Research on Calculation of Warning Zone Length of Freeway Based on Micro-Simulation Model

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ABSTRACT The traditional calculation method can only determine the minimum length of the warning zone. In this paper, it proposes a method to determine the length of freeway warning zone using VISSIM simulation model and surrogate safety assessment model (SSAM). The simulation model of freeway maintenance work zones is constructed based on VISSIM, and calibrates the VISSIM simulation model. Through improving the time to collision (TTC) model, the traffic conflict discrimination threshold of the freeway maintenance work zone was determined. Based on the average absolute percentage error (MAPE) of traffic conflict, the validity of VISSIM simulation model and threshold are verified. Meanwhile, the SSAM is used to determine the changing trend of the number of traffic conflicts; a linear regression model is established to analyze the relationship between simulated and observed traffic conflicts. In addition, under different traffic conditions, the relationship between travel time, delay, traffic conflict and the warning zone length is analyzed. Based on traffic conflict number and safety evaluation index, the optimal length of warning zone is determined, and the relationship between warning zone length and safety evaluation index is studied. The results show that the simulated traffic conflict is reasonable consistent with the observed traffic conflict; under different traffic conditions, travel time and delay increase slowly with the increase of warning zone length; traffic conflicts decrease with the increase of warning zone length, when the warning zone length is more than 2200 m, traffic conflicts show a certain convergence state; When the warning zone length is 2200m, the number of traffic conflicts, delay and safety evaluation index are the minimum, and the safety is the best. Therefore, the method can determine the optimal length of the warning area and improve the safety of the warning zone.

INDEX TERMS Maintenance work zones, simulation model, warning zone length, traffic conflict.

I. INTRODUCTION
During the freeway maintenance work zones, due to the need to close the lane, it is easy to cause traffic congestion in the warning zone. It will not only cause traffic delay, but also lead to traffic accidents, which will affect the safety of freeway operation. According to the report of road safety accidents in China [1], in 2018, traffic accidents on freeway accounted for 3.15% of total traffic accidents, and the freeway maintenance work zones caused a total of 1100 deaths; in addition, the death rate in the freeway maintenance zone in China is 3 times that in other areas [2]. Because vehicles in the warning zone need to continue to slow down, speed up, follow the car and change-lane and other complex operations, they are more likely to lead to traffic accidents. Relevant research shows that, compared with the road section of non-maintenance work zones, the traffic accidents in maintenance work zone are relatively high [3]–[5]. Among them, warning zone traffic accidents account for 72% of traffic accidents in the whole maintenance work zone [6]. This increase is due to the more complex driving environment in the warning zone, which not only causes rear end traffic accidents, but also causes change-lane traffic accidents [7].

The length setting of the freeway maintenance work zone has a significant impact on the traffic efficiency and driving safety of the maintenance work zone [8], [9]. Too short maintenance work zone has a negative impact on construction
efficiency; too long operation area will also have a negative impact on driving safety [10]. However, when the vehicle passes through the warning zone, if the warning zone is too short, the vehicle can not slow down in time, which is easy to cause traffic accidents; the length of the warning zone is too long, which reduces the efficiency of traffic operation. Therefore, it is necessary to study the length of freeway warning zone and analyze the relationship between warning zone length and safety evaluation index. This is conducive to improving the operation efficiency and safety of freeway maintenance work zone. This study proposes a method to determine the length of freeway warning zone using VISSIM simulation model and SSAM model. Based on VISSIM, the simulation model of freeway warning zone is established, and the VISSIM simulation model is calibrated. Based on the traffic conflict evaluation index, it determines the TTC model and the warning area traffic conflict discrimination threshold. Meanwhile, the validity of VISSIM simulation model and threshold is verified. In addition, based on the number of traffic conflicts and safety evaluation indicators, it determines the optimal length of freeway warning zone.

This study is organized as follows. Section II introduces the relevant literature and discusses the problems to be solved. Section III identifies the research framework and introduces the methods adopted. In section IV, the VISSIM simulation model is calibrated and the threshold of traffic conflict is determined. Meanwhile, the VISSIM simulation model and threshold are verified. Section V analyzes the results. Section VI summarizes conclusions and future research directions.

II. LITERATURE REVIEW
At present, many studies have been carried out on the safety of the maintenance work zone [11], [12]. Various management strategies and measures were proposed, including education of maintenance workers, layout of infrastructure and signs, strengthening of law enforcement to improve the safety of maintenance work zone [13]–[15]. However, these studies are mainly based on descriptive statistics to analyze the time and space distribution characteristics of accidents in maintenance work zone. Du and Razavi [16] proposed a control strategy to optimize freeway maintenance work zone by using nonlinear traffic flow model to improve the safety of maintenance work zone. Lu et al. [17] put forward a prediction framework of random capacity life distribution in work zone, which is used to analyze the change trend of capacity in maintenance work zone. Although there were many studies on the safety of maintenance work zone, but there were a few studies on the length of maintenance work zone. In particular, there is a lack of research on the length of warning zone. Chien and Schonfeld [18] optimized the maintenance cost of the maintenance work zone by determining the optimal length of the maintenance work zone of the two-lane highway. Ceder [19] used the optimization model to determine the optimal length of the two-lane maintenance work zone. Warning zone is an integral part of the freeway maintenance work zone, and the vehicle can adjust the driving state in the warning area to avoid the occurrence of traffic accidents. Relevant research shows that the frequency of traffic accidents is different in different zone of maintenance work zone, and warning zone is the main area causing traffic accidents [20]. Garber et al. [21] found that the proportion of traffic accidents in warning zone was higher than that in normal road section. In addition, Wen et al. [22] assessed the risk of collision in the maintenance work zone. The results show that the collision risk increases with the increase of traffic volume. And the study found that early confluence may be the most effective way to reduce the risk of collision. In addition, some scholars have studied the dynamic information sign layout and speed limit in the freeway warning zone, which shows that different dynamic information sign layout and speed limit have a significant impact on the safety of the warning zone [2], [23].

On the other hand, some micro-simulation models (VISSIM, Paramics and FREESIM) can be used to analyze the impact of maintenance work zone on traffic flow [24]. VISSIM has been widely used because of its flexibility in simulating real traffic conditions and its ease in collecting conflict data without manual observation [25]. Gabriel et al. [26] used VISSIM to simulate a relatively complex 24-km interstate freeway. The results show that VISSIM can realistically simulate complex freeways. Zang and Zhou [27] calibrated VISSIM to calculate the capacity under highway merger conditions. Shen et al. [28] and Fan et al. [29] used surrogate safety assessment model (SSAM) and VISSIM to evaluate the safety of freeway merger zones. The simulated conflicts generated by the VISSIM simulation model are identified by the SSAM model. The data analysis results show that there is a reasonable consistency between the simulation and the observed conflicts.

Most of the previous studies have analyzed the workspace length in the maintenance work zone, and the research on the length of the warning area is limited. It is found that changing the length of maintenance work zone can effectively reduce the occurrence of traffic accidents. As an integral part of the maintenance work zone, the warning zone has an important impact on the safety of the maintenance work zone. Osman et al. [30] analyzed the layout of different maintenance work zone, his study showed that the unreasonable length of warning zone would lead to the increase of traffic accidents. Moreover, reasonable calibration VISSIM simulation model can simulate the real road environment and obtain the optimal scheme [31], [32]. Therefore, the purpose of this study is to propose a method to determine the length of freeway warning zone. The VISSIM simulation model and threshold are calibrated and calculated considering the effect of VISSIM simulation model and threshold on the results.

III. METHOD
Freeway warning zone length can be determined by VISSIM simulation. The vehicle trajectory is generated in the VISSIM, and the simulated traffic conflict data are extracted
directly from the trajectory file using the SSAM. The warning zone length of freeway maintenance work zone is determined by traffic conflict number and safety evaluation index. The overall framework of the proposed method is shown in Figure 1. The framework mainly includes simulation model construction, simulation model calibration, threshold calculation, warning zone length calculation. The purpose of the simulation model construction is to obtain the travel time, traffic flow, delay and vehicle trajectory. Calibration of simulation model ensures the accuracy of simulation data. Threshold calculation is to obtain accurate traffic conflict data. The length of warning zone is determined by comparing the number of traffic conflicts and safety evaluation index.

A. VISSIM SIMULATION MODEL

VISSIM is a micro-simulation model, which can be used to simulate freeway maintenance work zones. According to China’s “Freeway Maintenance Safety Operation Regulations (JTGH30-2015)”, the freeway maintenance work zone consists of warning zone, upstream transition zone, buffer zone, workspace, downstream transition zone, and termination zone [23]; where, the minimum lengths of the warning zone, upstream transition zone, buffer zone, downstream transition zone, and termination zone are 2000m, 120m, 80m, 30m, 30m, the length of the working zone is no more than 4km [33].

In this study, it builds a simulation model of freeway maintenance work zone. A virtual detector for travel time and delay data collection were placed in the simulation model, which were located at the end of the warning zone. This paper uses the expected speed decision point to force a change in the expected speed of the vehicle. “Freeway Maintenance Safety Operation Regulations (JTGH30-2015)” stipulate that the distance between adjacent expected speed decision points is not less than 200 m, and the starting expected speed decision point is located at 1/2 of the length of the warning area [33]. Thus, two decision points for the expected speed are placed at half of the length of the warning zone, and the adjacent distance is 300m, as shown in Figure 2. According to the lane closure configuration obtained from the database of Hu-Rong freeway in Liu’an City, Anhui Province, the vehicle is coded to enter the freeway maintenance work zone at a free flow speed distribution (average normal distribution is 91.4km/h, standard deviation is 4.8km/h).

B. SSAM CONFLICT MODEL

The SSAM is a traffic conflict analysis model developed in the United States. The model analyzes the vehicle trajectory generated by the micro simulation model and uses alternative safety indicators to identify traffic conflicts (Two or more road users approach each other in space and time, and if either side does not change the track, there will be a collision, and this state becomes a traffic conflict) [34]. In SSAM, when the time to collision (TTC) is less than the threshold (Threshold is the value of identifying traffic conflicts in SSAM model), the conflict is judged [29]. In the freeway maintenance work zone, vehicles need to slow down and change lanes. When two or more vehicles approach each other at the same time, one party must take corresponding risk-avoidance actions, otherwise traffic conflicts will occur. Because there are protective facilities on the freeway to isolate the vehicles in different driving directions, the vehicle in different directions does not interfere with each other, so there is no forward conflict. Thus, the traffic conflicts in the Warning zone are mainly divided into rear-end collision and lane-change conflict. The rear-end collision refers to the sudden deceleration in the same lane; if no measures are taken, a collision is likely to occur, as shown in Figure 3. In Figure 3(a), the distance between the vehicles gradually decreases over time and increases if risk measures are taken. In Figure 3(b), the lead vehicle is a coordinate system, and the relative travel distance of the following vehicle decreases rapidly with time before the risk-avoidance measures are taken. The lane-change conflict means that in different lanes, vehicles in closed lanes change their driving directions and enter non-closed lanes. When the following vehicle on the non-closed lane keeps the driving direction unchanged, if no measures are taken, a collision may occur. The process of traffic conflict during lane change is shown in Figure 4.
C. TIME TO COLLISION

Time to Collision (TTC) refers to the time required until the conflict occurs when two vehicles continue to maintain the current speed and path [35]. In the freeway maintenance work zone, the conflict is mainly divided into the rear-end conflict and the lane-change conflict.

The Rear-End Conflict TTC of freeway maintenance work zone can be calculated from the following equation:

\[
TTC_R = \frac{x_{i-1}(t) - x_i(t) - L_{i-1}}{v_F - v_L}
\]  

(1)

where \(x_{i-1}(t)\) and \(x_i(t)\) are the vehicle position of leading vehicle and following vehicle at time \(t\), respectively. \(v_F\) is the speed of the following vehicle; \(v_L\) denotes the speed of the leading vehicle; \(L_{i-1}\) is the length of the leading vehicle.

Because the space headway between the two vehicles is difficult to measure during the movement of the vehicle, and the time headway is relatively simple. Thus, the equation (1) is transformed and the formula is as follows:

\[
TTC_R = \frac{v_F \cdot H_t - L_{i-1}}{v_F - v_L}
\]  

(2)

where \(H_t\) is time headway of between leading vehicle and the following one.

Calculation equations (3) and (4) of lane-change conflict TTC of freeway maintenance work zone show that:

When \(T_B \geq T_A\),

\[
TTC_L = T_B; \quad \text{if } T_B \leq T_A + L_A/v_A
\]  

(3)

When \(T_B \leq T_A\)

\[
TTC_L = T_A; \quad \text{if } T_A \leq T_B + L_B/v_B
\]  

(4)

where \(L_A\) is length of vehicle A in target lane; \(L_B\) is length of vehicle B in original lane; \(v_A\) and \(v_B\) are speed of vehicle A and vehicle B; \(D_A\) is distance of target lane vehicle A from taking measures to generate point to traffic collision point; \(D_B\) is distance of original lane vehicle B from taking measures to generate point to traffic collision point; \(T_A = D_A/v_A\) is travel time of target lane vehicle A; \(T_B = D_B/v_B\) is travel time of original lane vehicle B.

D. SAFETY EVALUATION INDEX

In order to reflect traffic safety in freeway warning zone more objectively, this paper uses the safety evaluation index as the evaluation index. Safety evaluation index refers to the ratio of the number of traffic conflicts to the throughput and length of warning zone [36]. The calculation formula is as follows:

\[
f = \frac{TC}{QL} \times 1000
\]  

(5)

where \(f\) is number of vehicle kilometer traffic conflicts (times/veh/km); \(TC\) is number of traffic conflicts (times); \(Q\) is traffic flow (pcu/h); \(L\) is the warning zone length (m).

In addition, in order to analyze the relationship between the length of warning zone and safety evaluation index, it selects linear regression model. The model is very sensitive to outliers and is widely used in the modeling of length and safety evaluation indexes [36]. First, assume the regression equation:

\[
y = \alpha + \beta x
\]  

(6)

where: \(\alpha = \alpha_y - \beta \alpha_x\) and \(\beta = \frac{\text{cov}(y,x)}{\sigma_x^2} = \frac{\rho \sigma_y}{\sigma_x};\)

The regression equation can be expressed as:

\[
Y = \alpha_y + (\frac{\rho \sigma_y}{\sigma_x})(x - \alpha_x)
\]  

(7)
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### TABLE 1. Expected speed distribution corresponding to different speed limits.

| Speed limit | 80 | 60 |
|-------------|----|----|
| Expected Car | 70−100 | 50−75 |
| Expected Truck | 60−70 | 45−65 |

\[
X = \alpha + \left(\frac{\rho \sigma_x}{\sigma_y}\right)(x - \alpha_y) \quad (8)
\]

To determine the regression equation, the \(\alpha\) and \(\beta\) were solved first. The formula is as follows:

\[
\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \quad (9)
\]

\[
\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i \quad (10)
\]

\[
\beta = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \quad (11)
\]

Therefore, the relationship between warning zone length and safety evaluation index is:

\[
y = y - \beta x = \bar{y} - \beta(x - \bar{x}) \quad (12)
\]

### IV. WARNING ZONE LENGTH CALCULATION

In this study, it provides the length of warning zone in the maintenance work zones of Hu-Rong freeway in Lu’an City, Anhui Province. VISSIM is used to model the warning area under the closure of outer lane. At the same time, the simulation model is set up and calibrated according to the actual road conditions data of Hu-Rong freeway. The simulation environment of VISSIM is consistent with the field environment.

#### A. SIMULATION MODEL PARAMETER

According to the actual road conditions in the maintenance zone of the Hu-Rong freeway, a two-way four-lane outside lane closure simulation model was constructed. According to field survey data, the lane width is 3.75m, the road longitudinal gradient is 0%. According to the provisions of the “Highway Maintenance and Safe Operation Regulations (JTG H30-2015)”, stepwise speed limit is adopted, the speed limits are 80km/h and 60km/h. According to the results of the speed survey of the maintenance section of the Hu-Rong freeway, the expected speed distributions of different vehicle types at different speed limits are shown in Table 1. Therefore, suppose the expected speed of the car is 50 km/h-100km/h, the expected speed of the truck is 45 km/h-70km/h. For the simulation model, the length of the warning zone varies in increments of 100 m (from 2000m to 2600m) and traffic volume changes in increments of 200pcu/h (from 1400pcu/h to 2000pcu). Hence, 28 times of simulations are required. The output parameters are the driving time, delay and vehicle trajectory of all vehicles.

#### B. MODEL CALIBRATION

In order to represent the conditions of road environment accurately and reliably, it is necessary to calibrate the simulation model. Fan et al. [29] have pointed out that the standstill (CC0) distance and the time headway (CC1) have significant influence on the traffic conflict of simulation. In this study, CC0 and CC1 were calibrated: (1) CC0 means the distance between vehicles when parking; and (2) CC1 means the desired time headway between vehicles. In VISSIM, the default value of CC0 and CC1 are 1.5m and 0.9s, and initialize the calibration process using default values. Parameter CC0 changes with an increment of 0.5m (CC0 from 1m to 5m) and parameter CC1 changes with an increment of 0.2m (CC0 from 0.7s to 2.5s); By constantly changing CC0 and CC1, the simulated capacity value generated in each case is shown in table 2. The results show that when CC0 and CC1 are 3.5m and 1.1s respectively, the difference between the observed capacity (1800pcuhpl) and the simulated capacity from the simulation model is the smallest. Lshak et al. [37] showed that the difference between the observed capacity value and the simulated capacity was the smallest, when CC0 and CC1 are considered to fully represent the actual driving behavior. Hence, the calibration parameters are shown in table 3. Compared with the non-maintenance area, the CC0 and CC1 are relatively large in the maintenance work zone. This is reasonable because drivers in the maintenance work zone are more cautious.

### TABLE 2. The flow according to CC0 and CC1.

| Index | CC0(m) | CC1(s) | CC2(m) | CC3(s) | CC4(m/s) | CC5(m/s) | CC6 | CC7(m/s²) | CC8(m/s²) |
|-------|--------|--------|--------|--------|----------|----------|-----|-----------|-----------|
| 0.7   | 1.90   | 0.90   | 4.00   | -0.60  | 0.11     | 0.11     | 11.44| 0.25      | 3.50      |
| 0.9   | 1.90   | 0.90   | 4.00   | -0.60  | 0.11     | 0.11     | 11.44| 0.25      | 3.50      |
| 1.1   | 1.90   | 0.90   | 4.00   | -0.60  | 0.11     | 0.11     | 11.44| 0.25      | 3.50      |
| 1.3   | 1.90   | 0.90   | 4.00   | -0.60  | 0.11     | 0.11     | 11.44| 0.25      | 3.50      |
| 1.5   | 1.90   | 0.90   | 4.00   | -0.60  | 0.11     | 0.11     | 11.44| 0.25      | 3.50      |
| 1.7   | 1.90   | 0.90   | 4.00   | -0.60  | 0.11     | 0.11     | 11.44| 0.25      | 3.50      |
| 1.9   | 1.90   | 0.90   | 4.00   | -0.60  | 0.11     | 0.11     | 11.44| 0.25      | 3.50      |
| 2.1   | 1.90   | 0.90   | 4.00   | -0.60  | 0.11     | 0.11     | 11.44| 0.25      | 3.50      |
| 2.3   | 1.90   | 0.90   | 4.00   | -0.60  | 0.11     | 0.11     | 11.44| 0.25      | 3.50      |
| 2.5   | 1.90   | 0.90   | 4.00   | -0.60  | 0.11     | 0.11     | 11.44| 0.25      | 3.50      |

### TABLE 3. VISSIM parameter settings.

| Parameter | VISSIM default | Warning Zone Setup Value |
|-----------|----------------|--------------------------|
| CC0(m)    | 1.50           | 3.50                     |
| CC1(s)    | 0.90           | 1.1                      |
| CC2(m)    | 4.00           | 7.20                     |
| CC3(s)    | -0.60          | -0.60                    |
| CC4(m/s)  | -0.11          | -0.11                    |
| CC5(m/s)  | 0.11           | 0.11                     |
| CC6       | 11.44          | 11.44                    |
| CC7(m/s²) | 0.25           | 0.25                     |
| CC8(m/s²) | 3.50           | 3.50                     |
| CC9(m/s²) | 1.50           | 1.50                     |
C. THRESHOLD CALCULATION

In order to determine the traffic conflict threshold of the freeway maintenance work zone, the WM-JD2.0 handheld multi-function traffic survey instrument, WM-LDS 3.0 portable laser measuring instrument and high-definition camera are used to collect the traffic parameters in the maintenance operation area of Hu-Rong freeway in Lu’an City, Anhui Province. It includes: speed, vehicle type (large and small vehicles), time headway, traffic conflict distance and initial speed of traffic conflict vehicles. At the same time, the professional video processing software is used to obtain the parameters such as vehicle position, vehicle motion track and so on. And the time headway less than 30.0s is analyzed, as shown in table 4.

The 85% cumulative frequency curve method is a common method in traffic engineering. According to the velocity distribution generated by the measured cumulative frequency curve, the velocity corresponding to 85% cumulative frequency is selected as the speed limit value \([38]-[40]\). In this paper, the TTC value corresponding to 85% cumulative frequency is used as the threshold to judge traffic conflicts. Through statistical analysis of the data, the cumulative frequency distribution of TTC is obtained, as shown in Figure 5. In the Figure 5, the TTC value corresponding to the 85% cumulative frequency is 2.0s. When 2.0s < TTC, the number of traffic conflicts is very small. Therefore, 2s can be used as a standard to determine the effectiveness of traffic conflicts. Where 2s < TTC, it is believed that there is no traffic conflict. Therefore, in this study, the TTC index is used to identify the traffic conflict in the freeway maintenance work zones, and the threshold value is set to 2.0s.

D. MODEL AND THRESHOLD VERIFICATION

The calibrated simulation model and the threshold of SSAM are verified by the mean absolute percentage error (MAPE) of traffic conflict to determine the reliability of simulation results \([29]\). In this study, the MAPE of Traffic conflict can be calculated by the following formal:

\[
MAPE_{cc} = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{cc_o^i - cc_s^i}{cc_o^i} \right| \tag{13}
\]

where \(cc_o^i\) is number of observed traffic conflicts; \(cc_s^i\) is number of simulation traffic conflict; \(n\) is number of simulations.

When the calculated mean absolute error percentage (MAPE) is less than or equal to 15%, the parameter setting meets the requirements \([28]\). It can be seen from table 5 that MAPE between the simulation model and the number of observed traffic conflicts is 10.2%.

In addition, the linear regression model is used to fit the simulated traffic conflicts and the observed traffic conflicts. The fitting results are shown in figure 6. The results show that there is a significant correlation between simulated traffic conflicts and observed traffic conflict data \((R^2 = 0.976)\). Ideally, the slope of the best fitting line for the fitting data is 1. In Figure 5, the slope is 1.002, which is very close to the ideal fitting line. Therefore, the calibrated VISSIM simulation model and threshold are effective.

V. SIMULATION RESULTS ANALYSIS

A. CHANGES OF TRAVEL TIME, DELAY AND TRAFFIC CONFLICT

In the study, under different conditions of traffic volume, the simulation of the lanes closure on the outer side of the freeway maintenance work zone was performed from the perspectives of travel time, delay and traffic conflict. The relationship between travel time, delay, traffic conflict and warning area...
length under different traffic volume conditions is shown in Figure 7(a-d). In Figure 7, under the conditions of different traffic volume, the travel time and delay remain basically unchanged as the length of the warning area increases. This is mainly because when the traffic volume is small, the road traffic density is less than the jam density, and when the traffic volume is large, the road traffic density is larger than the jam density, and the speed basically remains unchanged. In addition, with the increase of traffic volume, the travel time and delay gradually increase. This is because the traffic volume gradually reaches the road capacity, which will cause traffic congestion. Under different traffic volume conditions, the number of traffic conflicts decreases with the increasing length of the warning zone. When the length of the warning zone increases from 2000 m to 2200 m, the number of traffic conflicts will decrease sharply. After that, as the length of the warning zone increases, the number of traffic collisions remains the same.

B. SAFETY EVALUATION

In order to determine the length of freeway warning zone, the relationship among traffic flow, traffic conflict, delay and travel time under different warning area conditions are studied, as shown in Table 6. The results show that when the length of the warning zone is 2200 m, the traffic flow reaches the maximum (1864pcu/h); the traffic conflict, travel time and delay reach the minimum (2760, 436 s and 336.5 s, respectively). In figure 8, the warning zone length increases from 2000 m to 2200 m, traffic flow increases sharply, and then the traffic flow shows a certain degree of convergence. This is mainly due to the increase in the length of the warning area to some extent. With the exception of traffic flow, the length of warning zone increased from 2000 m to 2200 m, traffic conflict, travel time and delay showed a downward trend. As the length of warning area is more than 2200m, traffic conflict, travel time and delay increase slowly with the increase of warning area length. Compared with the warning zone of 2000 m, when the warning zone is 2200 m, the number of traffic conflicts and delays is reduced by 1312 and 45.4s respectively. Therefore, the reasonable warning zone length is 2200m.

Safety evaluation index values for different alert area lengths, as shown in table 7. Ye et al. [36] divided the freeway maintenance warning zone into four safety levels: safety ($f < 0.76$) relative safety ($0.76 \leq f < 1.45$) safety criticality ($1.45 \leq f < 2.66$) and danger ($2.66 \leq f < 3.73$). The results show that, when the length of warning area is 2200m, traffic conflict, travel time and delay increase slowly with the increase of warning area length. Compared with the warning zone of 2000 m, when the warning zone is 2200 m, the number of traffic conflicts and delays is reduced by 1312 and 45.4s respectively. Therefore, the reasonable warning zone length is 2200m.
of warning zone is 2.2 km, the safety evaluation index value is the smallest, which is 0.65. At the same time, the security of the warning zone is the best.

By calculating, the relationship between the length of the warning zone and the safety index is as follows $y = 3.60 - 1.20x$; at this point, $|r| = 0.803$.

VI. CONCLUSION AND DISCUSSION

This paper presents a method to determine the length of freeway warning zone using VISSIM simulation model and SSAM model. By improving the TTC model, the threshold of discrimination of traffic conflict in freeway warning area is determined. Meanwhile, the validity of using VISSIM simulation model and SSAM model to determine the length of warning zone is verified by comparing the simulated traffic conflict generated by VISSIM simulation model with the traffic conflict observed on site.

By establishing a simulation model of the closure of the outer lane of the freeway maintenance work zone, the variation law of travel time, delay and traffic conflict under different traffic volume conditions is analyzed. The simulation results show that the travel time and delay increase slowly with the increase of the length of the warning zone, but basically remain unchanged. Traffic conflicts decrease with the increase of warning zone length. In addition, by comparing the number of traffic conflicts and safety evaluation indexes under different warning area length conditions, the optimal length of freeway maintenance work zone is determined, and the relationship between warning zone length and safety evaluation index is analyzed. According to the research results, when the length of warning zone is 2.2-2.6 km, the safety of freeway maintenance work zone is better. In addition, when the warning length is 2200 m, the number of traffic conflicts, delay and safety evaluation index is the smallest, and the safety is the best.

One problem that should be emphasized is the calibration of the simulation model, which is essential for building a microscopic simulation model that truly reflects the real-world traffic conditions. In this study, only CC0 and CC1 parameters affecting traffic conflict are calibrated. However, other parameters in VISSIM were not calibrated. Moreover, for threshold calculation, this study only used TTC, it is not clear whether TTC is the best way to calculate traffic conflict threshold. At the same time, the maintenance type and the number of lanes in the freeway maintenance work zone have a certain impact on the traffic conflict. Therefore, in the future, other parameters in VISSIM can be calibrated, and the threshold can be calculated by considering other surrogate measure of safety (MTTC, PET, TTE, etc.). In addition, it can also analyze the influence of expressway maintenance type and lane number on traffic conflict, and the safety classification of freeway maintenance warning zone.

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