00 to 10:00 in the morning peak and from 16:00 to 17:00 in the evening peak. At that time, the reconstruction and extension project, that is, the subgrade construction, was in progress. The subgrade was filled and widened on both sides of the road. The original road was kept passing through, but the original guardrails on both sides were dismantled and replaced by temporary guardrails. The road was two-way with four lanes. The width of a lane was 3.75 m, and the speed was limited to 80 km/h. The specific collection location included K43 + 200, K51 + 500, K57 + 580, K58 + 600, K112 + 500, K130 + 500, K131 + 500, K133 + 200, K182 + 000, K186 + 000, K192 + 500, K205 + 000, K255 + 000, K257 + 700, K258 + 260, K266 + 800, K271 + 620, K277 + 500, K278 + 300, and K287 + 000. Data were acquired in each location for 30 min each in the morning and evening peaks.

3.1.2. Device. The PHANTOM 4 PRO UAV from DJI Technology Company was used. The maximum flight altitude of the UAV was 500 m, and the maximum flight time

was 30 min. We prepared 9 batteries; each battery took 8 hours to be fully charged. The maximum video resolution was 4K/60P. The UAV shot the video by hovering statically. The camera was positioned vertically downward, and the flying height was 350–450 m. The lens angle parameters of the UAV were used as bases for calculation. The shooting range was about 600–700 m in length and 300–350 m in width, as shown in Figure 3.

3.1.3. Data Processing. It consists of a video recognition and a traffic conflict identification program (see Figure 4).

- (1) Vehicles were identified and tracked via spatiotemporal context visual tracking algorithms based on an own-written program. The real-time continuous trajectory coordinates (X/Y), vehicle width, vehicle ID of all vehicles in the region, and other data served as the outputs. The identifying and tracking rate of video recognition program was about 90%. Most of the trajectory data errors can be controlled within 1 m, mainly including three major steps.

(a) Image Reading and Calibration

Considering the high airflow changes, the video captured by the UAV has a slight jitter, so the latter picture will gradually deviate from the original picture, and the subsequent picture needs to be matched and calibrated with the first frame based on the first frame.

There are many matching methods, and it is considered to select a partial region to calculate the correlation coefficient and then calculate the overall transformation matrix. Finally, in order to ensure the accuracy of the recognition, feature point matching is selected to calculate the transformation matrix.

Selecting the obvious reference object of the first frame such as road and road marking, establishing the coordinate system according to the horizontal direction and the vertical direction, and performing the rotation according to the affine transformation relationship between the pictures, the subsequent pictures can be successfully matched with the frame by frame.

(b) Vehicle Identification

Vehicle identification system usually includes ROI (Region of Interest) extraction and vehicle detection. First, the sequence image is subjected to ROI extraction, and then the image processing method is used to determine whether the area is a vehicle. If it is determined to be a vehicle, the vehicle can be tracked in a subsequent tracking module. Vehicle detection is a prerequisite for tracking, and accurate ROI extraction and vehicle detection can establish a solid foundation for tracking.

The adjacent frame subtraction algorithm is used to identify the ROI area by considering that the Jiqing Highway has the characteristics of faster vehicle speed, more frequent convergence, and less visibility caused by dust. For the detection line method is simple and efficient, so it is used for vehicle detection.



FIGURE 3: UAV collecting high-precision video.

(c) Vehicle Tracking

Tracking is easier when the vehicle is successfully detected. Most vehicle tracking methods follow a basic principle of using space distance to determine whether a vehicle in an adjacent frame is the same vehicle, thereby completing vehicle tracking in the time domain. Based on the characteristics of Jiqing Highway such as faster speeds, high dust, and low visibility, a tracking method called the spatiotemporal context was chosen. This method obtains the best target position by maximizing the target position likelihood function and learning using the fast Fourier transform. Compared with other mainstream methods, this method is more accurate and reliable, and it is more effective in implementation.

(2) About the identifying and tracking rate of video recognition program

We used to randomly select videos from the locations K57 + 580, K58 + 600, K182 + 000, K255 + 000, and K271 + 620 for a total of about 90 minutes for verification. Through statistical analysis, it was found that the video recognition program identified a total of 3,033 vehicles and continued to track 2,923 vehicles, while a total of 3,308 vehicles were recognized by manual observation. The initial identifying rate was about 92%, and the continuous tracking rate was about 88%.

The specific data are given in Table 1.

(3) About trajectory data recognition accuracy and reliability

As the dividing line (white dotted line) of all highways in China is 6 m long, the distance between the dotted lines is 9 m (see Figure 5). Therefore, the accuracy and reliability of the video recognition program can be judged by this standard.

Six hundred vehicles were randomly selected in part of the videos collected at the locations of K57 + 580, K58 + 600, K182 + 000, K255 + 000, and K271 + 620, and 2 s interval coordinate data of each vehicle in X-axis and Y-axis were randomly recorded. At the same time, the position of each vehicle in the video is manually marked by software called PicPick, which operates by clicking the image/video with a mouse to display and measure coordinates. After comparison, 8% of the trajectory errors are below 0.3 m, 21% of the trajectory errors are below 0.5 m, 44% of the trajectory errors are 0.7 m, and 82% of the trajectory errors are below 1 m. Therefore, most of the trajectory data errors can be controlled within 1 m.

- (4) Instantaneous speed, acceleration, vehicle spacing, vehicle driving angle, and other data in traffic conflict for every seven frames were then obtained according to the further processing of the continuous trajectory coordinate data and TTC-based recognition program. TTC is defined as “the time required for two vehicles to collide if they continue at their present speeds on the same path.” The calculation process is basically similar to the previous literature.

The differences lie in the following:

- (1) Vehicles are simplified to a point with mass (centroid point) without considering its shape
- (2) Considering the conflicts between the vehicle and the road facility, the definition and calculation are given in Figure 6

3.2. Historical Traffic Accident Data. The accident data included the time of accident occurrence (accurate to year, month, date, and hour), location of accident occurrence (station number and orientation), type of vehicle involved in accident (small, medium, or truck), type of accident (rear-end collision, overturning, or collision with central separators/guardrails), weather, level of severity, number of casualties (death or injured), and road financial loss, as shown in Figure 7.

Due to the limitation of UAV power, funding, weather, and accident being accidental, the location and time of conflict data collection cannot completely coincide with the actual historical data location and time. So, on the premise of satisfying the data analysis sample size, we need to reasonably expand the time period and location of historical accident data.

After on-site investigations and serious analysis, the period of accident data collection was from June 2017 to November 2017. This time period had little change compared to the time period of video data collection; possible influence conditions such as traffic volume, traffic composition (proportion of various vehicle type), lateral clearance, and traffic organization changed slightly.

Similarly, to eliminate the influence of conditions, we divided the highway into five sections (JQ-1–JQ-5) according to the actual situation such as traffic organization, traffic volume, traffic composition, and lateral clearance. So the situations in every different section were consistent in general. Each section comprised four video data collection locations (see Table 2).

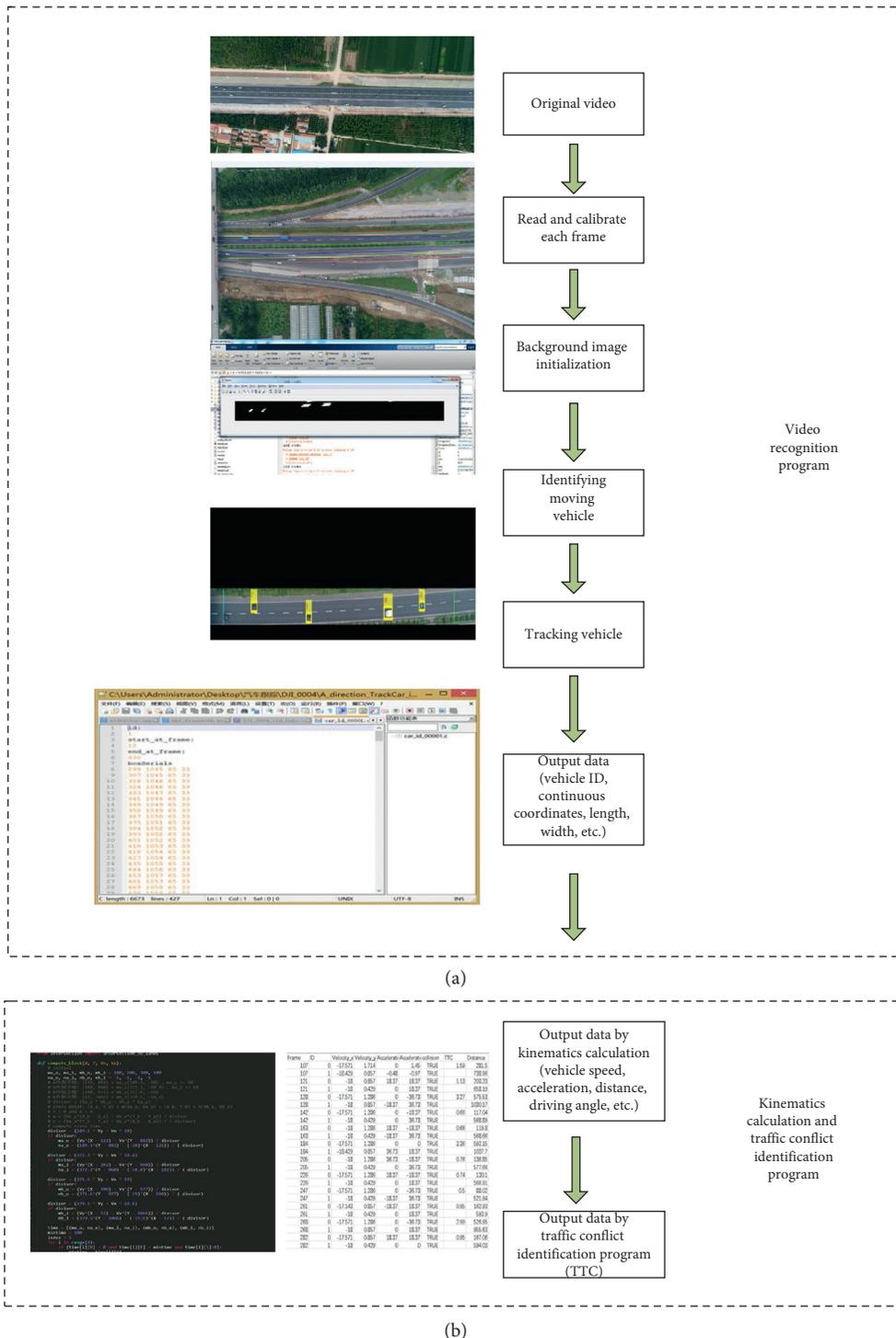


FIGURE 4: Flow-process diagram of video recognition and traffic conflict identification.

3.3. Other Data Processing and Assumptions

3.3.1. *Simplified Processing of TTC Threshold Values.* The conflict in the model in Chapter 2 must be a serious conflict. But no uniform basis for judging serious conflicts exists. As the roads, environments, and methods adopted in studies are different, the threshold values of severe

traffic conflicts adopted by different studies are also different, ranging from 1.0 s to 5.0 s of TTC [13, 20–26]. Therefore, the TTC threshold value of a serious conflict in this study ranged from 1.0 s to 5.0 s, and the step length was 0.5 s. For simplification, the TTC threshold values of vehicle-vehicle and vehicle-road facility conflicts were assumed to be the same.

TABLE 1: Identifying and tracking rate of video recognition program.

Collection locations	Video frames	Video duration (s)	Initial identifying vehicles	Continuous tracking vehicles	Manual observation vehicles	Initial identifying rate (%)	Continuous tracking rate (%)
K57 + 580	35850	1195	452	437	485	93	90
K58 + 600	15600	520	234	225	251	93	90
K182 + 000	33000	1100	738	701	795	93	88
K255 + 000	28880	963	572	558	628	91	89
K271 + 620	53100	1770	1037	1002	1149	90	87
Total	166430	5548	3033	2923	3308	92	88



FIGURE 5: Distance of dividing line of highway in China.

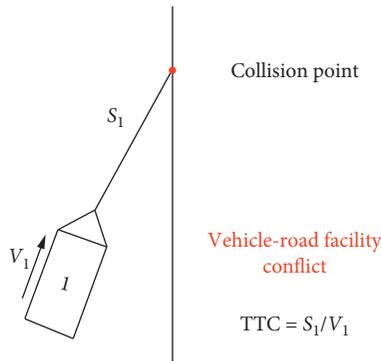


FIGURE 6: Definition and calculation of conflicts between the vehicle and the road facility.

Number	Time of accident occurrence	Location of accident occurrence (stake number/orientation)	Vehicle type of accident	Type of accident	Weather	Level of severity	Number of deaths	Number of injured	Road financial loss (CNY)
1	6/3/2016	Direction from Jinan to Qingdao 105K + 600M	Truck and truck	Raer-end	Foggy	Ordinary	0	0	4020
2	6/3/2016	Direction from Jinan to Qingdao 105K + 700M	Truck and truck	Raer-end	Foggy	Slight	0	0	500
3	6/3/2016	Direction from Jinan to Qingdao 59K + 300M	Truck	Roll-over	Sunny	Ordinary	0	0	3060
4	6/5/2016	Direction from Jinan to Qingdao 92K + 100M	Small car	Roll-over	Sunny	Ordinary	0	0	2250
5	6/6/2016	Direction from Jinan to Qingdao 91K + 500M	Small car	Roll-over	Sunny	Ordinary	0	0	3650
6	6/9/2016	Direction from Jinan to Qingdao 54K + 500M	Truck	Fire	Sunny	Ordinary	0	0	2300
7	6/10/2016	Direction from Jinan to Qingdao 36K + 500M	Small car	Hit the central reservations	Sunny	Slight	0	0	500
8	6/11/2016	Direction from Jinan to Qingdao 102K + 100M	Small car and small car	Raer-end	Sunny	Ordinary	0	0	4800

FIGURE 7: Chart of historical traffic accident data (partial translation display).

TABLE 2: Traffic data of each section.

Section	JQ-1	JQ-2	JQ-3	JQ-4	JQ-5
Station number at the beginning	K36 + 388	K100 + 400	K150 + 480	K214 + 910	K268 + 967
Station number at the end	K100 + 400	K150 + 480	K214 + 910	K268 + 967	K294 + 385
Length (km)	64	50	64	54	25
Percentage of small vehicles	68.9	66.4	63.8	62.5	61.4
Percentage of medium vehicles	9.5	9.7	7.6	8.2	8.5
Percentage of trucks	21.6	23.9	28.6	29.3	30.1
Station numbers of video data collection locations	K43 + 200, K51 + 500, K57 + 580, K58 + 600	K112 + 500, K130 + 500, K131 + 500, K133 + 200	K182 + 000, K186 + 000, K192 + 500, K205 + 000	K255 + 000, K257 + 700, K258 + 260, K266 + 800	K271 + 620, K277 + 500, K278 + 300, K287 + 000

3.3.2. *Assumptions of Vehicle Weight.* Vehicle weight was involved in the measurement model of conflict consequence severity in this study. Obtaining real-time and accurate vehicle weight data by using existing technologies is difficult. Thus, vehicle types in this study were classified as small and medium vehicles and trucks by measuring vehicle length. Vehicle weight was determined according to vehicle type (Table 3).

3.3.3. *Selection and Design of Influencing Factors.* The average traffic volume and truck rate of one-way lane were used as influencing factors in this study.

The experimental scheme was based on the data obtained from every 15 min of video. The actual values of each influence factor were rounded according to step length. For example, if the average traffic volume of the one-way lane was 1135 pcu/h, it was recorded as 1100 pcu/h; if the average traffic volume of the one-way lane was 1278 pcu/h, it was recorded as 1300 pcu/h. According to the actual data, the specific scope was designed as follows (Table 4).

4. Results and Discussion

There are four parts in this chapter: (1) Evaluation indicators of traffic history accident are calculated by historical traffic accident data: accident rate and accident severity rate. (2) Evaluation indicators of traffic conflict are conflict rate and conflict severity rate, where the conflict severity rate is calculated by continuous high-precision vehicle conflict data and is based on the potential collision consequences severity model in Chapter 2. (3) We had analyzed the relationship of conflict rates and conflict severity rates with influencing factors, that is, traffic volume and truck rate. (4) The correlation between conflicts and accidents is also calculated and verifies whether the evaluation indicators that take the consequences of conflict into account are superior to the traditional conflict rate indicators that only consider the number of conflicts; details are given in Figure 8.

4.1. Historical Accident Rate and Accident Severity Rate

- (1) Historical accident rate is calculated according to the following formula:

TABLE 3: Vehicle types.

Vehicle types	Small vehicle	Medium vehicle	Truck
Length (m)	4–6	7–9	10–20
Set weight (t)	1.5	5	30

TABLE 4: Design of influencing factor ranges.

Influence factors	Min.	Max.	Step length
Traffic volume (pcu/h)	300	1500	200
Truck rate (%)*	10	70	10

*Truck rate refers to the proportion of trucks in PCU.

$$A_n = \frac{N}{Q \times L} \quad (21)$$

In Formula (21), A_n refers to the accident rate in each section (JQ1–JQ5) within six months; N refers to the number of traffic accidents (including conflict accidents of two vehicles and one vehicle with facilities); L refers to the length of each section in km; and Q refers to the monthly average daily traffic volume of each section in pcu/d.

- (2) Historical accident severity rate is calculated according to the following formula:

$$A_s = \frac{M}{Q \times L} \quad (22)$$

In Formula (22), A_s refers to the accident severity rate in each section (JQ1–JQ5) within six months, M refers to the sum of direct economic losses in ten thousand yuan (RMB), L refers to the length of each section in km, and Q refers to the monthly average daily traffic volume of each section in pcu/d.

Accident data include the number of casualties and the economic losses in road administration and vehicles. Through normalization, the number of casualties is converted into direct

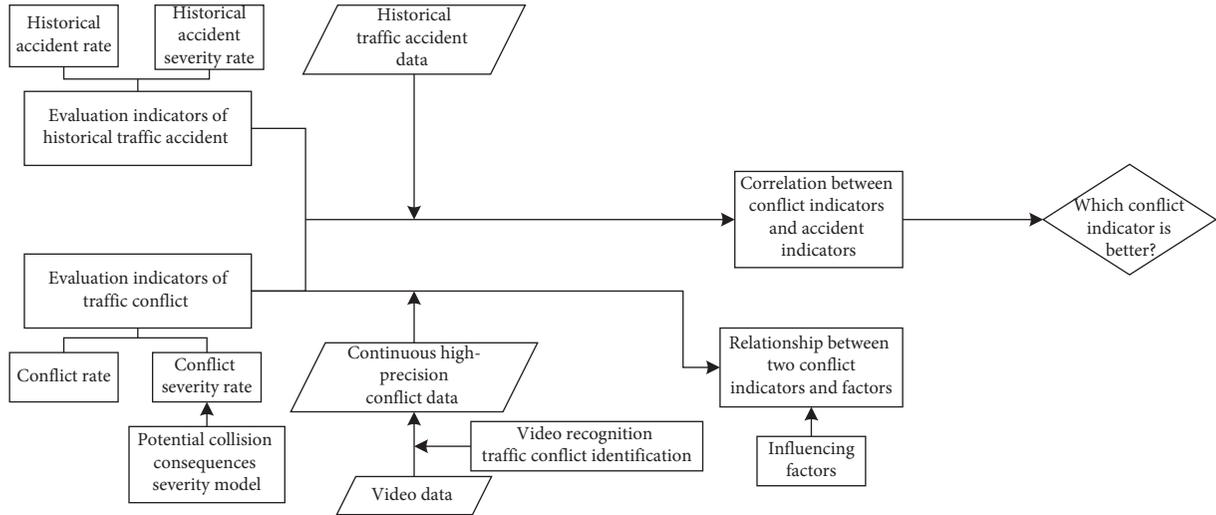


FIGURE 8: Analysis flow diagram.

economic loss. The literature shows that the average age of mortality in road traffic accidents in China is 40 years. On the basis of the retirement age of 60 years, the standard loss incurred in one working day resulting from one death is calculated as 5000. At present, China's per capita working day income is 200 yuan. Therefore, the direct economic loss per death is 1 million yuan. The direct economic loss per injured person is calculated at 30% of that per death, that is, 0.30 million yuan [27].

Therefore,

$$M = M_1 + M_2 + M_3. \quad (23)$$

In Formula (23), M_1 refers to the loss of road administration and vehicles, M_2 refers to the direct economic loss resulting from death, and M_3 refers to the direct economic loss resulting from injuries.

On the basis of formulas (21)–(23), the accident rates and accident severity rates of all sections in June–November 2017 can be calculated (Table 5).

4.2. Traffic Conflict Rate and Conflict Severity Rate

4.2.1. Traffic Conflict Rate. Conflict rate evaluation indicator that considers only the number of conflicts can be calculated according to the following formula:

$$R = \frac{N}{Q \times L}. \quad (24)$$

In Formula (24), R refers to the traffic conflict rate (n/pcu-km), N refers to the number of serious conflicts occurring in a time unit, L refers to the length of the data collection section (km), and Q refers to the traffic volume per hour in the data collection section (pcu/h).

4.2.2. Traffic Conflict Severity Rate. For comparison, traffic conflict severity rate is evaluated with the following formula:

$$s = \frac{\sum_{i=1}^{i=N} E_i}{Q \times L}. \quad (25)$$

TABLE 5: Accident rates and accident severity rates of all sections.

Sections	JQ-1	JQ-2	JQ-3	JQ-4	JQ-5
Accident rate $A_n(10^{-5})$	1.24	1.89	3.87	3.21	3.34
Accident severity rate $A_s(10^{-5})$	1.28	1.25	1.93	1.89	1.76

In Formula (25), s refers to the traffic conflict severity rate (J/pcu-km); N refers to the number of serious conflicts occurring in a time unit; E_i refers to the destructive energy hidden in each time of serious traffic conflict (J), that is, Formulas (12), (16), and (20); L refers to the length of the data collection section (km), and Q refers to the traffic volume per hour in the data collection section (pcu/h).

4.3. Relationship between Conflict Rate/Conflict Severity Rate and Influence Factors

4.3.1. Conflict Rates and Conflict Severity Rates of All Sections under Different TTC Threshold Values. On the basis of the discussion in Chapter 4.2, the average values of the conflict rate and conflict severity rate of each section under different TTC values are obtained. Figure 9 reveals that, with an increase in TTC threshold values, conflict rate and conflict severity rate increase; this effect is in line with the objective situation. If the threshold value is high, serious conflicts that meet the requirements will increase.

4.3.2. Relationship between Conflict Rate/Conflict Severity Rate and Traffic Volume. The relationships of conflict rate and conflict severity rate with traffic volume are established. Specifically, the conflict rate and conflict severity rate are the average values in all sections under different TTC threshold values. ANOVA shows that traffic volume has a significant impact on traffic conflict rate and traffic conflict severity rate ($p = 0 < 0.01$) (F test, where p refers to the probability that the traffic conflict rate is the same as the severity rate under different traffic volumes).

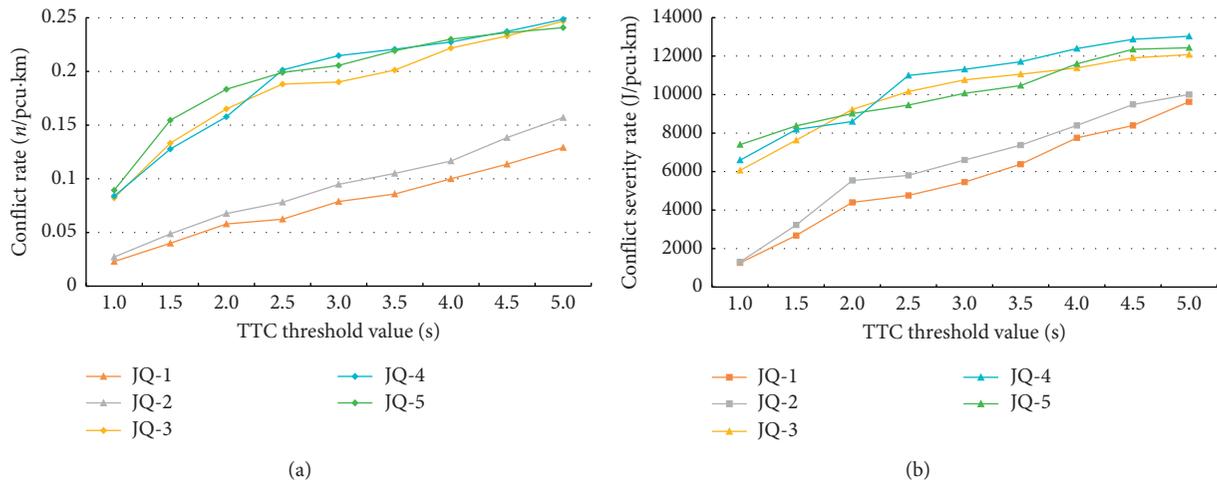


FIGURE 9: Conflict rates and severity rates of all sections under different TTC threshold values.

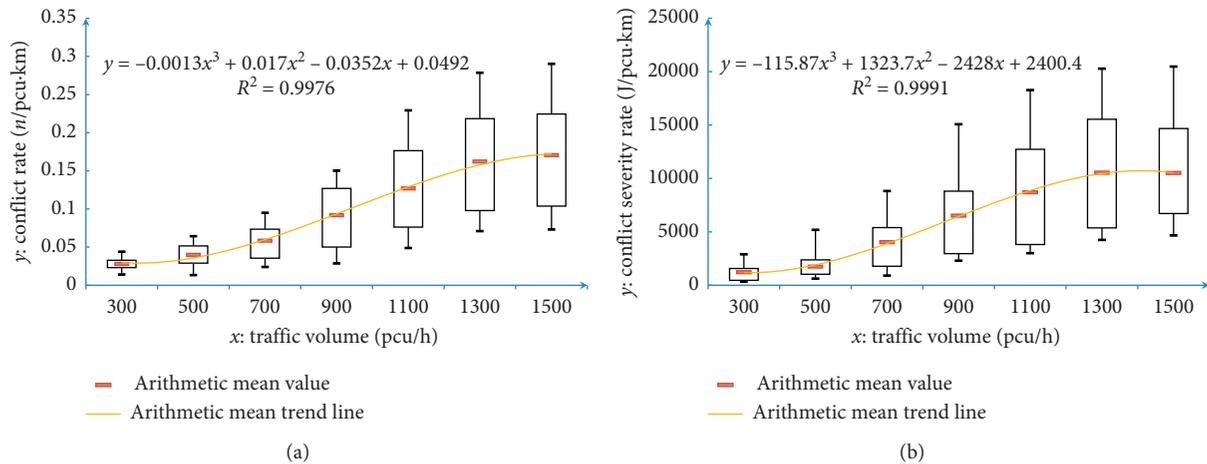


FIGURE 10: Distribution of traffic conflict rates and severity rates under different traffic volumes.

Figure 10 shows the distributions of conflict rates and severity rates under different traffic volumes. Traffic volume is positively correlated with the conflict and severity rate. When traffic volume in a one-way lane is less than 700 pcu/h, the average conflict and severity rates are low. With the increase in traffic volume, the average conflict rate and severity rate increase gradually. Moreover, when traffic volume exceeds 900 pcu/h, the average conflict and severity rates increase rapidly. This relationship is similar to that found in a study on the construction area of the Tomei Expressway in Japan that revealed that 70% of traffic accidents occur in a traffic jam and that the casualty rate caused by accidents in a crowded construction area is over 90%, which is eight to nine times that in noncrowded construction areas [28]. Therefore, a large traffic volume equates to an unsafe construction area. As traffic volume exceeds 1300 pcu/h, differences are observed between conflict rates and severity rates; the conflict rate continues to rise slightly, whereas the conflict severity rate declines slightly. This finding may be due to the saturation of traffic flow and the

decrease of the speed and the severity of a single conflict caused by excessive traffic volume. Therefore, the severity rate drops.

4.3.3. Relationship between Conflict Rate/Conflict Severity Rate and Truck Rate. The relationships of conflict rate and conflict severity rate with truck rate are established. Specifically, the conflict rate and conflict severity rate are the average values in all sections under different TTC threshold values. ANOVA shows that truck rate has a significant impact on traffic conflict rate and traffic conflict severity rate ($p = 0 < 0.01$) (F test, where p refers to the probability that the traffic conflict rate is the same as the severity rate under different truck rates).

The relationship between conflict rate and severity rate with truck rate is established, as shown in Figure 11. Under a low truck rate, the conflict rate is low. With a gradual increase in truck rate, the conflict rate gradually increases as well. Then, it reaches the maximum as the truck rate reaches

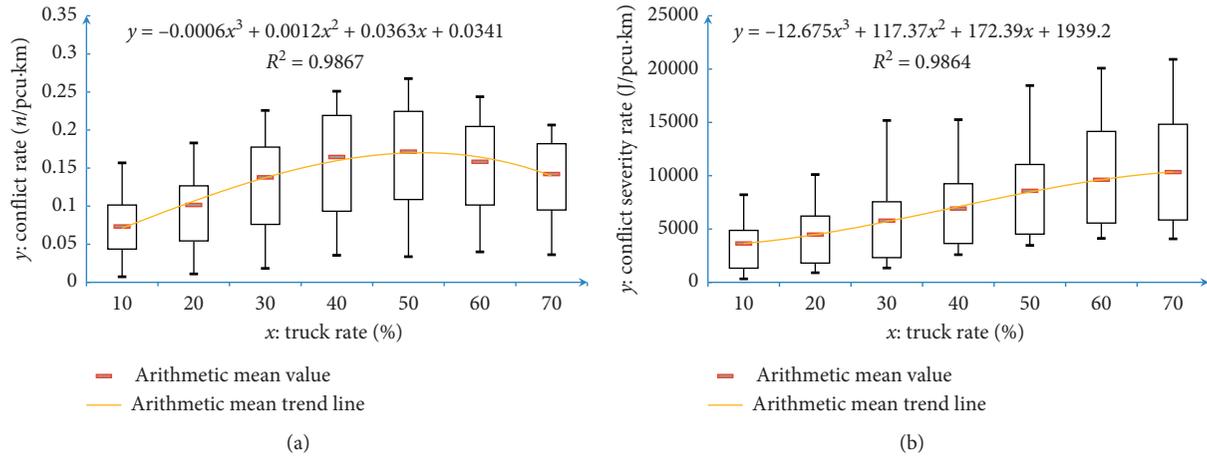


FIGURE 11: Distribution of traffic conflict rates and severity rates under different truck rates.

50%. Afterwards, the conflict rate gradually decreases. This result is similar to the law found by Liang et al. [29]; with an increase in truck rate, the number of conflicts increases first and then decreases, showing a single peak. The reason for this phenomenon is that the inadequate performance of trucks leads to a slower speed than those of other vehicle types, particularly small vehicles. As a result, the emergence of trucks in traffic flow inevitably leads to an increase in the overall speed difference in traffic flow, further causing an increase in conflict. However, when the number of trucks increases, the number of vehicles decreases under the same traffic volume. At the same time, the speed difference decreases gradually with an increase in the number of the same type of vehicles (large truck); thus, the conflict rate decreases gradually after reaching the peak value.

The comparison of conflict rate and severity rate with truck rate in Figure 6 shows that when the truck rate exceeds 50%, the conflict rate decreases, and the conflict severity rate increases, indicating that the severity of consequences caused by truck conflict is great. This finding is consistent with the phenomenon in which trucks easily cause serious accidents in construction areas, as discovered by Pigman and Agent [30].

4.4. Correlation between Conflict Rate/Severity Rate and Accident Rate/Severity Rate. Chapter 4.4 focuses on the correlation between traditional conflict rate and conflict severity rate that consider the consequence severity and accident rate/accident severity rate, respectively. The average values of the conflict rates and conflict severity rates of all sections are obtained. On the basis of the accident rates and accident severity rates of all sections within six months (Table 4), the correlation coefficients are obtained via Pearson correlation analysis.

Figure 12 reveals that conflict severity has higher correlation with either accident rate or accident severity rate than conflict rate does in most cases; in particular, conflict severity rate is most correlated with accident severity rate (purple line); under different TTC threshold values, the correlation is about 0.8–0.85. The correlation between conflict severity rate and

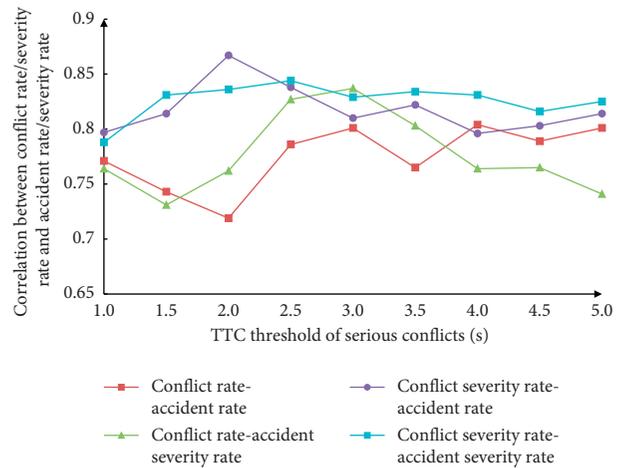


FIGURE 12: Correlation between conflict rate/severity rate and accident rate/severity rate under different TTC threshold values.

accident rate (blue line) is also high. By contrast, the traditional conflict rate has a low correlation (ranging from 0.7 to 0.8) with accident rate and accident severity rate (red and green line) in most cases of different TTC threshold.

As for the TTC threshold values, under low thresholds (1.0s, 1.5s) and high thresholds (more than 3.0s), the correlation values are low. In addition, correlation in the range of 2.0–3.0s is the highest. This result may be due to the low conflict threshold that leads to the strict criteria for detecting conflicts and to neglecting some risks that may lead to accidents. Moreover, a high threshold will allow several low-risk conflicts to be included in the calculation, although many low-risk conflicts do not lead to accidents; thus, the correlation is reduced.

5. Conclusions

This study aims to address the lack of research on the severity of the consequences of potential collisions in traffic conflict and proposes a new method for assessing traffic safety. High-

precision continuous vehicle microdata obtained by UAV tell us real-time conflict risk including traditional possibility/proximity severity of traffic conflict to a collision, and the consequence/outcome severity of potential collisions caused by conflicts as well, which is exactly what we need to improve.

In this paper, a severity model of potential collision consequences in traffic conflicts is proposed on the basis of vehicle collision theory. Serious conflicts among road vehicles develop into collision accidents when no evasion action is taken. After collision, some kinetic energy is converted into destructive energy, leading to vehicle deformation. We use this energy to reflect the potential consequence severity of traffic conflicts. The proposed model includes two categories: potential collision of vehicle-vehicle conflict and collision of vehicles and road facilities (e.g., guardrails).

The accurate videos of vehicles are collected by a UAV. Vehicle speed, acceleration, vehicle spacing, and other microscopic data of each traffic conflict at any time are obtained through further processing with a video recognition and traffic conflict recognition program (output once every seven frames). Traffic accident data were also collected.

On the basis of the conflict consequence severity model proposed in this study, the microscopic data of vehicles in traffic conflicts were substituted to calculate the conflict severity rates in all sections under different TTC threshold values. At the same time, the conflict rates in each section under different TTC threshold values that consider only the number of conflicts were also calculated. The conflict rates and conflict severity rates were linked to traffic volume and truck rate, respectively. The relationship models are found to be different.

Further correlation analysis of accident rate and accident severity rates showed that the conflict severity rate that considers conflict consequence severity has a higher correlation with accident rate and accident severity rate. At the same time, the threshold value of TTC was an important factor that influences correlation. When thresholds were low (1.0 s, 1.5 s) or high (more than 3.0 s), the correlation was low.

In summary, many current studies on the severity of traffic conflicts focused on the possibility of potential collisions, and less studies explored the severity of the consequences of potential collisions. According to vehicle collision theory, the formula for calculating the consequences severity of potential collision is obtained. The correlation verification of data shows that real risk is a little better reflected by conflict severity rate than by traditional conflict rate. The safety evaluation of traffic conflict should be a combination of both possibility and consequence of potential collisions.

The limitations of this study are some adoption of simplification and idealization processes. Real and complex processes should be considered in follow-up studies. Moreover, due to the time, fund, equipment constraints, and other reasons, the conflict data only cover some time periods in 18 days.

In the future, we will make improvements and follow-up studies from the following aspects: (1) Selection of indicators. Due to words limitation, only the most common TTC

was selected as an indicator for identifying conflicts. Each conflict indicator such as TTC, PET, and MaxD has its own advantages and disadvantages. Under different types of conflict/collision (such as crossing, rear end, and lane change), the differences between indicators are more obvious [31, 32]. We should select better indicators to identify conflicts for different types of conflicts later. (2) Expand the amount of data to collect more conflict and accident data, in addition to the in-depth analysis of the correspondence between the types of accidents and the types of conflicts. (3) This paper directly analyzes the correlation between serious conflicts and accidents under considering possibility/consequence severity and finds that the correlation was okay (probably due to the fact that collection locations were not many). Extreme value theory (EVT) sees a good accident prediction model with high prediction accuracy and correlation with field accidents. We may use mathematical methods such as EVT to predict accidents (number and severity) with more data later [31–33].

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

The data were collected in Jinan-Qingdao Highway in Shandong Province, China.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Study conception, design, and major writing were performed by Jiang Ruoxi and Zhu Shunying. Data collection was carried out by Wang Pan, Zou He, and Kuang Shiping. Analysis and interpretation of results were performed by Jiang Ruoxi and Wang Pan. Draft manuscript preparation was done by Jiang Ruoxi. All authors reviewed the results and approved the final version of the manuscript.

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