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Study on influencing factors of urban expressway section reliability under emergency accidents

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ABSTRACT: With the increase of urban expressway traffic volume, once a traffic accident occurs, it will pose a great threat to the normal operation of the section where it is located. In order to quantitatively study the impact of different factors on the reliability of the section in sudden traffic accidents, four influencing factors, including traffic volume, heavy vehicle mixing rate, number of lanes and lane width, are screened. Taking the average queue length, average number of stops and maximum queue length as the characteristic indexes of road reliability, the traffic data of Zhenwushan tunnel section of Chongqing Inner ring Expressway were collected. vissim simulation method was used to calculate the road reliability under different combinations of influencing factors. Then entropy weight method was used to calculate the contribution degree of each influencing factor to the road reliability. The results show that the weight of traffic volume is 0.66, which has the greatest impact on road reliability, followed by the number of lanes and heavy vehicle mixing rate, and the weight of lane width is 0.10, which has the least impact. The research results can provide reference for the safety guarantee and management of urban expressway in emergency.
KEYWORDS: urban expressway; An emergency; Road reliability; Influencing facto

I. INTRODUCTION

In recent years, with the development of the transportation industry, the demand for urban mobility has increased, and the number of vehicles has also risen. As a result, the frequency of traffic accidents on urban expressways has increased. Particularly, during peak hours, traffic accidents frequently occur, and external factors can vary in terms of their impact on the reliability of urban expressways when accidents happen. Therefore, research on the reliability of urban expressways is of great importance.

Yang Wencheng [1] and others studied the impact of adverse weather on road traffic safety and traffic flow, considering the effects of various adverse weather conditions on traffic flow, and conducted research on the reliability of road capacity. Chen Chenghui [2] and others analyzed expressway systems in various cities and summarized many experiences regarding the rationality of expressway construction. Zheng Nan [3] and his team proposed a simulation model based on VISSIM to simulate the traffic operation situation of the Chongqing inner ring expressway during major accidents. They analyzed a multivariate nonlinear model to predict the maximum waiting length and provided technical support for major accident responses. Liang Xue [4] compared different road conditions, environmental conditions, and traffic conditions during accidents, calculated the number of passable lanes on accident-prone road segments, and studied the impact of driver characteristics on traffic capacity, estimating the effective traffic capacity of expressways under different traffic accident conditions. Wang Wenbo [5] proposed a method for estimating the traffic capacity of urban expressway accident-prone road segments based on VISSIM simulations, simulating various types of traffic accidents to calculate the duration of congestion caused by sudden traffic accidents and estimating traffic capacity after accidents. Bao Jiashuo [6] used VISSIM microscopic simulation software to analyze the impact of the intersection flow ratio and the length of the intersection section on the traffic capacity of the intersection.

To assess the impact of sudden traffic accidents on the reliability of urban expressways, specific standard road segments were selected, and simulation experiments were conducted using

VISSIM simulation software. The correlation between various influencing factors and indicators such as waiting length upstream of the accident during sudden traffic accidents was analyzed. This allowed for the quantification of the impact of each factor on the road's reliability, ultimately comparing the importance of each factor. Based on the varying severity of each influencing factor on the changes in traffic flow, targeted warning and preventive measures were proposed to provide data support for decision-making by relevant departments.

II. ANALYSIS OF THE IMPACT FACTORS ON THE RELIABILITY OF URBAN EXPRESSWAYS UNDER SUDDEN ACCIDEN

2.1 Definition of the Reliability of Urban Expressways

The definition of reliability, according to relevant literature, is the ability of a product to perform its specified function under prescribed conditions and within a specified period of time [7]. Based on this definition, the reliability of an urban expressway refers to whether the traffic operation of the expressway maintains stability and accuracy over a certain period of time. This includes factors such as road traffic speed, travel time, and traffic conditions. The focus of this study is the reliability of urban expressways under sudden accidents. Specifically, it examines whether the traffic capacity of a section of the expressway can still meet the vehicle flow requirements under the influence of various factors after an accident occurs.

2.2 Severity of Sudden Accidents

Traffic accidents can be classified into four levels based on the number of fatalities and property damage: minor, normal, major, and catastrophic. However, it is difficult to determine the impact on road traffic flow solely based on these classifications. According to relevant literature and studies, the Highway Capacity Manual (HCM) [8] provides clear regulations on the remaining traffic capacity under different lane loss conditions. Therefore, this study uses the remaining traffic capacity after lane loss as an indicator to represent the severity levels of sudden accidents. Table 1 below illustrates this classification.

Table 1: Remaining Traffic Capacity After Different Lane Losses in Major Accidents

Number of One-Way Lanes	Loss of One Lane	Loss of Two Lanes	Loss of Three Lanes
2	0.35	0.00	N/A
3	0.49	0.17	0.00
4	0.58	0.25	0.13
5	0.65	0.40	0.20
6	0.71	0.50	0.26
7	0.75	0.57	0.36
8	0.78	0.63	0.41

2.3Selection of Factors Affecting the Reliability of Urban Expressways

Based on the Highway Capacity Manual (HCM) [9] from the United States, the Traffic Engineering Manual [10] in China, and the Highway Route Design Code [11], an analysis of the reliability of urban expressways under sudden accidents was conducted from four aspects: traffic volume, heavy vehicle infiltration rate, number of lanes, and lane width. The selection of these factors is based on the following reasons:

Relevant Research: Traffic volume, heavy vehicle infiltration rate, number of lanes, and lane width are commonly used factors in road reliability research. Zhang Liang [12] and others conducted related experiments on factors such as traffic volume, heavy vehicle infiltration rate, and number of lanes in the simulation of highway accidents using VISSIM, where these factors significantly impacted road reliability.

Practical Considerations: Traffic volume, heavy vehicle infiltration rate, number of lanes, and lane width are critical factors influencing road capacity and safety, and they are frequently used by traffic management authorities. In practical scenarios, these factors also significantly affect road reliability.

Comprehensive Consideration: These factors were selected based on a comprehensive evaluation of road capacity, traffic safety, and congestion. Their selection can comprehensively reflect the status of road reliability and provide essential guidance for road management and improvement.

Thus, traffic volume, heavy vehicle infiltration rate, number of lanes, and lane width were chosen as the factors influencing road reliability.

1.3.1 Traffic Volume

Traffic volume is one of the most fundamental traffic factors. Excessive traffic volume increases the pressure on the road, leading to a decline in road capacity, which in turn affects vehicle speed and traffic flow. When traffic volume exceeds the road's capacity, congestion occurs, speed decreases, and increased travel time and queue length further reduce road capacity, resulting in a saturated traffic flow state.

1.3.2 Heavy Vehicle Infiltration Rate

The heavy vehicle infiltration rate refers to the proportion of heavy vehicles in the traffic flow. Its impact on road reliability is mainly related to the restriction of road capacity and the influence of accident-related lane changes. Heavy vehicles require more time and space, and when there is a large number of heavy vehicles on the road, it leads to congestion and worsens the road conditions, thereby reducing road capacity. Additionally, once the proportion of heavy vehicles reaches a certain level, the vehicle density on the road increases, which can affect drivers' attention and reaction times.

1.3.3 Number of Lanes

The number of lanes primarily affects road reliability in terms of road capacity. The more lanes there are, the higher the road capacity, which reduces the probability of congestion and improves reliability. However, when traffic volume is excessive, insufficient lanes can cause congestion and reduce traffic efficiency, affecting reliability. Therefore, when planning and designing roads, it is essential to reasonably plan the number of lanes according to traffic demand and flow to ensure reliability and capacity.

1.3.4 Lane Width

Insufficient lane width can cause congestion and reduce traffic speed. Lane width should be reasonably planned based on road usage. Larger vehicles, buses, and coaches require wider lanes. If the lane width is too wide, it may lead to traffic dispersion and safety issues. The following table presents the conclusions derived from the study on the influence of urban road width on road capacity [14]:

Table 2: Saturation Flow Rates under Different Lane Widths

Lane Width (m)	2.80	2.90	3.00	3.10	3.20	3.30	3.40	3.65	3.75	4.00
Saturated Flow (pcu/h)	1469	1622	1636	1674	1698	1748	1800	1875	1905	1915

1.4 Representation Methods for Expressway Reliability Under Sudden Accidents

Sudden accidents can cause property damage or casualties, but the impact of such accidents on expressway reliability cannot be quantified by the consequences of the event. Since sudden accidents—whether caused by natural disasters or traffic incidents—affect road capacity, they lead to traffic congestion. As shown in Figure 1, when a traffic accident occurs, road capacity decreases. At this point, the traffic flow arriving upstream exceeds the road capacity, causing a queue. Once the accident is cleared, vehicles begin to pass through normally, and road capacity is restored. After a sudden event, vehicles cannot pass through the affected road section, and they must divert, disrupting normal traffic operations and creating bottlenecks that lower the affected section's road capacity. The capacity reduction caused by congestion is far greater than the reduction in road effective space caused by the event.

When a sudden accident occurs, traffic congestion forms in the road section, and the most intuitive three indicators of expressway reliability are average queue length, average stopping frequency, and maximum queue length, which are explained as follows:

Average Queue Length: On urban expressways, heavy traffic flow leads to frequent queues. The length of these queues directly affects vehicle speed and travel time. If the average queue length is long, it indicates slower vehicle speeds, longer travel times, and lower traffic efficiency. Conversely, shorter queues suggest higher traffic efficiency.

Average Stopping Frequency: With the heavy flow of traffic on urban expressways, vehicles are likely to stop more frequently. A higher average stopping frequency suggests slower vehicle speeds, longer travel times, and lower traffic efficiency. Conversely, a lower stopping frequency indicates higher traffic efficiency.

Maximum Queue Length: The maximum queue length refers to the longest queue observed on the urban expressway within a specific time period. This indicator reflects the extreme carrying capacity of the road's traffic flow. If the maximum queue length is short, it suggests lower traffic flow on the expressway, with higher traffic efficiency. Conversely, a longer maximum queue length indicates lower traffic efficiency.

In conclusion, the average queue length, average stopping frequency, and maximum queue length are key indicators for evaluating urban expressway reliability. They directly relate to the smoothness and efficiency of urban traffic. Monitoring and analyzing these indicators allows for the timely identification of traffic congestion issues and the implementation of appropriate measures to enhance the reliability of urban traffic.

III. THE STUDY OF URBAN EXPRESSWAY SEGMENT RELIABILITY UNDER SUDDEN INCIDENTS BASED ON VISSIM SIMULATION.

The VISSIM simulation software can be used to simulate traffic conditions on urban expressways during sudden incidents. Based on survey data and actual operational data of the road section, a preliminary road network is established as the foundation for the VISSIM simulation. The reliability changes of urban expressways during sudden incidents are mainly influenced by four factors: traffic volume, heavy vehicle infiltration rate, number of lanes, and lane width. An experimental plan is designed to quantitatively analyze the impact of these different factors on the reliability of urban expressways during sudden incidents, and to conduct a reliability analysis of the study section.

3.1 VISSIM simulation experiment parameter settings

After continuously adjusting the parameters and verifying the accuracy of the simulation scenario, the driving behavior parameters for VISSIM were determined. The selected car-following model is Wiedemann99, with a following distance of 1.50 meters, a headway time of 0.9 seconds, a car-following variable of 4.00 meters, a threshold for entering the car-following state set to -8.00, a threshold for the passive car-following state set to -0.35, a threshold for the active car-following state set to 0.35, speed fluctuation set to 11.44, acceleration fluctuation amplitude set to 0.25 m/s², stopping acceleration set to 3.50 m/s², the minimum front view distance set to 30 meters, the maximum set to 250 meters, temporary distraction duration and probability set to 0, maximum deceleration set to 4 m/s², and the safety distance reduction factor set to 0.6. These settings are used to simulate realistic driving behaviors under various traffic conditions.

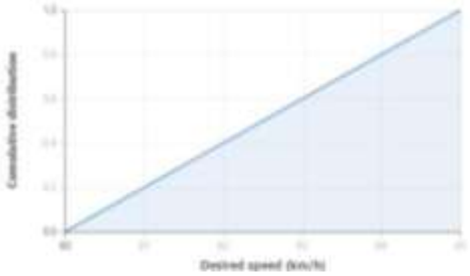

Figure 1: Desired Speed of Small Vehicles

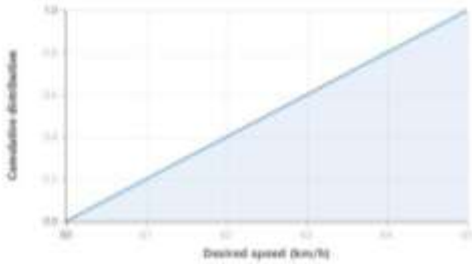

Figure 2: Desired Speed of Large Vehicles

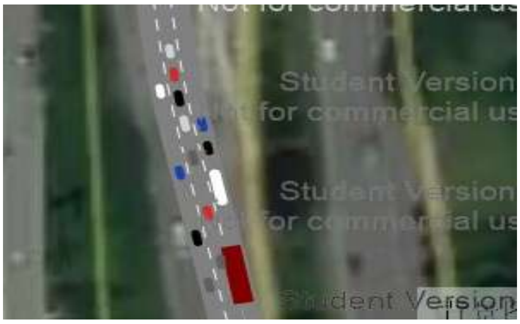

Figure 3: VISSIM Simulation Model

A roadblock is set in the middle of the section, with two types of severe emergency accidents assumed: one that occupies 1 lane and one that occupies 2 lanes, causing partial blockage of the lanes. Vehicles will switch to the lanes set as free, and when the traffic flow cannot pass, they will begin to queue. The roadblock is set on the leftmost lane where the accident occurs. After the accident, vehicles need to pass through the adjacent lanes, so a connector is placed between the unobstructed lanes to allow vehicles to continue moving. Data collectors are set upstream and

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downstream of the accident point, with a queue length counter placed 50 meters upstream of the incident point. The average queue length, stop count, and maximum queue length at the accident bottleneck are collected. The simulation cycle is set to 600 seconds, and the queue counter is configured to record results every 60 seconds.

This experiment design involves comparing road traffic under various conditions in real-world scenarios, simulating the severity of unexpected accidents: one affecting one lane and one affecting two lanes. The following five experiments are conducted under different levels of severity:

Experiment 1: Simulate the real-world scenario of an emergency accident. The real-world conditions are: a one-way three-lane road, heavy vehicle rate of 0.4, lane width of 3.75 meters, and traffic volume of 4190 pcu/h.

Experiment 2: Simulate the effect of lane width on road reliability, comparing a lane width of 3.50 meters with the standard 3.75 meters, with other conditions as a one-way three-lane road, heavy vehicle rate of 0.4, and traffic volume of 4190 pcu/h.

Experiment 3: Simulate the effect of the number of lanes on road reliability, setting the number of lanes to a one-way two-lane road, with other conditions as a heavy vehicle rate of 0.4, lane width of 3.75 meters, and traffic volume of 4190 pcu/h.

Experiment 4: Simulate the effect of the proportion of heavy vehicles on road reliability, setting the heavy vehicle rate to 0.8, with other conditions as a one-way three-lane road, lane width of 3.75 meters, and traffic volume of 4190 pcu/h.

Experiment 5: Simulate the effect of different traffic volumes on road reliability, setting the traffic volume to 3000 pcu/h, with a heavy vehicle rate of 0.8, and other conditions as a one-way three-lane road with a lane width of 3.75 meters and a heavy vehicle rate of 0.4.

IV. SIMULATION EXPERIMENT EVALUATION

4.1 Significance Analysis

In the simulation experiment, data on queue length, maximum queue length, and the number of parking stops were obtained. The significance of these three indicators will be analyzed. When using the Mann-Whitney U test, the commonly used significance level (alpha) is 0.05. If the p-value is less than 0.05, it indicates that there is a significant statistical difference between the test samples, and the null hypothesis is rejected. If the p-value is greater than 0.05, it indicates that there is no significant difference between the test samples, and the null hypothesis is accepted. The average queue length output from the VISSIM simulation of highway sections will be taken as the standard, and the queue length results under other factors will be compared to determine whether there is a significant difference from the standard result.

Table 3: Data Summary for Incidents Occupying One Lane

Incident Occupying One Lane	Average Queue Length	Maximum Queue Length	Average Parking Stops	p-value	Significance Analysis
Standard	185.76	398.49	64.1	/	/
Heavy Vehicle Occupancy 0.8	279.33	510.2	81.8	0.028	Significant
Lane Width 3.50m	247.94	498.45	100.6	0.096	Not Significant
Number of Lanes (Two Lanes)	363.66	510.19	50.4	0.01	Significant
Traffic Volume 3000 pcu/h	0	0	0	0	Significant

Table 6: Data Summary for Incidents Occupying Two Lanes

Incident Occupying Two Lanes	Average Queue Length	Maximum Queue Length	Average Parking Stops	p-value	Significance Analysis
Standard	363.68	510.21	162.9	/	/
Heavy Vehicle Occupancy 0.8	385.34	510.21	107.9	0.481	Not Significant
Lane Width 3.50m	364.77	510.21	133.3	0.922	Not Significant
Number of Lanes (Two Lanes)	435.75	510.21	11	0.015	Significant
Traffic Volume 3000 pcu/h	178.82	418.66	77.3	0.029	Significant

Based on the data in Tables 3 and 4, it can be seen that the main factors affecting the reliability of urban expressways in the event of an accident are the number of lanes, traffic volume, heavy vehicle occupancy, and fog traffic volume. Among these, the number of lanes and traffic volume have the most significant impact, while lane width does not significantly affect the reliability of the urban expressway. In cases where the accident severity is lower, the impact of each factor is relatively clear. However, as the severity of the accident increases, the impact of lane occupation becomes more significant, causing the influence of other factors to be less noticeable. The combined effect of traffic volume and the number of lanes remains significant, but when the number of occupied lanes reaches two, a completely blocked situation occurs, and the difference becomes more apparent compared to the standard condition, where only one lane provides service.

4.2 Contribution Ranking

Based on the analysis of various indicators and significance of each factor mentioned earlier, the entropy method will be used to rank the contribution of each factor. The purpose is to identify the weight proportion of each factor's impact on the reliability of urban expressways and compare the intensity of their influence. Here are the steps for the entropy method:

Step 1: Standardize the prepared data, as inconsistent units (scales) of indicators can lead to varying sizes of data across different indicators, which can affect the calculation results. To eliminate the impact of different units, the data needs to be processed before analysis.

$$y_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}}$$

when the indicator is a positive indicator

$$y_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}}$$

when the indicator is a negative indicator.

X_{ij}represents the corresponding value in the original data matrix, Y_{ij} represents the corresponding value in the standardized matrix after processing, minX_{ij} and maxX_{ij} represent the minimum and maximum values, respectively. The second step involves shifting the standardized data. Non-negative shifting in entropy method is a common data processing technique that can be used for data normalization and standardization to facilitate better data analysis and comparison. The third step involves calculating the matrix P_{ij} (the weight of indicator j under category i) from the shifted data.

$$p_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}$$

Calculate the required data in sequence: k (entropy index), e_j (entropy value of indicator j), g_j (difference coefficient of indicator j), Wj (dispersion degree of indicator j). Finally, calculate the weight proportion through the linear weighting method. After the above steps, the contribution weight proportions of each factor are as shown in the following Table 5

Table 5: Weight Ranking Results

Factor	Weight
Lane Width	0.10
Heavy Vehicle Mixing Ratio	0.42
Number of Lanes	0.47
Traffic Volume	0.66

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From the weight proportions of various factors, it can be seen that traffic volume has the highest influence, ranking first, followed by the number of lanes and the heavy vehicle mixing ratio ranking second and third, respectively, while the lane width has the least influence, ranking fourth.

The weight of lane width is the smallest at 0.1, indicating that the impact of lane width on traffic safety is relatively minor. This is because lane width is just one of the factors affecting vehicle driving safety, and compared to other factors such as traffic volume, heavy vehicle mixing ratio, and number of lanes, its impact on traffic safety is relatively less significant. Moreover, the influence of lane width is also related to road type, vehicle type, and other factors, hence its smaller weight in the analysis.

The weight of the heavy vehicle mixing ratio is 0.42, indicating a relatively significant impact on traffic safety. This is due to the safety hazards posed by heavy vehicles in traffic, such as longer braking distances and limited visibility, which can easily lead to traffic accidents. Additionally, the heavy vehicle mixing ratio can affect the road's load-bearing capacity and reduce traffic flow, leading to congestion and accidents.

The weight of the number of lanes is 0.47, indicating a significant impact on traffic safety. This is because the number of lanes is one of the key factors affecting road capacity; the more lanes there are, the greater the road capacity, and the number of lanes also affects vehicle speed and the likelihood of traffic accidents. Generally, more lanes allow for faster vehicle speeds, but they also influence lane-changing and overtaking behaviors; too few lanes can lead to traffic accidents.

The weight of traffic volume is the highest at 0.66, indicating the greatest impact on traffic safety. This is because traffic volume directly affects road capacity and the likelihood of traffic accidents. When traffic volume is too high, roads are prone to congestion and accidents, hence measures are needed to control traffic volume, such as restricting vehicle access times and adding traffic signals.

V. SUMMARY

Through simulation experiments on the Zhenwu Mountain Tunnel section of the Chongqing Inner Ring Expressway, the main findings are as follows:

Based on relevant literature, the severity of major accidents was graded, and the reliability of urban expressways was defined according to literature references. Different influencing factors were selected, and a brief analysis of the impact of each factor on road reliability and capacity was conducted, supported by relevant literature, to determine the corresponding influencing factors' data needed for subsequent simulations.

Through field surveys of the Chongqing Inner Ring Expressway, all data required for the simulation experiment were obtained. VISSIM was used to construct the selected section of the Chongqing Inner Ring Expressway, and the data were set in the VISSIM software for simulation experiments.

The impact of different levels of heavy vehicle mixing ratio, different numbers of lanes, different lane widths, and different traffic volumes on road reliability under various severities of major accidents was analyzed. Through significance analysis and the entropy method, the impact of each factor on the reliability of urban expressways was ranked. Based on the contribution weights of different factors, insights can be provided for the safety assurance and management of urban expressways during emergencies.

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