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*Research Article*

# Dynamic Risk Assessment and Control Framework for Work Zone and Its First Implementation under Simulation Environment

**Zhepu Xu**,[1] **Cancan Song**,[2] **and Jie Yu**[1]

[1]*School of Railway Transportation, Shanghai Institute of Technology, Shanghai 201418, China*
[2]*School of Civil Engineering, Shanghai Normal University, Shanghai 201418, China*

Correspondence should be addressed to Zhepu Xu; xuzhepu@126.com

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The number of road maintenance operations in China is increasing. Work zones can interfere with everyday driving and bring significant safety hazards to the throughput vehicles and construction personnel. However, there is currently a lack of effective methods to conduct a dynamic risk assessment of work zones and provide control guidance when necessary. Therefore, this study proposes a dynamic risk assessment and control framework for the work zones. The framework adopts a closed-loop control and dynamic monitoring architecture. A massive amount of microscopic data on vehicles' behavior is obtained based on advanced data collection technologies (including multicamera multiobject tracking, naturalistic driving, and microscopic traffic simulation). Traffic conflicts between single vehicle and two- or multivehicle are detected using vehicle behavior analyzing technology and the surrogate safety assessment model. A comprehensive assessment index, i.e., UTECN (unit total equivalent conflict number), is established that can consider the severity and possibility of accidents caused by conflicts based on the vehicle collision energy theory, probability theory, and risk management theory. A risk assessment standard is established based on the level of safety service. The framework is first implemented in a simulation environment, and its feasibility and effectiveness are verified by taking a work zone of Shanghai Waihuan Expressway S20 as a case study. The result shows that the framework has good practicality. Under a moderate traffic level, the risk of the work zone can be assessed within 20 minutes. It can be quickly and effectively controlled at an acceptable level after several iterations, which is of great significance for ensuring the safety of life and property of throughput vehicles and construction personnel within the work zone.

## 1. Introduction

Maintenance is an essential guarantee for maintaining roads in good condition. As China's road network enters the maintenance era, road maintenance operations are becoming increasingly important. However, the presence of maintenance work zones can interfere with the normal operation of traffic and pose significant safety hazards. Data from the United States shows that in the past 15 years, road maintenance work zones have caused many traffic accidents, with an average of 734 deaths, 348947 injuries, and nearly 1430000 property losses per year [1]. Although there is no such detailed accident data in China, considering the large population base, significant vehicle ownership, and more complex transportation environment, it is conservatively estimated that the traffic situation in China's work zones is more severe [2].

The safety issues in the work zones have attracted widespread attention from researchers domestically and internationally. Researchers have conducted qualitative and quantitative analyses of various factors in the work zone based on traffic accident databases, attempting to reveal the mechanism of accidents in the work zone and proposing a series of traffic control methods. Many of these experiences and achievements have been included in the maintenance and construction technical guidelines. For example, China released the first version of the "Safety Work Rules for Highway Maintenance" in 2004 [3] and revised it in 2015 [4], playing an important role in standardizing maintenance construction and risk control. However, these rules have not been able to prevent accidents in the work zone. The safety issues in the work zone remain serious. One possible reason is that these rules can only provide general guidance and not targeted dynamic control for each work zone scenario [5, 6]. The traffic environment on the road is dynamically changing. It is unknown whether the proposed control methods meet the requirements of the current work zone scenario, whether there are risks, and whether adjustments are needed [7–10].

In response to the above issues, this research proposes a dynamic risk assessment and control framework applicable to the work zones. Based on various advanced data collection methods, the risk assessment of the work zone can be completed in a short period (only 20 minutes at a moderate traffic level), and targeted control suggestions can be proposed when there are safety hazards in the work zone. Iterative/closed-loop control optimizes the work zone until it meets safety requirements. As the first implementation of the framework, this study uses simulation methods for data collection. The assessment and risk control model have been implemented, laying a solid foundation for subsequent case validation based on measured data. The contribution of this study is twofold: (1) A complete dynamic risk assessment and control framework for the work zone has been proposed, which can timely diagnose and control the risks in the work zone; (2) a detection and assessment method has been proposed to cover single vehicle conflicts, two vehicle conflicts, and multiple vehicle conflicts at one time.

The arrangement of other sections is as follows: Section 2 reviews the development of risk assessment methods for work zones. Section 3 presents the risk assessment and control framework. Section 4 shows the first implementation of this framework in a simulation environment. Section 5 summarizes the entire paper and provides prospects for future research.

## 2. Literature Review

In recent decades, research has mainly been based on accident databases [11]. The accident rate is the most direct reflection of the safety level in the work zone. Using accident rate as an evaluation indicator, researchers have identified many risk factors, including the length of the work zone, duration, traffic volume, speed limits, and traffic composition. They have qualitatively and quantitatively studied the impact of these factors on accident rates and established a relationship model between multiple factors and accident rates. This method, based on accident databases and using accident rates as an evaluation indicator, has significantly contributed to improving the safety of work zones. However, this method has apparent limitations [12, 13], mainly manifested in its high dependence on accident databases. If the database is incomplete, it is easy to draw one-sided or even incorrect conclusions.

Recognizing the limitations of the above methods, researchers have proposed surrogate indicators for accidents. These indicators are relatively easy to observe and have a strong correlation with accident indicators, which means that accident rates can be estimated through surrogate indicators. The proposal of surrogate indicators has extensively promoted the development of safety-related research in work zones [6]. Among numerous surrogate indicators, traffic conflict-based indicators have been widely recognized, mainly due to their similarity to the causes and processes of traffic accidents and the good correlation between particularly severe conflicts and accidents [13]. This technology, which uses traffic conflict as a surrogate evaluation indicator for safety assessment, is also known as the traffic conflict technique (TCT).

The well-known definition of traffic conflict is proximity-based: Traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged [14–16]. Based on this definition, indicators such as time to collision (TTC), proportion of stopping distance (PSD), and so on were proposed [17]. In promoting TCT, the Federal Highway Administration (FHWA) has made significant contributions. Its software, Surrogate Safety Assessment Model (SSAM), can import TRJ files generated by simulation software such as Vissim, detect two or multiple vehicle conflicts promptly, and output various indicators. The TRJ file is specially designed for SSAM; therefore, by organizing the data into this format (no matter whether the data is obtained through simulation or measured methods) and importing it into SSAM, the traffic conflict can be analyzed effectively.

However, as mentioned in its definition, it is targeted at two- or multivehicle conflicts without considering single-vehicle conflicts. Data from the United States indicates that in addition to two or multi-vehicle accidents, the situation of single-vehicle accidents is also severe in work zones [1]: from 2007 to 2021, a total of 9888 fatal accidents occurred, wherein 49.%, i.e., 4854 accidents were single-vehicle ones. In addition, nighttime construction is being accepted by many maintenance departments to avoid serious congestion caused by maintenance. Nighttime traffic volume is lower, and it is difficult to observe conflicts between two or multivehicles, while single-vehicle conflicts are relatively more severe [18]. The limitations of existing TCT being unable to detect single-vehicle conflicts are even more evident in this circumstance [17, 19].

Our previous research [16] proposed a single-vehicle conflict detection method based on another classic evasive behavior-based traffic conflict definition. The definition suggests that a traffic conflict is a phenomenon in which a road user must take evasive behavior (e.g., lane changing, braking) to avoid collision [15, 16, 20]. By executing automatic segmenting on the microscopic vehicle behavior data (MVBD) and setting thresholds, evasive behaviors can be detected, which means that the single vehicle conflicts are detected. Furthermore, through integrating the SSAM method, a method for all types of traffic conflict detection was proposed, which can effectively meet the needs of risk assessment in work zones.

Detecting traffic conflicts of all types is based on evasive behavior and proximity indicators, which can only characterize the possibility of accidents and cannot represent the severity of accidents. For example, TTC is used to detect two or multiple vehicle conflicts. When TTC is smaller than 1.5 s, a traffic conflict can be considered to occur. Assuming two conflicts are detected, with TTC less than 1.5 s, one conflict has a speed of 100 km/h for both vehicles, and the other has a speed of 5 km/h. Obviously, the former is more severe than the latter at the time of the accident, but the above severity judgment cannot be obtained solely from TTC indicators. For another example, deceleration is used to detect single-vehicle conflicts. When the deceleration is smaller than $-3.92\,\mathrm{m/s^2}$, a traffic conflict can be considered to occur. Assuming two conflicts are detected, with deceleration less than $-3.92\,\mathrm{m/s^2}$, one has a vehicle speed of 100 km/h, and the other has a speed of 5 km/h. Obviously, the former is more severe than the latter at the time of the accident, but the above severity judgment cannot be obtained solely from deceleration indicators. In fact, the assessment of conflicts should be conducted from two dimensions: the possibility of causing accidents and the severity of the accidents. The aforementioned detection of all types of traffic conflicts has only completed the first aspect of work, and a further improvement in its severity assessment is needed, which is a critical issue that needs to be addressed in this study.

We presented a preliminary result of safety assessment and risk control for work zones in 2019 [2], proposing a fast safety assessment and correction framework. However, that work did not involve detecting all types of traffic conflicts and did not consider the severity of establishing safety assessment methods and standards. This paper has significantly improved [2], with complete theory and excellent practicality.

## 3. Framework

The dynamic risk assessment and control framework is shown in Figure 1. The framework contains mainly five parts, i.e., (1) collect MVBD on-site, (2) execute risk assessment based on the collected data, (3) make the judgment whether the work zone is safe or not, (4) make risk control decisions when the work zone is at risk, and (5) execute the control measure. It can be seen that this is a dynamic closed-loop control process. After the execution of risk control measures, data will be continuously collected. Then, the next round of assessment will be conducted to evaluate the effectiveness of control measures until the work zone is safe. In addition, the safety status of the work zone will also change due to dynamic changes in road traffic flow. Therefore, this framework continues conducting dynamic data collection and assessment to ensure the work zone remains safe. The details of this framework are introduced as follows.

*3.1. Data Collection.* The first part is to collect the MVBD at the site of the work zone. The MVBD refers explicitly to the vehicle's trajectory, speed, and accelerations in this framework. The behavior data can be obtained using advanced data acquisition technologies such as video detection, naturalistic driving, and simulation-based data collection methods [16]. The video detection-based method uses cameras to record the traffic and machine vision to extract MVBD from the record. Especially at this stage, the maturity of multicamera technology makes it more convenient to obtain large-scale MVBD in the work zone [21]. The naturalistic driving-based method installs data acquisition instruments on the vehicle and collects MVBD in a naturalistic state. With the popularization of smartphones and smart cars, obtaining MVBD has become increasingly easy. With the help of crowdsourcing mode, a massive amount from the MVBD of vehicles passing through the work zone can be obtained [7]. The simulation-based method is to collect data directly from the simulation software. Through high-precision scene reconstruction and calibration, simulation software can obtain high-fidelity data and output rich indicators, making simulation methods popular among researchers [22].

*3.2. Risk Assessment.* Based on the massive amount of MVBD obtained through collection methods, a risk assessment of the work zone will be carried out, which will be introduced in three steps.

*3.2.1. Detection of All Types of Traffic Conflicts.* The first step is to perform all types of traffic conflict detection based on the MVBD collected in Section 3.1. Considering that the detection method was detailed in our previous work, this section will only provide a brief introduction. For more detailed information, please refer to [16].

The method can be summarized in Figure 2. Conduct detections for single-vehicle conflict and two- or multi-vehicle conflict based on MVBD, respectively. Wherein single-vehicle conflict detection utilizes vehicle behavior analysis methods, including automatic segmentation of vehicle behavior and behavior recognition (i.e., extracting fragments of risk avoidance behavior and determining their types), the conflict detection between two or multiple vehicles adopts an SSAM-based analysis method. It should be noted that the MVBD should be organized into TRJ file format and imported into SSAM software for automatic analysis. Through the above analysis, two detection results can be obtained. In fact, there is some overlap between these two sets of results. Some two- or multivehicle conflicts may also appear in the single-vehicle conflict detection results, and they should be removed. We adopted a straightforward but effective method: iterating the fragments of single-vehicle conflict and determining whether they are in the SSAM analysis results (based on spatial and temporal distance). If so, it indicates a conflict of two or multiple vehicles; if not, it is a conflict of a single vehicle.

*3.2.2. Comprehensive Assessment Indicator Calculation.* Based on our previous work, this paper proposes an indicator that can comprehensively evaluate the possibility and severity of accidents caused by conflicts, namely, the UTECN (unit total equivalent conflict number). The calculation process is shown in Figure 3. First, detect conflicts of single-vehicle, two-vehicle, or multivehicle separately. Then, calculate the severity and possibility of accidents caused by conflicts, and then calculate the risk values.

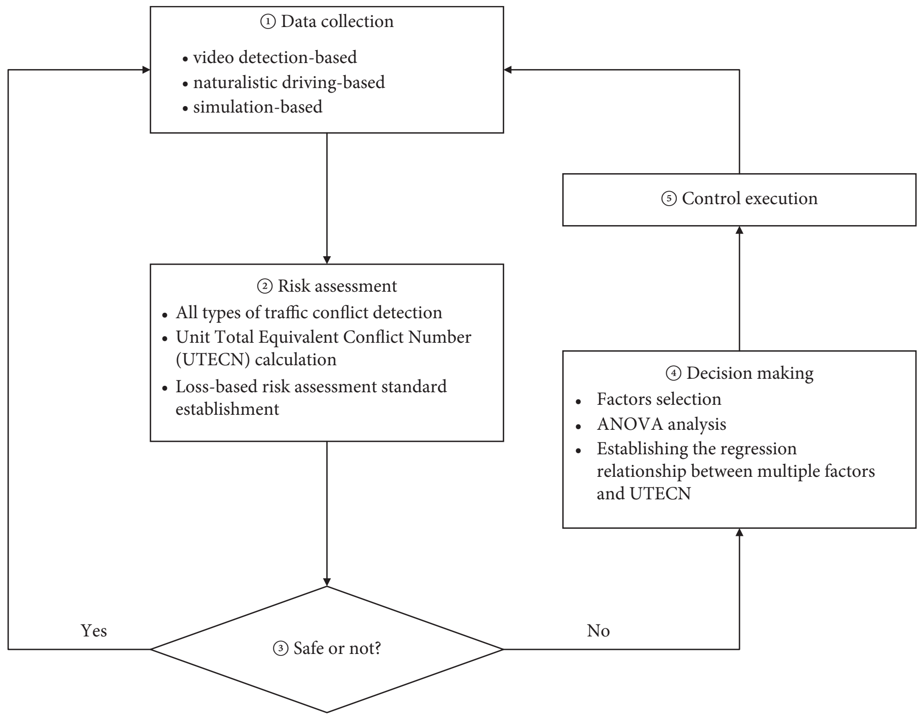



Figure 1: Dynamic risk assessment and control framework for work zones.

Finally, the equivalent number of conflicts is calculated by introducing the standard conflict risk value.

(1) Traffic conflict severity evaluation indicator establishment based on vehicle collision energy theory.

(i) Two or multiple vehicle conflicts

There is a loss of mechanical energy during the collision process, which can be used as an indicator to evaluate the severity of traffic conflicts. The following basic assumptions are made [23, 24]: ①Considering only the most unfavorable scenario of accidents, a vehicle collision is defined as a completely inelastic collision, where the driver does not take any avoidance measures throughout the entire process, i.e., maintaining the current speed and trajectory state unchanged. ②Vehicle collision is an ideal energy and momentum conversion process without considering the influence of external forces. ③The vehicle is a rigid body whose attribute parameters do not change before and after the collision, and vehicles become a whole after the collision.

There are only rear-end collisions and lane-changing collisions in work zones. The difference lies in whether the collision angle $\alpha$ is 0 or not. When $\alpha$ equals 0, it is a rear-end collision; otherwise, it is a lane-changing collision. The vehicle collision process is shown in Figure 4, and the calculation of energy loss of collision can be uniformly derived as follows.

According to the above assumptions, all mechanical energy loss during a vehicle collision is converted into plastic deformation energy, which satisfies the conservation of energy and momentum theorems. Let $E_{i,i-1}$ be the energy loss during the collision. Based on the conservation of energy before and after the collision, the following relationship can be obtained:

$$\frac{1}{2}\left(m_i + m_{i-1}\right)v'^2 + E_{i,i-1} = \frac{1}{2}m_i v_i^{\,2} + \frac{1}{2}m_{i-1}v_{i-1}^2. \tag{1}$$

Before and after the collision, the conservation of momentum theorem is satisfied in both the $x$ and $y$ directions.

$$\begin{aligned} m_{i-1}v_{i-1} + m_i v_{\mathrm{ix}} &= \left(m_i + m_{i-1}\right)v_x', \\ m_i v_{\mathrm{iy}} &= \left(m_i + m_{i-1}\right)v_y', \\ v_{\mathrm{ix}} &= v_i\cos\alpha, v_{iy} = v_i\sin\alpha, \\ v'^2 &= v_x'^2 + v_y'^2. \end{aligned} \tag{2}$$

By combining (1) and (2), the energy loss in collision $E_{i,i-1}$ can be calculated as follows:

$$E_{i,i-1} = \frac{1}{2}\frac{m_i m_{i-1}\left(v_i^2 + v_{i-1}^2 - 2v_i v_{i-1}\cos\alpha\right)}{m_i + m_{i-1}}, \tag{3}$$

wherein $m_i$ and $m_{i-1}$ is the mass of vehicle $i$ and $i-1$ (kg); $v_i$ and $v_{i-1}$ is the speed of vehicle $i$ and $i-1$ instantaneously before the collision happens (m/s); $v_x'$ and $v_y'$ is the speed component of $v'$ in the $x$ and $y$ directions, respectively (m/s);

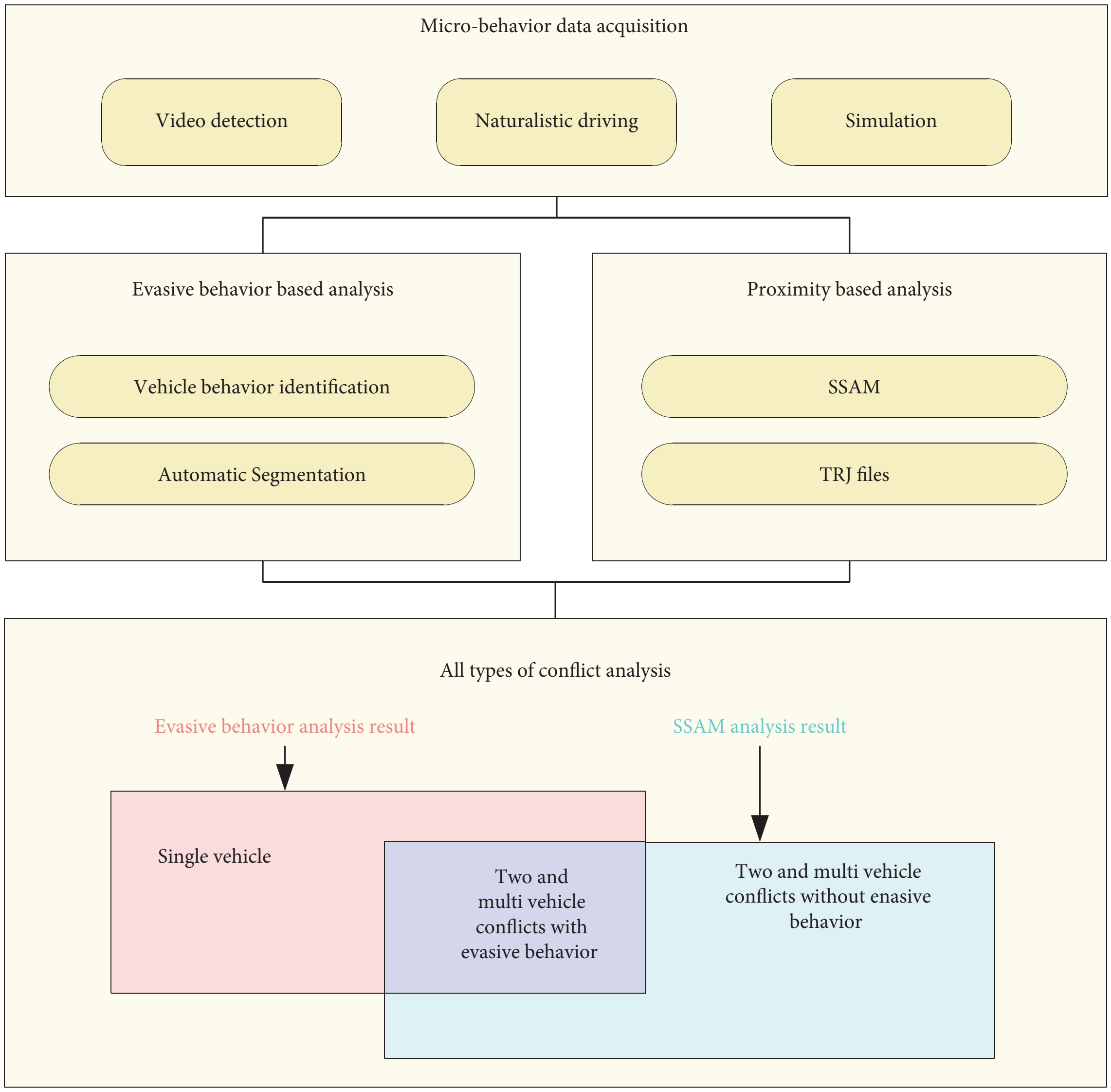



FIGURE 2: Structure for detecting traffic conflicts of all types.

and $v_x$, $v_y$ is the speed component of $v$ in the $x$ and $y$ directions, respectively (m/s).

(ii) Single-vehicle conflict

Similarly, the severity of a single-vehicle collision can also be measured by the energy loss of the collision. The same assumptions as two or multivehicle conflicts are made. The single-vehicle collision process is shown in Figure 5.

According to the above assumptions, all mechanical energy loss during a vehicle collision is converted into plastic deformation energy, which satisfies the conservation of energy and momentum theorems. Let $E$ be the energy loss during the collision. Based on the conservation of energy before and after the collision, the following relationship can be obtained:

$$\frac{1}{2}\left(m_1 + m_2\right)v'^2 + E = \frac{1}{2}m_1 v^2. \quad (4)$$

Before and after the collision, the conservation of momentum theorem is satisfied in the $x$ direction:

$$m_1 v = \left(m_1 + m_2\right)v'. \quad (5)$$

By combining (4) and (5), the energy loss in collision $E$ can be calculated as follows:

$$E = \frac{1}{2}\frac{m_1 m_2}{m_1 + m_2}v^2. \quad (6)$$

Specifically, when the collided fixed object is a facility with infinite mass (such as walls and trees), i.e., $m_2$ is infinite, and all kinetic energy of the vehicle is lost.

$$E = \frac{1}{2}m_1 v^2. \quad (7)$$

(2) Traffic conflict possibility evaluation indicator establishment based on the probability theory.

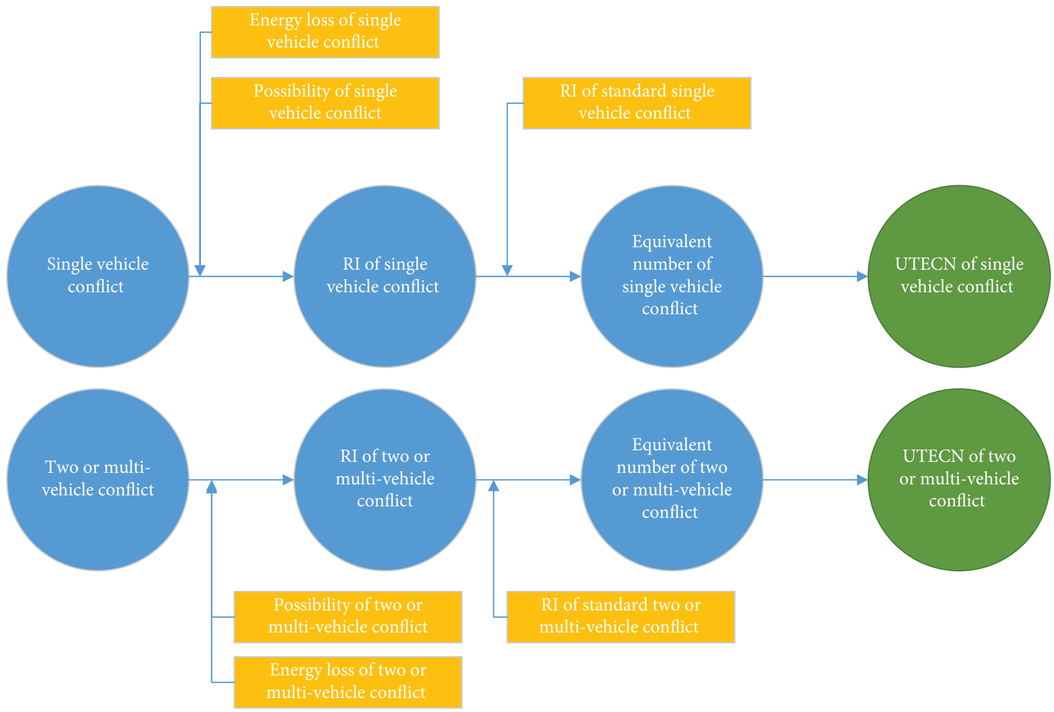



Figure 3: Calculation method for the comprehensive assessment indicator.

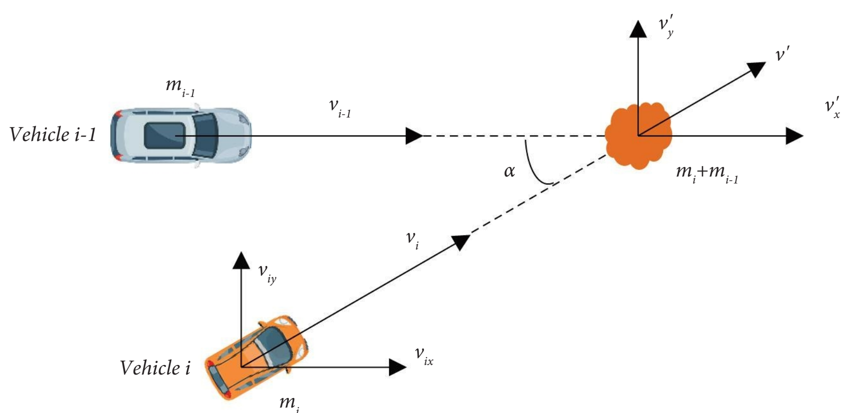



Figure 4: Schematic diagram of physical state transition during the collision between two vehicles.

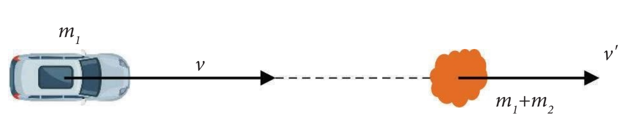



Figure 5: Schematic diagram of physical state transition during a single-vehicle collision.

(i) Two or multiple vehicle conflicts
TTC is essentially the time it takes for two or more vehicles to maintain their current physical state until a collision occurs. If the driver fails to take effective avoidance actions (braking and deceleration) to resolve traffic conflicts during this period, the conflict will become an accident. On the contrary, it can be considered a safe scenario if the driver makes timely avoidance actions within the TTC time range. In fact, in a safe scenario, TTC can be further divided into four parts, including driver response time $T_r$, driving operation coordination time $T_0$ (can take a value of 0.3 s according to [23]), shortest avoidance behavior time $T_s$, and safety margin time ts (under the most unfavorable conditions, the value is 0), i.e., $\text{TTC} = T_r + T_0 + T_s + t_s$.
The shortest avoidance behavior time $T_s$ is defined as the shortest time required for the driver to slow down to the preceding vehicle's speed. According to the relationship between the front and rear vehicles, calculations can be divided into three scenarios, as shown in the following equation:

$$T_s = \begin{cases} \dfrac{v_i - v_{i-1}}{a_{\max}}, & \text{rear – end,} \\ \dfrac{v_i \cos\alpha - v_{i-1}}{a_{\max}\cos\alpha}, & \text{rear vehicle lane changing,} \\ \dfrac{v_i - v_{i-1}\cos\alpha}{a_{\max}}, & \text{front vehicle lane changing.} \end{cases} \tag{8}$$

Wherein $v_{i-1}$ and $v_i$ are the speed of the front and rear vehicle, respectively (m/s); $a_{\max}$ is the maximum deceleration of the rear vehicle (m/s$^2$) and can be taken as 4.51 m/s$^2$ according to [23, 25]; and $\alpha$ is the lane change angle (°).

The driver's reaction time $T_r$ is influenced by individual differences, and adverse road conditions and fatigue can also significantly increase reaction time. Its probability density function is shown in the following equation (9) [26]:

$$f(T_r) = \frac{1}{\sqrt{2\pi \times 0.26} \times 0.9952} \cdot \exp\left[-\frac{(T_r - 1.32)^2}{2 \times 0.26}\right], T_r \in (0, +\infty). \tag{9}$$

Therefore, in the most unfavorable scenario, when TTC < Tr + T0 + Ts, i.e., the driver has insufficient time to resolve traffic conflicts, resulting in a traffic accident, the probability is $P(\mathrm{TTC} < T_r + T_0 + T_s)$. It is equivalent to calculate the probability $P(\mathrm{TTC} - T_0 - T_s < T_r)$, i.e.,

$$\begin{aligned} P(\mathrm{TTC} < T_r + T_0 + T_s) &= P(\mathrm{TTC} - T_0 - T_s < T_r) \\ &= 1 - \int_0^{\mathrm{TTC}-T_0-T_s} \frac{1}{\sqrt{2\pi \times 0.26} \times 0.9952} \exp\left[-\frac{(T_r - 1.32)^2}{2 \times 0.26}\right] dT_r. \end{aligned} \tag{10}$$

(ii) Single-vehicle conflict

The evasive behavior-based traffic conflict definition suggests that if the deceleration exceeds the threshold, it is considered a conflict, but will this conflict lead to an accident? This deceleration is the actual deceleration of the vehicle; is this deceleration sufficient? If it's not big enough, for example, if the actual deceleration is smaller than the needed deceleration, it can collide. Therefore, the probability of a single-vehicle accident occurring is $P_{\text{single}} = P(a_{\text{actual}} < a_{\text{need}})$.

Assuming the most unfavorable situation, the vehicle brakes sharply and stops just in front of the fixed object; that is, the distance between the vehicle and the fixed object is 0, the speed is 0, and the acceleration required for this process is $a_{\text{need}}$. Assuming that the vehicle adopts a uniform deceleration motion, $a_{\text{need}}$ is a constant value, and $a_{\text{need}} = v_{\text{actual}}/t_{\text{need}}$, then, the probability of a single-vehicle accident can be calculated as follows:

$$\begin{aligned} P_{\text{single}} &= P(a_{\text{actual}} < a_{\text{need}}) \\ &= P\left(a_{\text{actual}} < \frac{v_{\text{actual}}}{t_{\text{need}}}\right) \\ &= P\left(t_{\text{need}} < \frac{v_{\text{actual}}}{a_{\text{actual}}}\right) \\ &= P\left(T_r + T_0 + T_s < \frac{v_{\text{actual}}}{a_{\text{actual}}}\right) \\ &= P\left(T_r < \frac{v_{\text{actual}}}{a_{\text{actual}}} - T_0 - T_s\right) \\ &\cdot \int_0^{v_{\text{actual}}/a_{\text{actual}}-T_0-T_s} \frac{1}{\sqrt{2\pi \times 0.26} \times 0.9952} \exp\left[-\frac{(T_r - 1.32)^2}{2 \times 0.26}\right] dT_r. \end{aligned} \tag{11}$$

Wherein $T_0$ can be taken as 0.3 s; Ts can be calculated as $v_{\text{actual}}/a_{\max}$.

(3) Construction of risk indicator.

According to the basic theory of risk management, the risk is equal to the probability of an accident occurring multiplied by the accident loss. According to the previous deductions, the probability of an accident occurring is $P$, and the loss of the accident is $E$. The accident risk value can be obtained from the following equation:

$$\mathrm{RI} = P \times E. \tag{12}$$

(4) Number of equivalent conflicts.

Since most of the existing models for accident analysis are count models, they can be fully utilized by converting the above risk indicator into the number of traffic conflicts. For example, for a specific conflict, if the risk value is calculated to be 1000 and the risk value of a standard conflict is assumed to be 100, then this conflict is relatively severe, equivalent to 10 standard conflicts. Therefore, the key point of the equivalence method lies in selecting standard conflicts and determining their risk values.

According to statistical theory, when the risk value of traffic conflict reaches the 85% percentile, it is very close to an accident [27]. Therefore, the standard conflict risk indicator value can be obtained by drawing a cumulative percentage frequency chart of risk indicator values and selecting the 85% percentile as the risk indicator value. That is to say, when the risk indicator value of a conflict exceeds the standard indicator value, the conflict is already dangerous and is highly likely to evolve into a traffic accident and cause significant harm.

Therefore, the conversion formula for Equivalent Conflict Number (ECN) can be defined as follows:

$$\mathrm{ECN} = \frac{\mathrm{RI}}{\mathrm{RI}_b}. \tag{13}$$

Wherein RI is the risk indicator value of the conflict, and $\mathrm{RI}_b$ is the standard conflict risk indicator value.

Then, the calculation method for the traffic conflict evaluation index UTECN of a specific work zone within a certain evaluation period is as follows:

$$\mathrm{UTECN} = \sum_{i=0}^{n} \frac{\mathrm{ECN}_i}{\mathrm{Length}}. \tag{14}$$

Wherein $n$ is the total number of traffic conflicts; Length is the length of the assessed road section (km).

*3.2.3. Standard Establishment for Risk Assessment.* The comprehensive risk indicator established in 3.2.2 cannot yet tell us whether a specific indicator value is safe/dangerous or how safe/dangerous it is. A standard for risk assessment needs to be established. This paper adopts the theory of LOSS (Level of Safety Service) to construct [28].

LOSS is proposed with reference to the concept of road level of service. It refers to the level of safety service that road facilities can provide to all traffic participants or the feeling of traffic participants towards the level of safety service that road facilities can provide. In the LOSS analysis, indicators such as accident frequency, accident rate, number of deaths and injuries, and traffic volume can define the safety service level of road sections.

Generally, the LOSS is divided into four levels, and the corresponding safety service levels from high to low are LOSS-1, LOSS-2, LOSS-3, and LOSS-4. The corresponding conditions for each LOSS are as follows.

(i) LOSS-1: The safety status of facilities is excellent, and the safety service quality that traffic participants can feel is high. Road safety is at a high level, and there is almost no possibility of further improvement and the department only needs to maintain the current situation.

(ii) LOSS-2: The safety status of facilities is good, and the safety service quality that traffic participants can feel is higher than expected. Certain measures can be taken to improve the safety situation further and achieve the optimal state.

(iii) LOSS-3: The safety status of facilities is fair, and the safety service quality that traffic participants can feel is lower than expected. There is still significant room for improvement in the current safety situation, and corresponding measures must be taken to improve it.

(iv) LOSS-4: The safety status of facilities is poor, and the safety service quality that traffic participants can feel is far lower than expected. Generally, it can be considered that sections with LOSS-4 are accident-prone sections, which pose significant safety hazards. Risk control measure is required to execute imperatively; otherwise, more traffic accidents will occur.

The establishment of LOSS standards can be carried out as follows:

(1) Draw a scatter plot of traffic volume and assessment indicator (for this study, it is the ECN).

(2) Divide the traffic volume into several equal and continuous intervals.

(3) Calculate the mean $E_i$ and standard deviation $\delta_i$ of the assessment indicator of each traffic volume interval according to equation:

$$E_i = \frac{\sum_{k=1}^{j} A_k}{j},$$
$$\delta_i = \sqrt{\frac{\sum_{k=1}^{j} \left(A_k - E_i\right)}{j-1}}. \tag{15}$$

Wherein, $E_i$ is the mean of the assessment indicators of all the sections within the $i$ volume interval; $\delta_i$ is the standard deviation of the assessment indicators of all the sections within the $i$ volume interval; $A_k$ is the assessment indicator value of the $k$ road section; $j$ is the number of road sections within the I volume interval.

(4) Calculate the $E_i + 1.5\delta_i$, $E_i$, $E_i - 1.5\delta_i$ within each traffic volume interval. Then three sets of data can be obtained, namely, ($E_i + 1.5\delta_i$, volume$_i$), ($E_i$, volume$_i$), and ($E_i - 1.5\delta_i$, volume$_i$).

(5) By conducting regression analysis on the three sets of data, the following models can be obtained:

$$y_i = f_i(\text{Volume}), i = 1, 2, 3. \tag{16}$$

Wherein $y_1$ is the upper bound of the LOSS gradation; $y_2$ is the mean of the LOSS gradation; $y_3$ is the lower bound of the LOSS gradation; and volume is the traffic volume, vehicles/hour.

(6) The three curves $y1$, $y2$, and $y3$ divide the scatter plot into four regions, from bottom to top, which are LOSS-1, LOSS-2, LOSS-3, and LOSS-4. The schematic diagram is shown in Figure 6, where $y1$, $y2$, and $y3$ are the dividing lines of LOSS.

With LOSS, evaluating whether the work zone is safe is very simple; simply compare it with the LOSS of normal road sections. For example, suppose the LOSS of the section where the work zone is located is LOSS-1 under normal conditions. In that case, the ideal state for the operation period is maintaining the safety service level at LOSS-1 through control measures. However, in reality, it is not easy to maintain a level of safety service consistent with normal road sections due to work zones. In other words, achieving this goal requires a very high cost (at the extreme, by detouring all the upstream vehicles, the safety service level of this work zone section must be LOSS-1). Thus, the department can establish an acceptable LOSS reduction after comprehensively considering various factors. For example, the department may accept that during the construction period, the safety service level of the road section decreases by one level. Then, when the actual LOSS in the work zone is downgraded by more than two levels, control measures must be taken.

*3.3. Decision-Making for Risk Control.* Using the above-mentioned method, a dynamic risk assessment can be conducted for the work zone. When it is found that the risk is unacceptable, i.e., the safety service level is lower than the acceptable level, control measures should be taken. Then, what control measures should be taken to quickly eliminate risks and adjust the level of safety service to an acceptable range? This can be answered by constructing a relationship between multiple factors and UTECN based on a large amount of historical data.

Existing research has explored the impact of multiple factors such as working area length, traffic volume, and the proportion of large vehicles on accidents in work zones [11]. For example, research has shown that the proportion of large vehicles significantly impacts accidents in the work zone. Conversely, when it is found through measured data that the large vehicle proportion is high and the risk value is high, the risk can be reduced by reducing the proportion of large vehicles. Therefore, selecting factors and modeling the relationship between factors and accidents are keys to this framework. Reviewing existing literature [11], it was found that factors affecting the safety of work zones include the proportion of large vehicles, traffic volume, speed limit, merging type, road grades, lane closures, and adverse weather conditions. Considering that the purpose of modeling in this section is to serve risk control decision-making, it is recommended to choose factors controllable by the department as the key consideration. As for modeling the relationship between multiple factors and accidents in work zones, it includes Poisson and negative binomial (NB), zero-inflated NB and Poisson, truncated regression, generalized additive model, Conway Maxwell Poisson model, and negative multinomial model, etc [11, 29]. After establishing the model, analyzing the marginal effects of each factor can guide control decisions.

## 4. First Implementation

To verify the feasibility of this framework, this section implements it for the first time in the form of a case study. This maintenance operation was carried out on the Shanghai Waihuan Expressway S20 (a two-way, eight-lane expressway with a speed limit of 80 km/h) to repair the pothole in lanes 1 and 2. Only lanes 1 and 2 are closed to reduce construction's impact on traffic (see Figure 7). The lengths of the warning area and work area are 500 m and 170 m, respectively. The traffic volume is 3500 vehicles/hour. The proportion of large vehicles is 0.22. This case uses simulation methods to collect MVBD; the simulation software is Vissim. Accurate restoration of the work zone site was conducted in Vissim, and the model was calibrated using measured data.

*4.1. Data Collection under Simulation Environment.* Vissim can output detailed data. This case sets the simulation resolution to 20-time steps per simulation second. The output file selects the vehicle number, acceleration, world coordinate front $x$, world coordinate front $y$, world coordinate rear $x$, world coordinate rear $y$, speed, simulation time, vehicle type, and weight. Vissim can also directly output the TRJ file data required by SSAM.

*4.2. Detection of Traffic Conflicts.* Our previous research [16] has established the traffic conflict detection method and implemented it through coding in MATLAB. After importing the MVBD exported from Vissim into the single-vehicle conflict detection program, a total of 30 single-vehicle conflicts were identified. When the TRJ file generated from Vissim was imported into SSAM, a total of 188 two or multivehicle conflicts were detected. The number of single-vehicle conflicts is 25, and the number of two or multivehicle conflicts is 188. Part of the conflicts and their key parameters are shown in Tables 1 and 2.

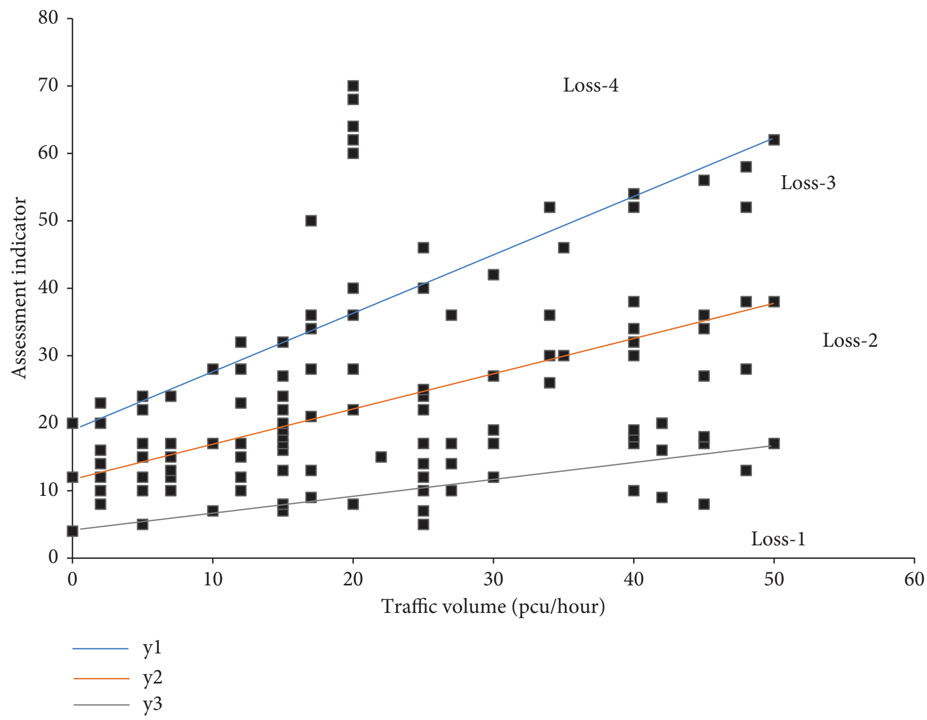



Figure 6: Schematic diagram of LOSS.


Figure 7: Work zone model established in Vissim.

Table 1: Single vehicle conflicts and their key parameters (part).

| Index | Vehicle Id | Time (s) | $X$ | $Y$ | Acceleration-$x$ (m/s$^2$) | Acceleration-$y$ (m/s$^2$) | Speed (km/h) |
|---|---|---|---|---|---|---|---|
| 1 | 3470 | 3650.1 | 2095.8 | 411.6 | −4.6 | 0 | 49.6 |
| 2 | 3473 | 3648.8 | 2082.7 | 410.3 | −4.7 | −0.1 | 44.9 |
| 3 | 3540 | 3725.6 | 2141.6 | 415.8 | −4.5 | 0.7 | 45.7 |
| 4 | 3701 | 3834.1 | 3438.8 | 600.6 | −6.9 | 0 | 66.9 |
| 5 | 3853 | 3983.5 | 3438.8 | 600.6 | −6.2 | 0 | 67.5 |

Table 2: Two or multiple vehicle conflicts and their key parameters (part).

| Index | TTC (s) | Conflict angle (°) | Conflict type | First VID | First VMinTTC (m/s) | Second VID | Second VMinTTC (m/s) |
|---|---|---|---|---|---|---|---|
| 1 | 0.8 | 0 | Rear end | 3434 | 3.05 | 3430 | 8.02 |
| 2 | 1.3 | 0 | Rear end | 3450 | 6.22 | 3436 | 8.79 |
| 3 | 1.4 | −6.17 | Lane change | 3408 | 9.92 | 3454 | 21.8 |
| 4 | 1.5 | −0.02 | Rear end | 3458 | 0.59 | 3456 | 3.45 |
| 5 | 1.1 | 0 | Rear end | 3365 | 1.48 | 3376 | 1.21 |

*4.3. Calculation of Assessment Indicator.* Based on the data in 4.3, the conflict severity and possibility calculation method in 3.2.2 were implemented in MATLAB. The results were obtained, as shown in Tables 3 and 4, respectively. Due to the uncertainty of the standard conflict risk value, it is not yet possible to calculate the equivalent number of traffic conflicts, which will be determined by simulating a large scale of the S20 and conducting a statistical analysis, as shown in Section 4.4.

Table 3: Risk value calculation for single vehicle conflicts (part).

| Index | Energy loss (J) | Probability of occurrence | Risk value (J) |
|---|---|---|---|
| 1 | 2024249 | 0.91 | 1846203 |
| 2 | 147572.9 | 0.80 | 117380.7 |
| 3 | 712398.1 | 0.84 | 594948 |
| 4 | 241817.7 | 0.62 | 149930.6 |
| 5 | 316535.6 | 0.82 | 259507.2 |

Table 4: Risk value calculation for two or multiple vehicle conflicts (part).

| Index | Energy loss (J) | Probability of occurrence | Risk value (J) |
|---|---|---|---|
| 1 | 1954.4 | 0.99 | 1928.3 |
| 2 | 466.8 | 0.81 | 380.1 |
| 3 | 2651862.2 | 0.95 | 2521651.7 |
| 4 | 2383.6 | 0.70 | 1669.4 |
| 5 | 21.9 | 0.86 | 18.7 |

*4.4. Standard Establishment.* To establish a risk assessment standard for the S20 Expressway, this study simulated a large scale of the S20 for 75 kilometers in Vissim. Using the same conflict analysis method as for the above work zone, the conflicts, severity, possibility, and risk index corresponding to each conflict were obtained for this model. Draw the cumulative frequency distribution curves of the risk indices of single vehicle conflict and two or multiple vehicle conflict in S20, respectively; take the 85% percentile risk value as the standard risk value for each type of conflict. For single-vehicle conflicts, the standard conflict risk value is 58000 J; for two or multivehicle conflicts, the standard conflict risk value is 490000 J. The equivalent number of conflicts for each conflict in Section 4.3 can be calculated using the standard risk value. For example, for the first single vehicle conflict in Table 3, with a risk value of 1846203 J, the equivalent number of traffic conflicts is $1846203/58000 = 31.8$. For the first two or multivehicle conflicts in Table 4, with a risk value of 1928.3 J, the equivalent number of traffic conflicts is $1928.3/490000 = 0.004$. The total number of equivalent conflicts in the work zone is obtained by adding up all the equivalent numbers of conflicts. And the UTECN can be obtained by dividing the length of the work zone, i.e., 1 km in this case. For single-vehicle conflicts, the UTECN value is 173 per km; for two or multivehicle conflicts, the UTECN value is 170 per km.

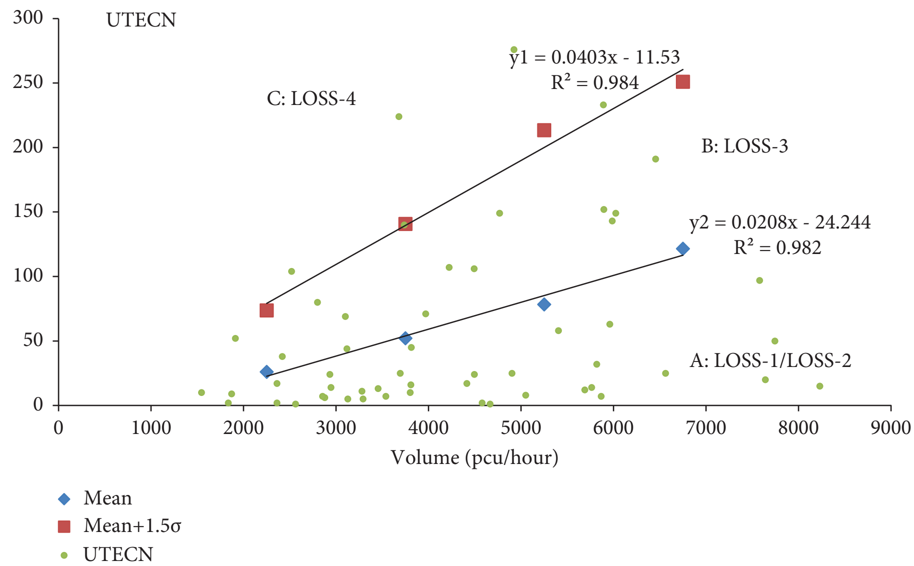
To determine the risk level of the work zone, it is necessary to establish risk assessment standards. According to the steps introduced in Section 3.2.3, divide S20 into units with a length of 1 km and calculate the UTECNs and traffic volume for each section. These sections are grouped according to their traffic flow with a width of 1000 vehicles per hour, and the mean, standard deviation, mean −1.5·standard deviation, the mean+1.5·standard deviation of UTECNs in each group are calculated to obtain the distribution shown in Figure 8.

It can be seen that the fitting line of the mean and the one of the mean + 1.5 standard deviation divide the region into three regions (since the mean −1.5 standard deviation is less than 0, the (0, mean −1.5 standard deviation) and (mean −1.5 standard deviation, mean) regions can be merged). Area A indicates a low risk and belongs to LOSS 1 and 2. Area B has a high risk and belongs to LOSS 3. Area C has a very high risk and belongs to LOSS 4.

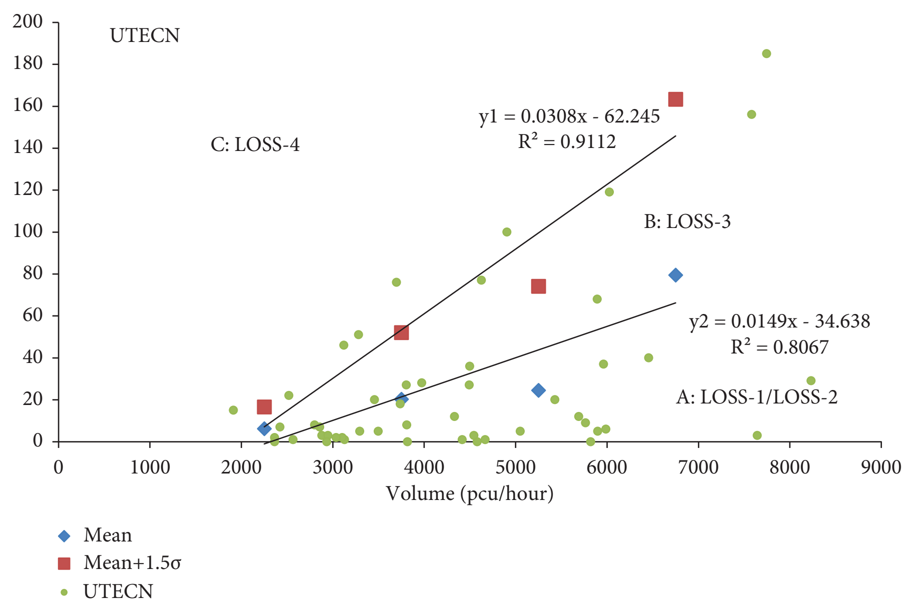
The traffic volume in this work zone is 3500 vehicles/hour. The UTECN for single-vehicle conflict is 173. It is located in Area C in Figure 8, of which the LOSS is 4. Therefore, it can be determined that the risk value of single-vehicle conflicts is very high. The UTECN of two or multivehicle conflicts is 170. It is located in Area C in Figure 8, of which the LOSS is 4. Therefore, it can be determined that the risk value of conflicts between two or more vehicles is also very high. In fact, through S20 simulation, it was found that the LOSS of the section where this work zone is located is 1 or 2 in the normal state (i.e., when no work zone exists). It can be seen that the presence of the work zone seriously affects the LOSS, and specific measures need to be taken. If conditions permit, optimizing and elevating the LOSS to LOSS 1 and LOSS 2 is recommended. If conditions do not permit, the LOSS should also be elevated to at least LOSS 3; otherwise, it is easy to cause accidents. So, what specific measures should be taken? The answer will be obtained in 4.5.

*4.5. Decision Making.* A regression relationship between multiple factors of the work zone and UTECN will be established in this section. Referring to previous research [11], 5 factors are selected for analysis, including the length of the warning area, the speed limit of the warning area, the length of the working area, traffic volume, and the proportion of large vehicles. Each factor considers four levels, as shown in Table 5. One-way analysis of variance (ANOVA) is adopted to explore the sensitivity of these factors to the impact of UTECN. 20 sets of experiments were designed, each of which only changed the value of one factor based on the real scenario in Section 4.1. For example, when analyzing the sensitivity of traffic volume, only changing the traffic volume to 2000, 2500, and 3000 vehicles/hour and keeping other factors consistent with the real scenario. Perform two parallel experiments in each set. After the simulations are completed, the aforementioned method is used to calculate UTECNs, and one-way ANOVA is performed on SPSS. The results are shown in Table 6. It can be seen that the proportion of large vehicle, traffic volume, and speed limit of the warning area have a significant impact on single-vehicle conflicts, while the length of the warning area and the length of the working area do not show significant differences ($p > 0.05$). The proportion of large vehicles, traffic volume, speed limit of the warning area, and length of the warning area have a significant impact on multivehicle conflicts, while the length of the working area does not show significant differences ($p > 0.05$).

According to the ANOVA results, subsequent analysis will only consider the impact of the proportion of large vehicles, traffic volume, speed limit of the warning area, and length of the warning area on UTECN. Design 16 orthogonal experiments (as shown in Table 7). Set up two parallel experiments for each experiment. Conduct simulations separately, and then calculate the UTECNs in each work zone.




(a)




(b)

Figure 8: LOSS for S20. (a) Single-vehicle conflicts. (b) Two or multivehicle conflicts.

Table 5: Factors and levels considered in the case study.

| Length of the warning area (m) | Speed limit of the warning area (km/h) | Length of the working area (m) | Traffic volume (vehicles/h) | Proportion of large vehicle |
|---|---|---|---|---|
| 400 | 80 | 200 | 2000 | 0.1 |
| 600 | 70 | 300 | 2500 | 0.2 |
| 800 | 60 | 400 | 3000 | 0.3 |
| 1000 | 50 | 500 | 3500 | 0.4 |

Table 6: ANOVA results.

| Factors | Single-vehicle conflict | | Multivehicle conflict | |
|---|---|---|---|---|
| | $F$ | $p$ | $F$ | $p$ |
| Proportion of large vehicle | 7.365 | 0.042* | 20.283 | 0.007** |
| Traffic volume | 15.307 | 0.012* | 7.753 | 0.038* |
| Length of the working area | 0.436 | 0.74 | 1.163 | 0.427 |
| Speed limit of the warning area | 20.896 | 0.007** | 14.98 | 0.012* |
| Length of the warning area | 0.277 | 0.84 | 7.727 | 0.039* |

$^{*}p < 0.05$, $^{**}p < 0.01$.

Table 7: Experiment design and equivalent conflict analysis results.

| Experiment index | Length of the warning area (m) | Speed limit of the warning area (km/h) | Traffic volume (vehicles/h) | Proportion of large vehicle | UTECN of two or multivehicle conflict | UTECN of single-vehicle conflict |
|---|---|---|---|---|---|---|
| 1 | 400 | 80 | 2000 | 0.1 | 1 | 3 |
| 2 | 400 | 70 | 2500 | 0.2 | 21 | 6 |
| 3 | 400 | 60 | 3000 | 0.3 | 137 | 59 |
| 4 | 400 | 50 | 3500 | 0.4 | 214 | 128 |
| 5 | 600 | 80 | 3000 | 0.4 | 180 | 106 |
| 6 | 600 | 70 | 3500 | 0.3 | 158 | 45 |
| 7 | 600 | 60 | 2000 | 0.2 | 37 | 1 |
| 8 | 600 | 50 | 2500 | 0.1 | 21 | 4 |
| 9 | 800 | 80 | 3500 | 0.2 | 114 | 139 |
| 10 | 800 | 70 | 3000 | 0.1 | 11 | 6 |
| 11 | 800 | 60 | 2500 | 0.4 | 35 | 2 |
| 12 | 800 | 50 | 2000 | 0.3 | 11 | 28 |
| 13 | 1000 | 80 | 2500 | 0.3 | 25 | 19 |
| 14 | 1000 | 70 | 2000 | 0.4 | 30 | 25 |
| 15 | 1000 | 60 | 3500 | 0.1 | 57 | 57 |
| 16 | 1000 | 50 | 3000 | 0.2 | 70 | 60 |
| Real scenario | 500 | 80 | 3500 | 0.22 | 170 | 173 |

The average of parallel experiments was taken as the final result of each experiment set and summarized with the actual scenario to obtain the results shown in Table 7.

Based on previous research [11, 30], a regression relationship between multiple factors and UTECNs was established using Poisson regression. The results are shown in Table 8:

Results show that, for single-vehicle conflicts, the speed limit of the warning area, traffic volume, and large vehicle proportion significantly impact UTECN. Their contribution ranking is traffic volume > proportion of large vehicles > speed limit in the warning area. McFadden $R^2$ is 0.652, which means that the three factors can explain the 65.2% change in the UTECN. The regression model can be written as log $(u) = -3.157 + 0.017$ Speed limit of the warning area $+ 0.002$, traffic volume $+ 2.995$, and proportion of large vehicle (where $u$ represents the expected mean).

For two- or multivehicle conflicts, the speed limit of the warning area, traffic volume, and large vehicle proportion have a significant positive impact on UTECN, and the length of the warning area has a significant negative impact on UTECN. Their contribution ranking is traffic volume > proportion of large vehicles > length of the warning area > speed limit in the warning area. McFadden $R^2$ is 0.789, which means that the five factors can explain the 78.9% change in the UTECN. The regression model can be written as log $(u) = -0.832–0.001$. Length of the warning area +0.009. The speed limit of the warning area +0.001. Traffic volume $+ 3.871$. Proportion of large vehicle (where $u$ represents the expected mean).

It can be seen that for this work zone, reducing traffic volume or the large vehicle proportion can effectively reduce UTECN. Reduce the traffic volume to 2500 vehicles/hour through measures such as detours and rerun the simulation. Results show that the UTECN of two or multivehicle conflicts is 9, the one for single-vehicle conflicts is 43, and the new LOSS of the work zone is improved to LOSS 3. Alternatively, by controlling the proportion of large vehicles passing through upstream, such as by reducing the proportion of large vehicles to 0.1. The results show that the UTECN of two or multivehicle conflicts is 9, the one for single-vehicle conflicts is 53, and the new LOSS of the work zone is improved to LOSS 3. Therefore, this risk control is effective and significant.

In fact, there are many other factors that can be considered, such as the number of closed lanes, lighting conditions, whether signal control is used, whether traffic police arrive at the scene, etc. By collecting a large amount of data and including the factors into the regression analysis model,

Table 8: Poisson regression results.

| Index | Regression coefficient | |
|---|---|---|
| | Single vehicle conflict | Two or multi-vehicle conflict |
| Length of the warning area | — | $-0.001^{**}$ ($-4.256$) |
| Speed limit of the warning area | $0.017^{**}$ (5.760) | $0.009^{**}$ (3.632) |
| Traffic volume | $0.002^{**}$ (20.279) | $0.001^{**}$ (20.184) |
| Proportion of large vehicle | $2.995^{**}$ (8.550) | $3.871^{**}$ (12.352) |
| Constant | $-3.157^{**}$ ($-8.483$) | $-0.832^{*}$ ($-2.469$) |
| Sample size | 17 | 17 |
| Likelihood ratio test | $\chi^2$ (3) = 658.041, $p < 0.001$ | $\chi^2$ (4) = 901.705, $p < 0.001$ |
| McFadden $R^2$ | 0.652 | 0.789 |

Dependent variable: UTECN. $^{*}p < 0.05$ $^{**}p < 0.01$ $z$ statistics in parentheses.

the control decision library can be further enriched. Considering that this is the first implementation of the framework and certain control measures cannot be restored in a simulation environment, this study only analyzed five factors. Subsequent research will be based on actual data to investigate the effects of other factors on risk control.

*4.6. Discussion.* As the first implementation, this case adopts a simulation method that is easier to obtain data than actual measurement, which verifies the feasibility of the framework and methods to some extent. If measured data is used, such as data collected through a camera, the data extracted by the camera should be organized according to the requirements of the aforementioned program. For example, according to SSAM's requirements, trajectory data should be organized into TRJ format to be directly imported into SSAM for traffic conflict analysis. For the MVBD acquisition of the entire road, collecting data on a large scale is not easy. It can be replaced by collecting data in several typical sections and calculating the total number of equivalent conflicts, which can also achieve good results. These changes are only reflected in data collection and do not require any changes to the framework, indicating that this framework can adapt well to the needs of on-site measurement.

This case only studied the influence of the length of the warning area, speed limit in the warning area, large vehicle proportion, traffic volume, and length of the working area on UTECN in the work zone. Many other factors have not been considered, such as weather conditions, lighting conditions, the length of the transition area, etc. It explains why the $R^2$ of the regression models is not particularly high. Further research will consider more factors for modeling, and these improvements do not require changes to this framework.

Finally, whether the LOSS of the work zone needs to be improved is actually a comprehensive optimization problem. The presence of work zones will inevitably affect the LOSS, and improving LOSS comes at a cost, including owner cost (required to add/change facilities) and user costs (due to detours and congestions). This paper has not yet considered calculating costs and benefits and only proposes basic judgment principles. When it is found that the LOSS of the work zone has decreased, in principle, various measures should be taken to restore the level to the normal level. If conditions do not allow and the ideal state cannot be achieved, it should also be ensured that the service level in the work zone does not differ too much from the normal level. For example, descending by one level is acceptable, but measures should be taken when the descent reaches two levels. Comprehensive consideration of various costs and benefits to guide decision-making will be done as follow-up research.

## 5. Conclusions and Outlook

This paper constructs a dynamic risk assessment and control framework applicable to work zones, which has the following distinct characteristics: (1) collecting massive MVBD through multiple cameras or naturalistic driving or simulation. (2) Detecting single-vehicle conflicts and two or multivehicle conflicts in the work zone based on risk avoidance behavior analysis and SSAM analysis. (3) Integrating the severity and possibility of accidents caused by conflicts to obtain comprehensive risk indicators and the equivalent total number of traffic conflicts. (4) Establishing a risk assessment standard based on the level of safety service. (5) Constructing a risk control decision-making method based on Poisson regression. (6) Adopting closed-loop control and dynamic evaluation for architecture. The framework was first implemented under a simulation environment using a work zone of the Shanghai Waihuan Expressway S20 as a case study. The following conclusions can be obtained:

(1) This framework adopts an all types of traffic conflict analysis technology, which has the ability to quickly assess the safety condition of the work zone. At a moderate traffic level, it only takes 20 minutes to conduct a risk assessment for the work zone, which is very suitable for high-frequency and short-duration maintenance operations.
(2) This framework has good practicality. Computer vision applications are very common, and large-scale multi-target tracking technology is relatively mature. Alternatively, naturalistic driving methods can obtain large-scale measured MVBD in the work zone. It can be input into various models for rapid analysis by organizing it in a predetermined format (for SSAM, it needs to be converted to TRJ format).

Next, we will conduct further research in the following areas: (1) designing a large-scale MVBD collection method and device based on multicamera and multitarget tracking technology suitable for the work zone; (2) conducting an actual data collection for a certain work zone to further validate the feasibility, effectiveness, and superiority of the framework and method proposed in this paper in practice. (3) Establishing a road network LOSS database based on the total number of equivalent conflicts to prepare conditions for risk assessment standards and guide the risk control decision-making of actual work zones.

## Data Availability

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

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

## Authors' Contributions

Zhepu Xu (first author and corresponding author) conceptualized the study, curated the data, performed formal analysis, was responsible for funding acquisition, investigated the study, proposed methodology, administered the project, provided the resources, provided the software, validated the study, performed the visualization, wrote the original draft, and wrote, reviewed, and edited the study .

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## References

[1] Nhtsa, "Fatality analysis reporting system (FARS)," 2023, https://www.nhtsa.gov/research-data/fatality-analysis-reporting-system-fars.

[2] Z. Xu and Q. Yang, *Fast Safety Assessment and Correction Framework for Maintenance Work Zones*, arXiv e-prints, New York, NY, USA, 2019.

[3] Shanghai Highway Management Office, *Safety Work Rules for Highway Maintenance(JTG H30-2004)*, Ministry of Communications, Shanghai, China, 2004.

[4] Research Institute of Highway Ministry of Transport, *Safety Work Rules for Highway Maintenance (JTG H30-2015)*, Ministry of Communications, Shanghai, China, 2015.

[5] H. Abdulsattar, A. Mostafizi, and H. Wang, "Surrogate safety assessment of work zone rear-end collisions in a connected vehicle environment: agent-based modeling framework," *Journal of Transportation Engineering, Part A: Systems*, vol. 144, no. 8, Article ID 4018038, 2018.

[6] A. Arun, M. M. Haque, A. Bhaskar, S. Washington, and T. Sayed, "A systematic mapping review of surrogate safety assessment using traffic conflict techniques," *Accident Analysis and Prevention*, vol. 153, Article ID 106016, 2021.

[7] Z. Xu and Q. Yang, "Novel fast safety assessment method for the buffer section of maintenance work zone," *IET Intelligent Transport Systems*, vol. 13, 2019.

[8] W. Cheng, *Theory and Application of Urban Traffic Conflict Technique*, Science Press, Beijing, china, 2006.

[9] J. Weng and Q. Meng, "Analysis of driver casualty risk for different work zone types," *Accident Analysis and Prevention*, vol. 43, pp. 1811–1817, 2011.

[10] A. Laureshyn and V. András, *The Swedish Traffic Conflict Technique- Observer's Manual*, Lund University, Lund, Sweden, 2018.

[11] H. Yang, K. Ozbay, O. Ozturk, and K. Xie, "Work zone safety analysis and modeling: a state-of-the-art review," *Traffic Injury Prevention*, vol. 16, no. 4, pp. 387–396, 2015.

[12] G. Liang, F. Wang, W. Wang, X. Sun, and W. Wang, "Assessment of freeway work zone safety with improved cellular automata model," *Journal of Traffic and Transportation Engineering*, vol. 1, no. 4, pp. 261–271, 2014.

[13] Q. Meng and J. Weng, "Evaluation of rear-end crash risk at work zone using work zone traffic data," *Accident Analysis and Prevention*, vol. 43, no. 4, pp. 1291–1300, 2011.

[14] H.-C. Chin and S.-T. Quek, "Measurement of traffic conflicts," *Safety Science*, vol. 26, no. 3, pp. 169–185, 1997.

[15] G. Davis and J. Hourdos, *Development of Analysis Methods Using Recent Data*, National Academies Press, Washington, DC, USA, 2012.

[16] Z. Xu and D.-S. Chen, "Detection method for all types of traffic conflicts in work zones," *Sustainability*, vol. 14, no. 21, Article ID 14159, 2022.

[17] L. Zheng, K. Ismail, and X. Meng, "Traffic conflict techniques for road safety analysis: open questions and some insights," *Canadian Journal of Civil Engineering*, vol. 41, no. 7, pp. 633–641, 2014.

[18] M. Zhao and N. J. Garber, *Crash Characteristics at Work Zones*, Virginia Transportation Research Council, Virginia, VA, USA, 2001.

[19] S. M. S. Mahmud, L. Ferreira, M. S. Hoque, and A. Tavassoli, "Reviewing traffic conflict techniques for potential application to developing countries," *Journal of Engineering Science and Technology*, vol. 13, pp. 1869–1890, 2018.

[20] B. L. Allen, B. T. Shin, and P. J. Cooper, *Analysis of Traffic Conflicts and Collisions*, Transportation Research Board, Washington, DC, USA, 1978.

[21] R. Iguernaissi, D. Merad, K.-E. Aziz, and P. Drap, "People tracking in multi-camera systems: a review," *Multimedia Tools and Applications*, vol. 78, no. 8, pp. 10773–10793, 2018.

[22] S. M. S. Mahmud, L. Ferreira, M. S. Hoque, and A. Tavassoli, "Micro-simulation modelling for traffic safety: a review and potential application to heterogeneous traffic environment," *IATSS Research*, vol. 43, 2019.

[23] J. Wang, *Research on Traffic Conflict and Driving Risk in Nighttime Traffic Control Zone for Maintenance Work of Expressway*, Chongqing Jiaotong University, Chongqing, China, 2022.

[24] H. Wen, J. Wu, W. Qi, L. Wu, and K. Zhang, "CP-CS fusion model for on-ramp merging area on the Highway," *Journal of South China University of Technology*, vol. 48, p. 8, 2020.

[25] S. Wu, T. Li, X. Lin, B. Pan, and Z. Wang, "Study on parking sight distance of expressway based on braking deceleration," *Journal of Highway and Transportation Research and Development*, vol. 38, pp. 51–59, 2021.

[26] M. Guo and S. Li, "Driving fatigue quantification based on driver's reaction time," *Journal of Jilin University (Engineering and Technology Edition)*, vol. 50, pp. 951–955, 2020.

[27] Q. Xiang, J. Lu, C. Lu, and X. Ge, *Road Traffic Conflict Analysis Technique and its Application*, China Science Publishing and Media Ltd, Beijing, China, 2008.

[28] Q. Han, *Research on Freeway Traffic Safety Evaluation Method- A Case Study of Jinghu Freeway in Tianjing Section*, Harbin Institute of Technology, Harbin, China, 2016.

[29] H. Pan, Y. Wang, D. Li, J. Chen, J. Song, and Y. Yang, "Evaluating and forecasting rear-end collision risk of long longitudinal gradient roadway via traffic conflict," *Journal of Jilin University (Earth Science Edition)*, vol. 53, 2022.

[30] J. Ambros, C. Jurewicz, S. M. Turner, and M. Kiec, "An international review of challenges and opportunities in development and use of crash prediction models," *European Transport Research Review*, vol. 10, no. 2, 2018.