Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 15, No. 1, 2025

Sensitivity Analysis and Traffic Safety Risk Assessment of Expressways Using AHP-TOPSIS-RSR.

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Abstract: To reduce and prevent traffic accidents, it is essential to transition from a reactive approach of "punishing after the fact to proactive preventive measures. This paper presents a traffic safety risk evaluation system for expressways, integrating 16 factors such as steering performance and road conditions. A model for assessing traffic safety risk on expressways is proposed using a combination of the AHP-TOPSIS-RSR approach. The AHP method helps form the evaluation matrix, while the TOPSIS method, incorporating entropy, is used to determine the relative closeness between the overall traffic safety risk index and ideal values. These values are then categorized based on expressway risk grades using a hierarchical standard. Additionally, a sensitivity analysis model is introduced through an orthogonal test to compute the sensitivity values of each factor and rank the most influential factors. The proposed method is validated through the Yongwu Expressway. The findings show that the safety risk of the Yongwu Expressway is rated as Level I, indicating a high-risk situation. The sensitivity values for factors like fatigue/unlicensed driving, vehicle speed, road layout, traffic flow, adverse weather conditions, and emergency response systems are 0.4721, 0.5088, 0.7598, 0.8142, 0.5296, and 0.4685, respectively, marking them as the most sensitive risk factors. The risk assessment accurately mirrors the traffic safety conditions of the Yongwu Expressway.

Keywords: Traffic engineering; traffic safety; AHP method; orthogonal test; risk evaluation; sensitivity analysis; expressway.

1. 1 Introduction

The severe traffic safety situation on China's expressways urgently requires preventive management of traffic accidents transforming post-accident punishment into pre-accident prevention and shifting from emergency management to routine management [1,2,3]. Conducting risk assessment and sensitivity analysis on road sections provides a scientific foundation for proposing particular and targeted Risk management for traffic safety strategies and safety measures [4,5,6]. Fig. 1 below shows the distribution of traffic accidents by district in China, which illustrates the regions most affected by severe traffic safety risks.

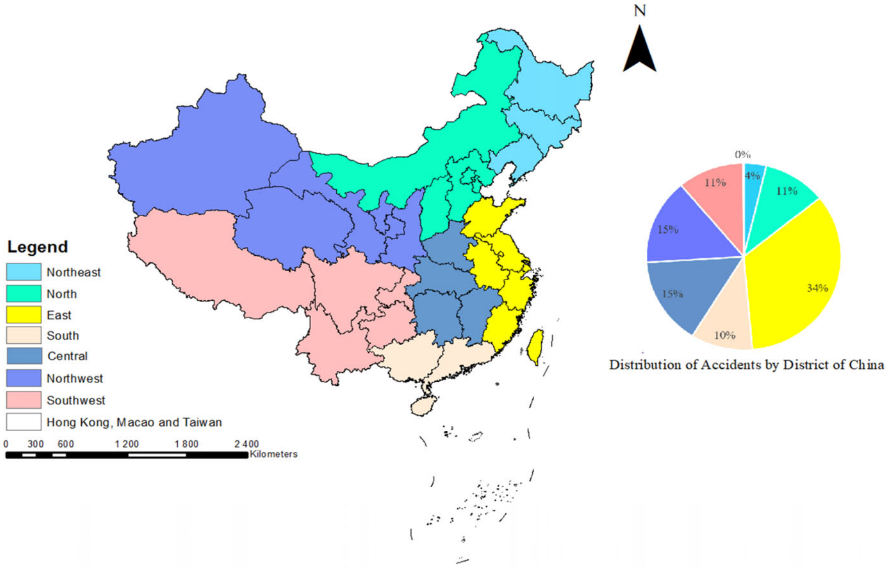

Figure 1. Division of different regions of China and distribution of accidents by district [7].

Foreign research on road traffic risk factor analysis (accident causation theory) is extensive. According to the development of safety system engineering, it can generally be divided into single-factor (human error) causation theory, multi-factor (three elements of road traffic) causation theory, and comprehensive factor (system integration) causation theory [8,9]. Empirical studies further support these theories by analyzing real-world accident data. Empirical studies further support these theories by analyzing real-world accident data. Ali et al. founded that human factor, particularly over speeding (RII = 0.833) and failure to obey traffic laws (RII = 0.826), are the leading causes of accidents, confirming the single-factor causation theory. The study also highlights vehicle defects, poor road infrastructure, and environmental conditions as significant contributors, aligning with the multi-factor approach. Additionally, the need for an integrated strategy combining stricter law enforcement, better infrastructure, and public awareness campaigns supports the comprehensive causation theory. Additionally, the study supports the multi-factor causation theory by demonstrating that vehicle-related issues and road conditions significantly contribute to traffic crashes. Brake failures (RII = 0.776), defective lighting, and poor vehicle maintenance were identified as major accident risk factors. Moreover, road infrastructure deficiencies, including poor street lighting (RII = 0.754), uneven road surfaces (RII = 0.726), and lack of proper road signage, were found to substantially increase accident risks [9].

Literature proposed three means to encourage road risk management through road analysis transportation of hazardous materials examining previous statistics on accidents, and referencing national laws [10,11]. Saaty et al suggested the Analytic Hierarchy Process (AHP), which divides difficult issues into multiple ordered tiers, quantitatively expresses the proportional significance of each level according to the purpose facts, and derives the analysis of the entire problem through the analysis of each level [12]. Chakraborty et al. proposed the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is an effective and widely adopted method in multi-objective decision-making, based on the closeness of evaluation objects to the ideal target [13]. A study by McKowen et al introduced a technique for a sensitivity analysis method based on the penalty function method, which converts constrained problems into unconstrained problems using penalty functions [14]. A complementary study by Olden et al presented a sensitivity analysis method based on randomization testing. [15]. An alternate study by Borgonovo et al. applied sensitivity analysis methods to estimate the risk of investment projects, processing multiple economic indicators such as Net Present Value (NPV) and Internal Rate of Return (IRR) [16]. In China, road traffic safety risk analysis is mainly based on traditional accident causation theory, considering only a single factor among human, vehicle, road, and environment, with a focus on human factors. Another piece of work by Qiu et al. analyzed road traffic safety in Western China, identifying differences in accident causes between the Eastern and Western regions. As shown in Fig. 2, over-speeding, overloading, and driver errors are the leading causes of accidents in both regions, with these factors being more prevalent in the Eastern region. In contrast, the Western region experiences a higher incidence of accidents due to vehicle failure, bad weather, and road conditions. The study emphasizes that poor road infrastructure and limited emergency response capabilities in high-altitude areas contribute to the severity of accidents in the Western region, which supports the argument for a more comprehensive approach to traffic risk analysis, accounting for environmental and infrastructural factors [17].

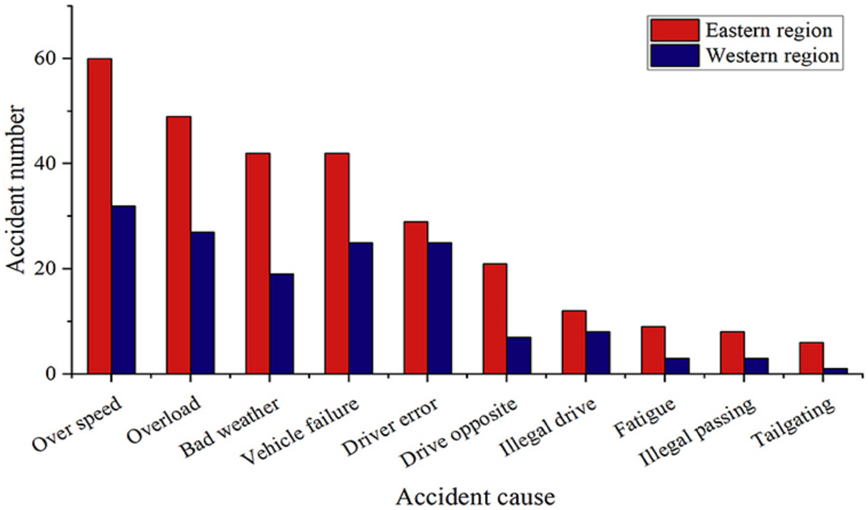

Figure 2. Distribution of reasons for extremely serious traffic accidents in the eastern and western regions [17]

Although some analyses consider multiple factors, they often neglect the interactions between factors, breaking the logical relationships between them. Another study by Wang et al. explained that the Rank Sum Ratio (RSR) method, established by Tian Fengdiao, integrates classical statistical techniques with modern non-parametric methods to provide a comprehensive evaluation approach. This method generates a dimensionless statistical indicator, allowing for objective ranking and comparison of multi-criteria datasets [18].

A further study by Fu et al. provided a sensitivity analysis method using orthogonal experiments, and has been widely used in the establishment of tank mobility performance evaluation systems and industrial and agricultural production [19]. Based on this, this paper addresses the above research status and shortcomings, proposing a traffic safety risk assessment method for expressways based on the AHP-TOPSIS-RSR method. It classifies the overall safety of road sections based on regression analysis results and analyzes the impact of various risk factors on traffic safety risk. Using the sensitivity analysis method based on orthogonal experiments, it identifies indicators that significantly affect the evaluation results and ranks the sensitive indicators.

2. Risk Assessment Index System

The selection and establishment of assessment indicators for expressway traffic safety risks should consider the attributes of the expressway traffic safety system, as well as elements such as the economic, social, and topographical circumstances of the region where the expressway is located, and the level of traffic safety [20]. By integrating the application of similar assessment indicators both domestically and internationally, and through summarization, analysis, comparative research, comprehensive analysis, and consideration, an expressway traffic safety risk evaluation index system is established [21]. This paper primarily examines the system from five perspectives: human, vehicle, road, environment, and management.

2.1. Traffic Participants

In the closed-loop system of expressway traffic with specific functions, humans, as traffic participants, are the most critical factor affecting traffic safety and play a dominant role. Since expressways implement fully closed traffic control, the human factors in traffic accidents are mainly reflected in the responsibility of in-vehicle participants, with some cases involving violations by external traffic participants. This perspective is supported by Bucsuházy et al. who explain that most safety studies conclude that human errors are the main cause of accidents" and that "traffic accidents result from multiple interacting factors, including the driver's behavior, mental and physical condition, and decision-making. Their study points out that in-depth accident investigations have shown that inattention, fatigue, and incorrect assessment of situations are among the most common human-related causes of road accidents [22].

2.2. Vehicles

Vehicles are an essential component of the expressway traffic system. Through investigations of traffic accidents on Chinese expressways, it has been found that the main vehicle-related issues causing accidents include overloading, speeding, tire blowouts, brake failure, and steering failure. This idea is supported by Zhu et al. who analyzed hazardous materials transportation accidents in China and identified vehicle failures as a significant cause of road incidents. The study states that vehicle factors, such as brake failures, improperly closed doors or valves, and mechanical malfunctions, contributed to a notable portion of hazmat transportation accidents. This reinforces the notion that technical failures in vehicles play a critical role in expressway traffic safety, further emphasizing the need for proper vehicle maintenance and regulatory enforcement to reduce accident risk. The Fig.3 provides an overview of various aspects of distribution of Accidents by the number of vehicles, evacuations, poisonings, and secondary accidents. A significant portion, 61.36%, involve a single vehicle, often due to driver errors or mechanical failures. Two-vehicle accidents accounted for 33.42%, mostly occurring on urban roads, where collisions and minor scrapes are more frequent. Multi-vehicle accidents were less common at 5.22%, often caused by adverse weather conditions and slippery roads, which reduce vehicle control [7].

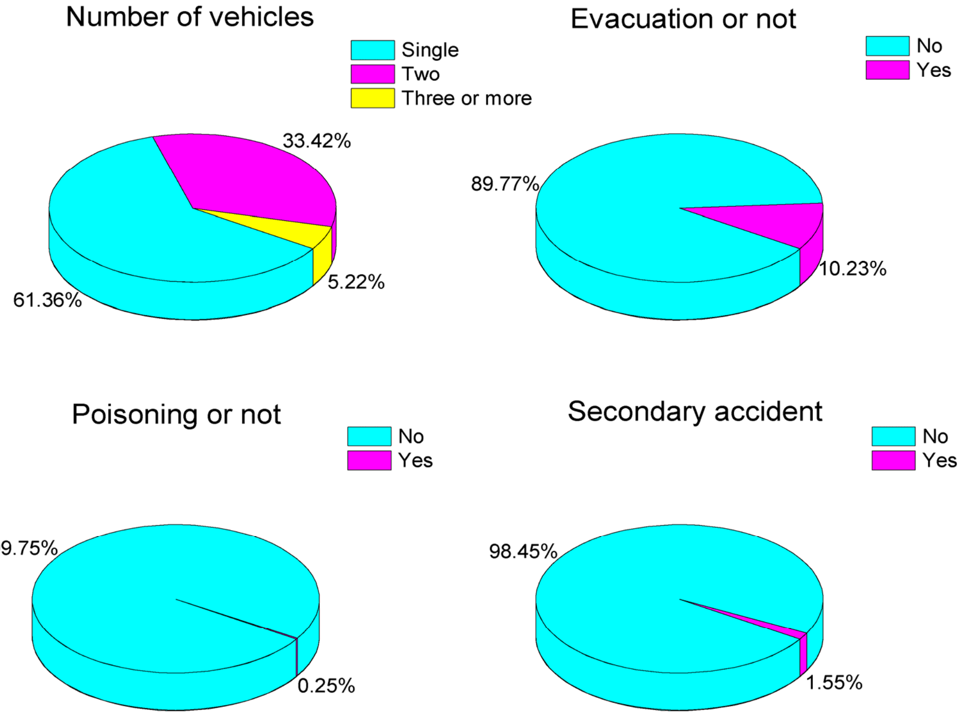

Figure 3. Distribution of Accidents by the number of vehicles, evacuations, poisonings, and secondary accidents [7].

In some cases, hazardous materials posed risks to nearby populations, leading to evacuations in 10.23% of accidents. However, incidents involving poisoning were minimal, with only 0.25% of cases leading to toxic exposure, suggesting that most hazardous materials were properly contained. Secondary accidents were also rare, occurring in 1.55% of incidents, typically due to hazardous material leaks that resulted in fires or explosions. Proper vehicle maintenance, careful handling of hazardous materials, and effective emergency response strategies remain essential for reducing risks on expressways [7].

2.3. Road

Road factors play a significant role in the occurrence of traffic accidents [23,24]. The rationality of the geometric alignment elements and the coordination of alignment combinations have a considerable impact on accident occurrence [25,26,27]. This is confirmed by Wang et al. who examined the safety implications of highway geometric design. Their research indicates that the coordination between horizontal and vertical alignments significantly affects accident rates. They emphasize that properly designed and coordinated alignments, where the transitions between curves and slopes are smooth, reduce the risk of accidents. In contrast, poorly coordinated alignments, such as sharp curves or abrupt elevation changes, can create hazardous driving conditions, increasing the likelihood of accidents [28]. This reinforces the importance of careful geometric design and alignment coordination in improving highway safety.

The design of special sections, as well as the smoothness and skid resistance of the road surface, are also factors affecting the safe operation of expressways. This is confirmed by Jima et al. who analyzed the impact of road geometric formation on traffic crashes and severity levels. Their study found that horizontal curves significantly influence accident severity, while intersections contribute substantially to road traffic crashes [29].

2.4. Environment

Environmental factors affecting traffic safety can be broadly divided into geographical environment, traffic environment, and weather conditions [30,31]. The geographical environment refers to the road geological conditions and hazardous obstacles on the roadside, which can influence driving safety. Under the same conditions, the number of traffic accidents depends on the traffic environment, which includes traffic conditions and traffic safety facilities. Traffic conditions determine driving speed, traffic flow patterns, and the level of driver stress. The proper setup of traffic safety facilities significantly impacts accident occurrence. Weather conditions, such as wind, rain, fog, ice, and snow, also affect driving safety. Adverse weather can impair drivers' visibility, leading to misjudgments and accidents. During rain or snow, the road's skid resistance decreases, and reduced tire adhesion can cause skidding and accidents [32,33,34]. This environmental perspective is supported by Chen et al. (2025), who demonstrate that in China, the structural features of the road environment such as intersection complexity, road alignment, segregation type, and road classification have a significant influence on the occurrence of accidents involving vulnerable road users. Their findings show that accidents are more frequent in poorly designed environments, especially where traffic control is absent and physical separation between road users is lacking [35].

Complementing this infrastructure-focused analysis, Liu et al. (2020) emphasize how, in rural China, the lack of protective environmental conditions including close proximity to roads, absence of safe recreational spaces, and limited use of safety equipment further increases exposure to road hazards for young children. Together, these studies reinforce the idea that road traffic injuries are strongly shaped by the quality and safety of the surrounding environment, rather than by isolated behaviors alone [36];The Fig. 4 provided shows regional climate risks across China, directly impacting traffic safety.

Figure 4. Map of regional extreme weather risks in China [37].

These weather-related factors are further illustrated by the regional climate risks across China, as shown in Fig. 4, which describes the varying climate challenges faced by different regions, each contributing to hazardous driving environments. For example, Northwest China, as depicted in Fig. 4, faces snowmelt flooding, making roads slippery during the spring. This poses a direct danger to traffic safety, particularly when combined with the reduced road traction during melting snow, increasing the likelihood of skidding accidents. North China experiences warming and drying, leading to the creation of heat island effects, which exacerbate the risks of flooding. This degradation of road conditions, coupled with increased traffic, directly affects the safety of drivers by making roads more prone to wear and less stable, particularly during extreme weather events. Northeast China, warming faster than the national average, is prone to summer flooding and permafrost thawing. The thawing of permafrost makes the ground unstable, causing road damages and making roads prone to shifting and cracking, which greatly impairs driving safety. Southwest China is vulnerable to seasonal droughts, which affect the stability of roads and infrastructures. The region faces pressure on its transportation networks due to unstable road conditions, posing a risk to driving safety, especially in rural areas where road maintenance can be less frequent. South China, frequently impacted by heatwaves, floods, and typhoons, faces hazardous conditions that further contribute to accidents. These weather events, as shown in Fig.4, make roads more dangerous by increasing flooding risks, weakening road surfaces, and impairing visibility. Central China deals with severe droughts and floods that affect road integrity. Waterlogged roads are especially problematic, increasing the potential for accidents due to poor road conditions and diminished vehicle control during adverse weather events. East China is at risk from typhoons and rising sea levels, as indicated in Figure 4, leading to urban flooding and severe road damage. The region's vulnerability to such weather-related issues makes driving conditions hazardous, with flooding causing roads to become impassable and increasing the risk of accidents. Each of these regional climate risks contributes to creating hazardous driving conditions, aligning with the weather-related factors, such as rain, snow, heatwaves, and flooding, which increase the likelihood of traffic accidents [37].

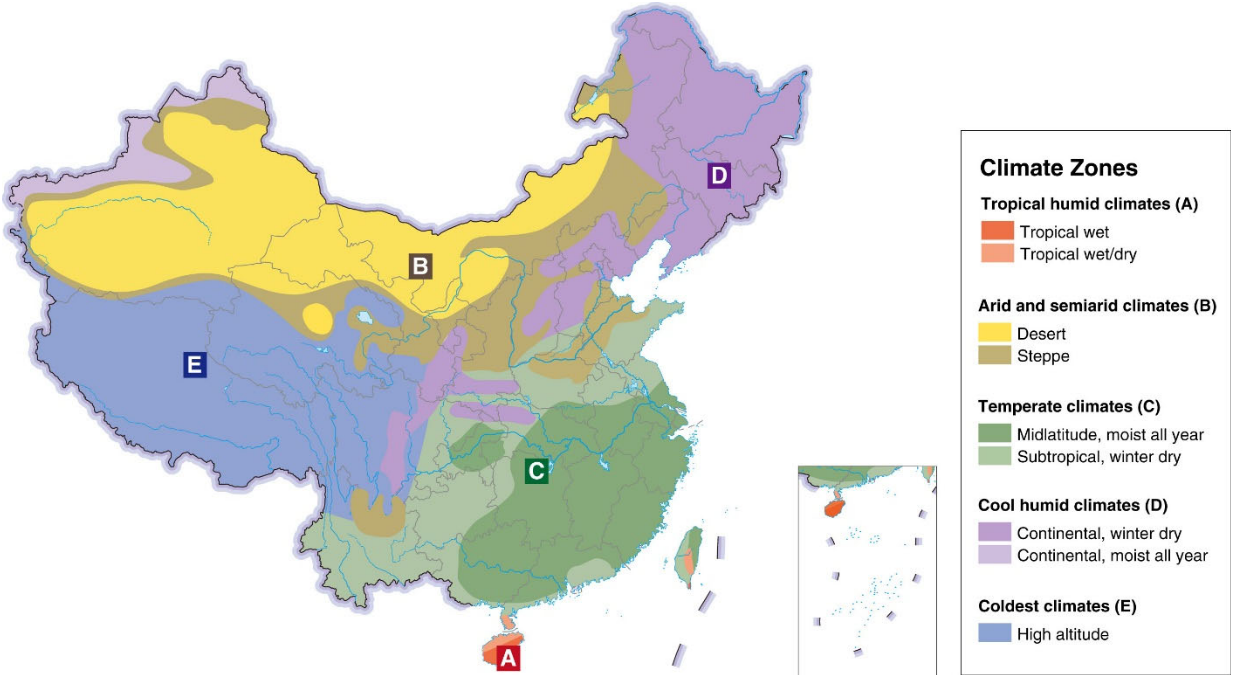

Figure 5. Climate Zones of China [37]

The Fig.5 further emphasizes how the varying climate zones across China influence road conditions and driving safety. The Tropical humid climates (A) in the southernmost regions of China are prone to heavy rainfall, leading to slippery roads and reduced visibility, which increases the risk of accidents due to hydroplaning. Arid and semiarid climates (B) in the northwestern regions experience sandstorms and temperature extremes, reducing road traction and impairing visibility. Temperate climates (C) in eastern and southern China, while generally milder, can still face seasonal flooding, which can destabilize roads. Cool humid climates (D) in the northeastern regions experience cold winters with ice and snow, making roads slippery and increasing accident risks. Finally, Coldest climates (E) in high-altitude regions like Tibet present the challenge of icy roads and challenging weather, particularly during the winter months, which significantly impair road safety.

2.5. Management

Expressway safety management measures are essential for system operation. The level of management directly affects the occurrence of accidents and the extent of losses after an accident, particularly the effectiveness of the rapid rescue system, which is crucial for reducing fatalities. Therefore, the evaluation of management level includes the management system, the competence of management personnel, and the accident rescue system.

The expressway traffic safety risk e index system constructed in this paper is organically composed of five subsystems, describing the safety status of expressway traffic operations from the perspectives of human, vehicle, road, environment, and management. It includes 10 secondary indicators and 16 corresponding sub-indicators, as shown in Table 1.

3. Expressway Traffic Safety Risk Assessment Based on the ATR Method

3.1. ATR Risk Assessment Method (AHP-TOPSIS-RSR)

In the field of road traffic safety risk assessment, both domestic and international research commonly employs methods such as the accident rate method, accident intensity method, grey evaluation method, fuzzy comprehensive evaluation method, Analytic Hierarchy Process (AHP), and BP neural network method. Each method has its own advantages, disadvantages, and applicable conditions [38].

Given the comprehensive, complex, and uncertain nature of traffic safety risk factors, as well as the applicable conditions of relevant assessment methods, this paper proposes a novel comprehensive traffic safety risk assessment method: AHP-TOPSIS-RSR, which combines the Analytic Hierarchy Process (AHP), the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and the Rank Sum Ratio (RSR) method.

Analytic Hierarchy Process (AHP): Proposed by Saaty, AHP is a qualitative and quantitative analysis and assessment method. It can repeatedly and uniformly handle quantitative and qualitative issues in decision-making until they meet objective requirements. AHP has unique advantages in evaluating complex systems [39]. AHP works by using pairwise comparisons to create ratio scales for both discrete and continuous criteria. This allows AHP to simultaneously address qualitative and quantitative factors. By breaking down complex decision problems into hierarchical structures, it facilitates the comparison of various criteria and subcriteria, leading to prioritized rankings. This approach is highly effective in analyzing complex systems, as it integrates both qualitative judgments and quantitative data, providing a thorough examination of interdependent factors [40,41]. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS):

Table 1. Evaluation Index System

Subsystem	Secondary Indicators	Influencing Factors
	In-vehicle Participants	1. Fatigue/Unlicensed Driving
Human Factors	External Participants	2. Risky Behavior of Maintenance Workers
		3. Steering Performance
Vehicle Factors	Vehicle performances	4. Braking Performance
		5. Overloading
	Vehicle over limit	6. Speeding
		7. linear conditions
Road Factors	Road Alignment	8. Roadbed Slopes
	Roadbed and Pavement	9. Road Surface Smoothness and Skid Resistance
		10. Traffic Conditions
Environmental Factors	Traffic Environment	11. Traffic Safety Facilities
	Meteorological environment	12. Bad Weather
		13. Traffic Safety Management System
Management Factors	Security Management	14. Management Personnel Competency
		15. Rescue Mechanism
	Rescue management	16. Rescue capability

First proposed by Hwang and Yoon, TOPSIS is a ranking method that approximates the ideal solution. Its basic approach is as follows: first, an initial decision matrix is established. Then, based on the normalized initial matrix, the optimal and worst solutions (i.e., the positive and negative ideal solutions) among the limited alternatives are identified. Next, the distances between each evaluation object and the optimal and worst solutions are calculated to determine the relative closeness of each evaluation alternative to the optimal solution. Finally, the alternatives are ranked based on this closeness, which serves as the basis for evaluating their superiority and inferiority [42].Rank Sum Ratio (RSR) Method: Zhao et al. proposed that the Rank Sum Ratio (RSR) method, developed by Tian Fengdiao in 1988, is a comprehensive evaluation technique that ranks evaluation indicators and converts them into a dimensionless statistical value, the RSR. This method uses parametric statistical analysis to determine the distribution of the RSR values and interpret the results. Zhao applied this method in combination with the TOPSIS technique to evaluate laboratory management performance across seven provincial Centers for Disease Control and Prevention (CDC) laboratories in China [43].

The AHP-TOPSIS-RSR method first uses AHP to establish an evaluation matrix and normalize it. Then, by introducing entropy weight into the TOPSIS method, the comprehensive traffic safety risk evaluation index value and the relative closeness value c_i to the ideal solution are calculated. Finally, by combining the RSR method and based on the grading standards for expressway traffic safety risk levels, the c_i values are categorized to determine the membership grade of the expressway traffic safety risk level.

The combination of AHP-TOPSIS-RSR overcomes the limitations of the traditional TOPSIS method, which typically relies on expert assessment or AHP to determine the weight factors of evaluation indicators, thus reducing the influence of subjectivity. It retains the advantage of TOPSIS in sensitively reflecting differences between indicators while utilizing the RSR method to address the issue of TOPSIS being unable to reasonably categorize the superiority and inferiority of evaluation objects. The integration of these three methods complements their strengths [44].

3.2. Risk Assessment Model

(1) Evaluation Matrix

Based on the AHP (Analytic Hierarchy Process) evaluation index system (with a basic number of indicators n), and according to the risk indicator scoring table, the initial risk assessment matrix is established by using the expert scoring method and taking the average value [45]. The setting of the warning limit value is a crucial part of safety risk assessment. When the indicator value deviates from the normal level beyond the warning limit, it indicates the presence of danger [46]. Currently, a more mature approach is to use systematic methods for analysis. Systematic methods mainly refer to research based on various combined objective principles, including the majority principle, half principle, minority principle, mean principle, mode principle, negative principle, and parameter principle, among others [47]. According to each principle, a warning limit value is determined.

Subsequently, the warning limit values determined by various principles are averaged, and appropriate adjustments are made to derive the final warning limit values for each indicator [48]. To distinguish the boundaries between intervals, the value of "extremely likely" is assigned as 10, and "almost impossible is assigned as 0. The middle range is further divided into three levels: "somewhat possible, quite likely, and very likely. The specific assignments are shown in Table 2.

Table 2. Risk Indicator Scores

Likelihood of Causing Traffic Accidents	Almost Impossible	Somewhat Possible	Quite Likely	Very Likely	Extremely Likely
Risk Score	0 - 1.0	2.0 - 3.0	4.0 - 6.0	7.0 - 8.0	9.0 - 10.0

$$X = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{31} & \cdots & x_{3n} \end{pmatrix} \tag{1}$$

Where: X is the evaluation matrix.x_{ij} is $i-th$ value value of the $j-th$ risk indicator in the risk evaluation matrix. i=1,2,3:i = 1 represents the minimum value from the expert scoring method.i = 2 represents the maximum value from the expert scoring method. i = 3 represents the average value from expert scoring method. j = 1, 2, …, n

(2) Dimensionless Normalization of the Evaluation Matrix

To eliminate dimensions and unify the quantities, the initial risk evaluation matrix undergoes dimensionless normalization.

$$y_{ij} = \frac{x_{ij}-x_{min}}{x_{max}-x_{min}} \tag{2}$$

Where: y_{ij} is $i-th$ value value of the $j-th$ risk indicator in dimensionless decision matrix.

x_{ij} is the original value of the $i-th$ evaluation for the $j-th$ risk matrix.

x_{min} is minimum value in the evaluation matrix.

x_{max} is the maximum value in the evaluation matrix.

(3) Determining Indicator Weights Using the Entropy Weight Method

The concept of entropy is used to determine the weights of the evaluation indicators, which helps avoid the influence of subjective factors. The entropy weight method determines the weights based on the amount of information provided by the observed values of each indicator. The more dispersed the data distribution, the greater the uncertainty. When the system may be in m different states, the entropy value H_j of the $j-th$ risk indicator is:

$$H_j = \frac{1}{ln\,(n)}\sum_{i=1}^{m} p_{ij} \ln\,(p_{ij}) \tag{3}$$

$$p_{ij} = \frac{(1+y_{ij})}{\sum_{k=1}^{m}(1+y_{kj})} \tag{4}$$

Where: p_{ij} is the probability corresponding to $i-th$ value of the $j-th$ risk indicator that affects the change in the system's entropy value.i = 1,2, … $m.j$ = 1,2, … n

The degree of dispersiong_j of the evaluation data for the $j-th$ indicator can be expressed as $g_j = -H_j$.The greater the difference in the given indicator values x_{ij} , the larger the $g_j$value, indicating that the indicator contains and transmits more information and is of higher importance. Conversely, a smaller g_j value indicates lower importance. If the values x_{ij} for all schemes are equal, the evaluation values are absolutely concentrated, and the indicator has no effect on the comprehensive evaluation. Therefore, the weight of the $j-th$ indicator can be represented using the entropy measure. After determining the weights of all indicators, a diagonal matrix—indicator weight matrix—is constructed with these weights as the elements on the main diagonal.

$$W= \begin{bmatrix} w_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & w_n \end{bmatrix} \tag{5}$$

$$w_j = \frac{(1-H_J)}{n-\sum_{j=1}^{n} H_J} \tag{6}$$

Where W is the indicator weight matrix; w_j is the entropy weight for each evaluation indicator, where j =1, 2, …, n.

(4) Constructing the Normalized Weighted Matrix

Based on the indicator weight matrix, we can obtain the weighted data matrix Z, where the elements z_{ij} are defined as:

$$z_{ij} = y_{ij}.\ w_j \tag{7}$$

(5) Determining the Ideal Solution and Negative Ideal Solution Determine the reference samples.

The maximum values from the evaluation samples from the optim al sample, with the optimal sample point (ideal solution) z^+being

$$z^+=(\ z_1{}^+,\ z_2{}^+\ ,\ldots,\ z_n{}^+\ ) \tag{8}$$

The minimum values from the evaluation samples from the worst sample, with the worst sample point (negative ideal solution) z^- being

$$z^- = (z_1{}^-,\ z_2{}^-,\ldots,\ z_n{}^-) \tag{9}$$

where:

$$z_j^+ = \max_{1\le i\le m}\{y_{ij}\}\ z_j^- = \min_{1\le i\le m}\{y_{ij}\} \tag{10}$$

(6) Calculate the Distance to the Ideal Solution and Negative Ideal Solution

Calculate the distances D_i^+ , D_i^- and the relative closeness c_i to the ideal solution.

The distances from the sample point to the optimal sample point and the worst sample point, D_i^+ and D_i^- , are respectively:

$$D_i^+ = \sqrt{\sum_{j=1}^{n}(z_{ij} - z_j^+)^2} \ , \ D_i^- = \sqrt{\sum_{j=1}^{n}(z_{ij} - z_j^-)^2} \quad (11)$$

The relative closeness C_i , is defined as:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (12)$$

The larger the value of c_i, the closer it is to the ideal solution, and the lower the traffic safety risk level.

(7) Calculate the Rank-Sum Ratio R_i and Determine the RSR Distribution

The rank-sum ratio refers to the average rank of rows (or columns) in a table. It is a non-parametric comprehensive index with the characteristics of a continuous variable in the range of 0 to 1. It serves as an interface and entry point for integrating non-parametric and parametric statistics, with strong statistical information capabilities. The basic idea of using the rank-sum ratio method for statistical analysis is to obtain a dimensionless statistical quantity R_i through rank transformation in a matrix, and to rank the evaluation objects based on the value of R_i.

The relative closeness c_i in the TOPSIS method ranges between 0 and 1, similar to the distribution of R_i in the rank-sum ratio method. This allows for further RSR analysis. Since c_i values lie between 0 and 1, they can replace the rank-sum ratio R_i for classification. Based on the value of R_i , groups are formed, and the frequency f , cumulative frequency f', average rank $\bar{R}$, and $\bar{R}/\ n$ values are listed. The corresponding probability unit value y is then calculated.

(8) Determine the RSR regression Equation

Using y as the independent variable and R_i as the dependent variable, the regression equation is estimated as:

$$\hat{R} = a + \beta_y \quad (13)$$

where:$\hat{R}$ = is the statistical regression value of the rank-sum ratio;y is the probability unit;a and $\beta$are parameters of the regression equation.

3.3. Risk Evaluation Criteria

The reasonable classification method based on RSR (Rank-Sum Ratio) is used to classify the risk evaluation criteria. The reasonable classification method is based on the normal distribution, and the classification is determined by the standard normal deviation. It conducts a comprehensive evaluation of multiple indicators based on the statistical quantity RSR and proposes a reasonable number of classifications. The cumulative area under the standard normal curve represents the percentiles for each classification. This paper will not delve further into this topic; for more details, please refer to literature [49].

According to the reasonable classification method of RSR, the evaluation of highway traffic safety risk levels can be categorized, thereby determining the traffic safety risk level of the evaluated highway. Based on the standard normal deviation classification, the number of classifications is set to 5. The corresponding percentiles and probability units for each classification are shown in Table 3.

Table 3. Degree of Risk Warning Alarm

Warning Level	Description	Percentile Rang p	Probability unit y
Level 1	Extreme Alarm	Below 3.593	Below 3.2
Level 2	Severe Alarm	3.593 - 27.425	3.593 - 27.425
Level 3	Moderate Alarm	27.425 - 72.575	4.4 - 5.6
Level 4	Mild Alarm	72.575 - 96.407	5.6 - 6.8
Level 5	No Alarm	Above 96.407	Above 6.8

4. Sensitivity Analysis Based on Orthogonal Experimental Design

Based on determining the traffic safety risk level, the sensitivity of numerous uncertain risk factors to traffic safety is analyzed and calculated. This helps to assess their impact on traffic safety risks, establish the primary and secondary relationships among risk factors, and identify the main risk factors that significantly influence traffic safety.

Through sensitivity analysis, the influence degree (i.e., sensitivity coefficient) of each indicator on traffic safety is calculated. This allows for the identification of sensitive indicators, focusing on the main contradictions affecting traffic safety, and avoiding subjective misjudgments. By ranking the sensitivity coefficients, the indicators affecting traffic safety are classified into sensitive risk indicators and general risk indicators, providing a clear primary and secondary relationship among risk indicators. This serves as a basis for proposing specific and targeted traffic safety improvement measures for sensitive risk indicators.

4.1. Orthogonal Experimental Design

Methods for sensitivity analysis include sensitivity analysis based on the generalized reduced gradient method, penalty function method, geometric programming method, and methods that do not require second-order information [50]. However, these sensitivity analysis methods often rely on optimization algorithms, and different optimization algorithms lead to different analysis methods. Additionally, they require the optimization problem to be continuously differentiable, which is often not satisfied in practical problems. As a result, their application and promotion are somewhat limited.

Orthogonal experimental design refers to a method of arranging experimental schemes using orthogonal tables. It is a sensitivity analysis method that does not depend on specific algorithms and is applicable to discrete, non-differentiable, or implicit optimization problems. It has the advantages of orthogonality, typicality, and comprehensive comparability.

An orthogonal table is a mathematical table constructed based on the idea of balanced distribution and combinatorial mathematics theory. In orthogonal experimental design, the range analysis method is generally used to determine the optimal levels of factors and the primary and secondary relationships of the experimental indicators [51]. The range reflects the degree of influence of factors on the experimental indicators and embodies the sensitivity of the function to the variables.

4.2. Sensitivity Analysis Model

(1) Determine the Objective Function

The mathematical model of highway traffic safety risk performance can be simply described as:

$$E = f(l_1, l_{2,\ldots,} l_n) \tag{14}$$

where:E is the risk performance value, which is the relative closeness c_i value of the indicator value to the "ideal solution" in risk evaluation;$f()$ is the performance function; $l_1, l_2, \ldots, l_n$ are the risk indicators; n is the number of indicators.

(2) Select an Appropriate Two-Level Orthogonal Table

For a two-level orthogonal table $l_a(2^c)$, the construction rules are:

$$\begin{cases} a = 4t \\ c = a - 1 \end{cases} \tag{15}$$

where:a the number of experiments to be conducted;c is the number of columns in the orthogonal table, where one column can accommodate one factor; $a \geq (n+1)/4$, and n is the number of indicators.

(3) Determine the Variation Design Scheme

Considering that all factors have been normalized and are dimensionally consistent, the same variation amount h is taken. Based on this, the levels of each factor can be determined, as shown in Table 4.

Table 4. Levels of Factors

Level	l_1	l_2	...	l_n
1	$l_1(1-h)$	$l_2(1-h)$	...	$l_n(1-h)$
2	$l_1(1+h)$	$l_2(1+h)$	...	$l_n(1+h)$

Variation Design scheme based on the first n columns of the orthogonal table $l_a(2^c)$

(4) Invoke the Risk Performance Model and Calculate the Objective Function Values

The risk performance model invokes the TOPSIS model from the risk evaluation to map risk indicators to risk performance values. The risk performance value is the relative closeness c value of the comprehensive risk value to the "ideal solution" in risk evaluation.

$$E(s) = C(l_1, l_{2,\ldots} l_n), \ s = 1,2,\ldots,a \tag{16}$$

(5) Calculate the Average Values of the Objective Function and Constraint Functions

The average values of the risk performance values corresponding to each level of each factor reflect the degree of the risk level under that factor and level.

$$\overline{m}_{jk} = \frac{\sum E(l = l_{jk})}{count\,(l = l_{jk})} \tag{17}$$

Where: $\overline{m}\,j_k$ is the average risk performance value corresponding to the $k-th$ level of the $j-th$ risk indicator, l_{jk} is the indicator value of the $k-th$ level of the j -th risk indicator, $j = 1,2,\ldots,n$; $k = 1,2$; the count function is used to calculate the number of items in the list that meet the conditions.

(6) Calculate the Range of the Objective Function Values

Since all variables have been normalized, the range of the objective function corresponding to each variable can be directly used. Otherwise, to eliminate the influence of dimensions, the relative range of the objective function corresponding to each variable should be used.

The range R_j of the average risk performance values for the j -th risk indicator is calculated as:

$$R_{J=\max}\ [\overline{m}_{j1}, \overline{m}_{j2}] - \min\,[\overline{m}_{j1}, \overline{m}_{j2}] \tag{18}$$

(7) Calculate the Sensitivity of Each Design Variable

The level difference of the risk indicators reflects the degree of difference of each factor under different levels. The sensitivity S_j of the risk indicator is:

$$S_j = \left| \frac{R_j}{l_{j1} - l_{j2}} \right| \tag{19}$$

(8) Early Warning of Sensitive Risk Factors

By sorting the sensitivity values:

$$S_{j=} \max_{1 \leq j \leq n}(S_j) \tag{20}$$

5. Example Verification

5.1. Overview

This paper selects the Yongwu (Yong'an-Wuping) Expressway in Fujian Province, specifically the A4 and A5 contract sections, for case analysis. The A4 contract section is located in Liancheng County, Longyan City. The area through which the section passes is in the northern part of the Dai Mao Mountain Range, predominantly characterized by hilly and low-mountain terrain, with some areas featuring mid-low mountain terrain. The region includes intermountain basins and valleys of varying elevations, such as the Gutian Basin, with significant terrain fluctuations and relative height differences ranging from 80 to 560 meters. Fig.**6** illustrates the location of the Yongwu Expressway in Fujian Province and provides a visual representation of the terrain in this area.

Figure 6. The Yongwu Expressway and its location in Fujian Province. *Source: Zhou & Sheate* [52] .

This paper selects the Yongwu (Yong'an-Wuping) Expressway in Fujian Province, specifically the A4 and A5 contract sections, for case analysis. The A4 contract section is located in Liancheng County, Longyan City. The area through which the section passes is in the northern part of the Dai Mao Mountain Range, predominantly characterized by hilly and low-mountain terrain, with some areas featuring mid-low mountain terrain. The region includes intermountain basins and valleys of varying elevations, such as the Gutian Basin, with significant terrain fluctuations and relative height differences ranging from 80 to 560 meters.

The A5 contract section is also located in Liancheng County, Longyan City. The section traverses complex geomorphological units, primarily low-mountain and hilly terrain, interspersed with intermountain basins and narrow valleys of varying elevations and extents. The terrain is highly undulating, with steep slopes generally ranging from 23° to 35°, and in some areas reaching 40° to 50°. The A5 contract section is also located in Liancheng County, Longyan City. The section traverses complex geomorphological units, primarily low-mountain and hilly terrain, interspersed with intermountain basins and narrow valleys of varying elevations and extents. The terrain is highly undulating, with steep slopes generally ranging from 23° to 35°, and in some areas reaching 40° to 50°.

5.2. Result Analysis

5.2.1. Evaluation Implementation

(1) Risk Evaluation

Based on the ATR risk evaluation model establishment method, the risk evaluation model is constructed for the A4 and A5 contract sections of the Yongwu Expressway. According to the risk evaluation model calculation steps (1), (2), (3), (4), (5), and (6), the relative closeness C_2 of the comprehensive risk evaluation value to the "ideal solution" is 0.3748. From calculation step (7), the RSR distribution is determined. Based on the value of R_j , the data is grouped, and the frequency f , cumulative frequency f' , average rank $\bar{R}$, and $\bar{R}/n$ values are listed. The corresponding probability unit value y is then calculated, as shown in Table 5.

Table 5. RSR Distribution and Corresponding Probability Unit Values

R_i	f	f'	$\frac{\bar{R}}{n}$ X 100%	Probability Unit $\boldsymbol{y}$
1	1	1	33	Above 6.8
0.3748	1	2	66	2.4988
0	1	3	92	Below 3.2

According to calculation steps (7) and (8), using y as the independent variable and R_i as the dependent variable, the regression equation is obtained as:

$$\hat{R}= -0.1875 + 0.1688 \times 2.4988 = 0.2343 \qquad (21)$$

Based on the reasonable classification method of RSR, the traffic safety risk level of the evaluated expressway section is classified, resulting in the traffic safety risk level of the evaluated expressway section being Level I - Extreme Alarm, indicating a high-risk level.

(2) Risk Sensitivity Analysis

Using the sensitivity analysis method based on orthogonal experimental design, the risk evaluation model is established for the A4 and A5 contract sections of the Yongwu Expressway, constructing a two-level orthogonal table $L_{20}(2^{19})$. According to the sensitivity analysis model calculation steps (1), (2), (3), (4), (5), and (6), with a variation h of 30%, the range of the objective function values is obtained, as shown in Table 6 on the next page (the indicator numbers in the table correspond to the influencing factors in Table 1).According to calculation step (7), the sensitivity of each factor's risk indicators is calculated using the range analysis method, as shown in Table 7 on the next page. According to calculation step (8), the sensitivity distribution graph is obtained, as shown in Fig.7 on the next page, and the sensitive risk factors are determined.

Table 6. Extremum of objective function differences

Indicator	1	2	3	4	5	6	7	8
Range	0.0357	0.0411	0.0372	0.0411	0.0372	0.0596	0.0596	0.0383
Indicator	9	10	11	12	13	14	15	16
Range	0.0411	0.0019	0.0236	0.0287	0.0411	0.0411	0.0596	0.0585

Table 7. Sensitivities of risk indicators

Indicator	1	2	3	4	5	6	7	8
Sensitivity	0.4721	0.3568	0.2874	0.4269	0.2849	0.5088	0.7598	0.3916
Indicator	0.4721	0.3568	0.2874	0.4269	0.2849	0.5088	0.7598	0.3916
Sensitivity	0.3586	0.8142	0.2143	0.5296	0.3615	0.2893	0.4685	0.3974

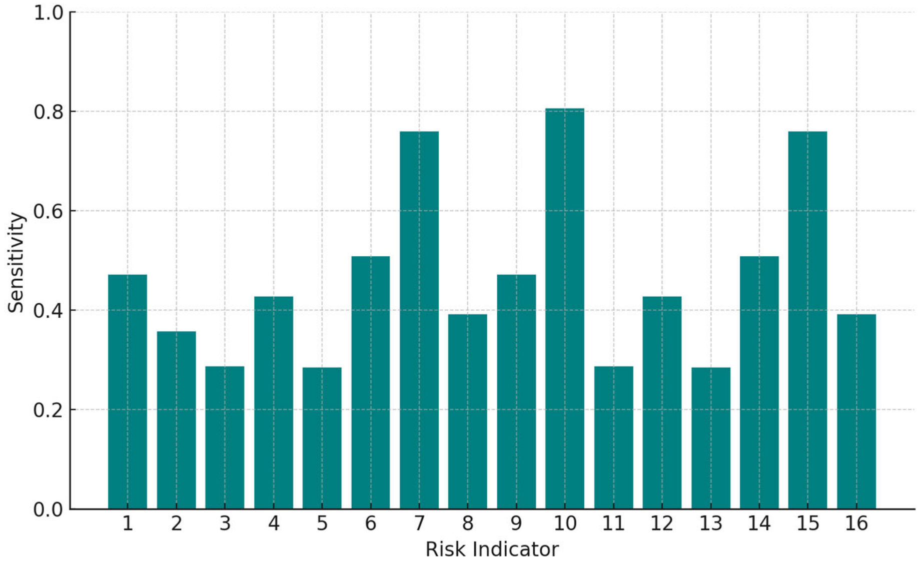

Figure 7. Sensitivities distribution of risk indicator

5.2.2. Result Analysis

(1) Risk Evaluation Results

Through the evaluation, the traffic safety risk level for the A4 and A5 contract sections of the Yongwu Expressway is determined to be: Level I – Huge Warning. This risk level is in an unacceptable state and requires urgent implementation of safety measures to control, reduce, or eliminate the risks.

(2) Sensitivity Analysis Results

As shown in Fig.7, six risk indicators exhibit high sensitivity:1 (Fatigue/Driving without a license),

6 (Vehicle Speeding),7 (Road Alignment Conditions),10 (Traffic Conditions),12 (Adverse Weather),15 (Rescue Mechanism). Their sensitivity values are:0.4721, 0.5088, 0.7598, 0.8142, 0.5296, and 0.4685, respectively. These are considered traffic safety-sensitive risk indicators.

(3) Evaluation Results Analysis

The risk evaluation results are consistent with the actual situation, reflecting the traffic safety status of the Yongwu Expressway quite accurately. The risk sensitivity analysis results are in line with the potential risk effects of the Yongwu Expressway, indicating that the analysis is reasonable and reliable. Therefore, by taking corresponding safety measures for sensitive risk factors, the risk level can be significantly reduced, improving driving safety and achieving good safety protection results.

6. Conclusion

Based on the principles of system analysis and integration, the AHP-TOPSIS-RSR method for expressway traffic safety risk assessment is developed. This method addresses the shortcomings of the three individual methods while retaining their advantages, enriching the existing risk assessment system and expanding the application scope of AHP, TOPSIS, and RSR methods.

The sensitivity analysis method based on orthogonal experiments is introduced to evaluate expressway traffic safety risk factors. With this method, the sensitivity of these risk factors is analyzed, and the risk indicators are classified into sensitive and general indicators based on their primary and secondary relationships. Since the sensitivity of factors such as fatigue/unlicensed driving, vehicle speeding, road alignment, traffic conditions, adverse weather, and rescue mechanisms is relatively high, reaching 0.4721, 0.5088, 0.7598, 0.8142, 0.5296, and 0.4685, respectively, these factors are identified as sensitive traffic safety risk indicators.

This paper primarily focuses on the static conditions of expressway traffic safety risk assessment and sensitivity analysis. Considering the uncertainty and variability of expressway traffic safety risks, future research will focus on dynamic real-time early warning systems for expressway traffic safety risks in the road network environment.

Acknowledgments

This work was a collaborative effort among several students and departments at Huaiyin Institute of Technology. Special thanks to the Faculty of Business Studies, the Transportation Engineering Department, and my supervisor, Zhu Honglan, for his invaluable support and contributions throughout the process. I would also like to acknowledge the academic environment and resources provided by Huaiyin Institute of Technology, which facilitated the completion of this work.

References

[1] G. Zhang, K. K. W. Yau, and G. Chen, “Risk factors associated with traffic violations and accident severity in China,” Accid. Anal. Prev., vol. 59, pp. 18–25, Oct. 2013, doi: 10.1016/j.aap.2013.05.004.

[2] B. Wang and C. Wu, “Using an evidence-based safety approach to develop China’s road safety strategies,” J. Glob. Health, vol. 9, no. 2, p. 020602, doi: 10.7189/jogh.09.020602.

[3] W. Zhang, O. Tsimhoni, M. Sivak, and M. J. Flannagan, “Road safety in China: Analysis of current challenges,” J. Safety Res., vol. 41, no. 1, pp. 25–30, Feb. 2010, doi: 10.1016/j.jsr.2009.12.003.

[4] Z. Yang, H. Wang, and B. Chen, “Assessment of urban waterlogging-induced road traffic safety risk and identification of its driving factors: A case study of Beijing,” Transp. Res. Part Policy Pract., vol. 183, p. 104080, May 2024, doi: 10.1016/j.tra.2024.104080.

[5] J. Wang, C. Ma, S. Wang, X. Lu, and D. Li, “Risk Assessment Model and Sensitivity Analysis of Ordinary Arterial Highways Based on RSR–CRITIC–LVSSM–EFAST,” Sustainability, vol. 14, no. 23, p. 16096, Dec. 2022, doi: 10.3390/su142316096.

[6] D. S. Rao, M. S. Rao, and V. V. S. K. Rao, “Assessment of Road Condition: Traffic Safety Requirement,” EAI Endorsed Trans. Energy Web, vol. 10, Nov. 2023, doi: 10.4108/ew.4472.

[7] S. Zhu, S. Zhang, H. Lang, C. Jiang, and Y. Xing, “The Situation of Hazardous Materials Accidents during Road Transportation in China from 2013 to 2019,” Int. J. Environ. Res. Public. Health, vol. 19, no. 15, p. 9632, Aug. 2022, doi: 10.3390/ijerph19159632.

[8] S. Firdaus, PetroSync Blog. Accessed: Mar. 14, 2025. [Online]. Available: https://www.petrosync.com/blog/accident-causation-theories/

[9] A. S. B. Ali et al., “Factors contributing to road traffic accidents in the Gaza Strip a comprehensive analysis,” Sci. Rep., vol. 14, no. 1, p. 31198, Dec. 2024, doi: 10.1038/s41598-024-82431-6.

[10] C. Ma, J. Zhou, and D. Yang, “Causation Analysis of Hazardous Material Road Transportation Accidents Based on the Ordered Logit Regression Model,” Int. J. Environ. Res. Public. Health, vol. 17, no. 4, p. 1259, Feb. 2020, doi: 10.3390/ijerph17041259.

[11] J. Guo and C. Luo, “Risk assessment of hazardous materials transportation: A review of research progress in the last thirty years,” J. Traffic Transp. Eng. Engl. Ed., vol. 9, no. 4, pp. 571–590, Aug. 2022, doi: 10.1016/j.jtte.2022.01.004.

[12] T. L. Saaty and L. G. Vargas, Models, Methods, Concepts & Applications of the Analytic Hierarchy Process, vol. 175. in International Series in Operations Research & Management Science, vol. 175. Boston, MA: Springer US, 2012. doi: 10.1007/978-1-4614-3597-6.

[13] S. Chakraborty, “TOPSIS and Modified TOPSIS: A comparative analysis,” Decis. Anal. J., vol. 2, p. 100021, Mar. 2022, doi: 10.1016/j.dajour.2021.100021.

[14] J. Mckeown, “PARAMETRIC SENSITIVITY ANALYSIS OF NONLINEAR PROGRAMMING PROBLEMS,” 1980, Accessed: Mar. 14, 2025. [Online]. Available: http://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=PASCAL8130457564

[15] J. D. Olden and D. A. Jackson, “Illuminating the ‘black box’: a randomization approach for understanding variable contributions in artificial neural networks,” Ecol. Model., vol. 154, no. 1–2, pp. 135–150, Aug. 2002, doi: 10.1016/S0304-3800(02)00064-9.

[16] E. Borgonovo and L. Peccati, “Uncertainty and global sensitivity analysis in the evaluation of investment projects,” vol. 104.

[17] J. Qiu, G. Liu, A. Yang, K. Li, H. Zhao, and M. Qin, “Analysis on alteration of road traffic casualties in western China from multi-department data in recent decade,” Front. Public Health, vol. 10, p. 972948, Nov. 2022, doi: 10.3389/fpubh.2022.972948.

[18] Z. Wang, S. Dang, Y. Xing, Q. Li, and H. Yan, “Applying Rank Sum Ratio (RSR) to the Evaluation of Feeding Practices Behaviors, and Its Associations with Infant Health Risk in Rural Lhasa, Tibet,” Int. J. Environ. Res. Public. Health, vol. 12, no. 12, pp. 15173–15181, Dec. 2015, doi: 10.3390/ijerph121214976.

[19] C. Fu, T. Guo, Y. Sui, T. Zhu, and B. Huang, “Working condition sensitivity analysis and optimal structure parameter determination of IVT based on CFD and orthogonal experiment,” Case Stud. Therm. Eng., vol. 64, p. 105479, Dec. 2024, doi: 10.1016/j.csite.2024.105479.

[20] L.-L. Sun, D. Liu, T. Chen, and M.-T. He, “Road traffic safety: An analysis of the cross-effects of economic, road and population factors,” Chin. J. Traumatol., vol. 22, no. 5, pp. 290–295, Oct. 2019, doi: 10.1016/j.cjtee.2019.07.004.

[21] A. Paliotto, M. Meocci, A. Terrosi, and F. La Torre, “Systematic review, evaluation and comparison of different approaches for the implementation of road network safety analysis,” Heliyon, vol. 10, no. 7, p. e28391, Apr. 2024, doi: 10.1016/j.heliyon.2024.e28391.

[22] K. Bucsuházy, E. Matuchová, R. Zůvala, P. Moravcová, M. Kostíková, and R. Mikulec, “Human factors contributing to the road traffic accident occurrence,” Transp. Res. Procedia, vol. 45, pp. 555–561, 2020, doi: 10.1016/j.trpro.2020.03.057.

[23] N. Casado-Sanz, B. Guirao, and M. Attard, “Analysis of the Risk Factors Affecting the Severity of Traffic Accidents on Spanish Crosstown Roads: The Driver’s Perspective,” Sustainability, vol. 12, no. 6, p. 2237, Mar. 2020, doi: 10.3390/su12062237.

[24] “Road factors play a significant role in the occurrence of traffic accidents - Google Search.” Accessed: Mar. 17, 2025. [Online]. Available: https://www.google.com/search?client=firefox-b-d&q=Road+factors+play+a+significant+role+in+the+occurrence+of+traffic+accidents&dlnr=1&sei=9QfXZ5rtMYzf1e8PivfSmAE

[25] “https://xxgk.mot.gov.cn/jigou/glj/202107/P020210706517905491391.pdf.” Accessed: Apr. 04, 2025. [Online]. Available: https://xxgk.mot.gov.cn/jigou/glj/202107/P020210706517905491391.pdf

[26] X. Zhao, Y. Ding, Y. Yao, Y. Zhang, C. Bi, and Y. Su, “A multinomial logit model: Safety risk analysis of interchange area based on aggregate driving behavior data,” J. Safety Res., vol. 80, pp. 27–38, Feb. 2022, doi: 10.1016/j.jsr.2021.11.002.

[27] H. Mohammed, “THE INFLUENCE OF ROAD GEOMETRIC DESIGN ELEMENTS ON HIGHWAY SAFETY,” vol. 4, no. 4.

[28] L. Wang, “Safety Evaluation for Highway Geometric Design Based on Spatial Path Properties,” J. Adv. Transp., vol. 2023, pp. 1–14, Sep. 2023, doi: 10.1155/2023/6685010.

[29] D. Jima and T. Sipos, “The Impact of Road Geometric Formation on Traffic Crash and Its Severity Level,” Sustainability, vol. 14, no. 14, p. 8475, Jul. 2022, doi: 10.3390/su14148475.

[30] B. E. Horn and A. Hh. Jansson, “TRAFFIC SAFETY AND ENVIRONMENT,” IATSS Res., vol. 24, no. 1, pp. 21–29, 2000, doi: 10.1016/S0386-1112(14)60014-5.

[31] A. Lobo, S. Ferreira, I. Iglesias, and A. Couto, “Urban Road Crashes and Weather Conditions: Untangling the Effects,” Sustainability, vol. 11, no. 11, p. 3176, Jun. 2019, doi: 10.3390/su11113176.

[32] A. Sheykhfard, F. Haghighi, S. Saeidi, M. SafariTaherkhani, and S. Das, “Understanding the influence of environmental factors on driver speed: A structural equation modeling analysis,” IATSS Res., vol. 48, no. 3, pp. 427–439, Oct. 2024, doi: 10.1016/j.iatssr.2024.08.001.

[33] K. B. Lankarani, S. T. Heydari, M. R. Aghabeigi, G. Moafian, A. Hoseinzadeh, and M. Vossoughi, “The impact of environmental factors on traffic accidents in Iran,” J. Inj.

Violence Res., vol. 6, no. 2, Jul. 2014, doi: 10.5249/jivr.v6i2.318.

[34] S. Das, S. Barua, and A. Hossain, “Unraveling the complex relationship between weather conditions and traffic safety,” J. Transp. Saf. Secur., pp. 1–40, Dec. 2024, doi: 10.1080/19439962.2024.2435307.

[35] Y. Chen, Y. Tian, Z. Ouyang, and J. Zhu, “Influence of road environmental factors on traffic accidents involving vulnerable road users through negative binomial models,” PLOS ONE, vol. 20, no. 2, p. e0317601, Feb. 2025, doi: 10.1371/journal.pone.0317601.

[36] Y. Liu et al., “Social and environmental risk factors for road traffic injuries among children under five in rural China,” Medicine (Baltimore), vol. 99, no. 17, p. e19825, Apr. 2020, doi: 10.1097/MD.0000000000019825.

[37] J. S. Ji et al., “China’s public health initiatives for climate change adaptation,” Lancet Reg. Health - West. Pac., vol. 40, p. 100965, Nov. 2023, doi: 10.1016/j.lanwpc.2023.100965.

[38] W. Kriswardhana, B. Toaza, D. Esztergár-Kiss, and S. Duleba, “Analytic hierarchy process in transportation decision-making: A two-staged review on the themes and trends of two decades,” Expert Syst. Appl., vol. 261, p. 125491, Feb. 2025, doi: 10.1016/j.eswa.2024.125491.

[39] T. L. Saaty, “The analytic hierarchy process (AHP),” J. Oper. Res. Soc., vol. 41, no. 11, pp. 1073–1076, 1980.

[40] T. L. Saaty, “How to make a decision: The analytic hierarchy process,” Eur. J. Oper. Res., vol. 48, no. 1, pp. 9–26, Sep. 1990, doi: 10.1016/0377-2217(90)90057-I.

[41] R. W. Saaty, “The analytic hierarchy process—what it is and how it is used,” Math. Model., vol. 9, no. 3–5, pp. 161–176, 1987, doi: 10.1016/0270-0255(87)90473-8.

[42] K. P. Yoon and C.-L. Hwang, Multiple Attribute Decision Making: An Introduction. SAGE Publications, 1995.

[43] C. Zhao et al., “Evaluation of Laboratory Management Based on a Combination of TOPSIS and RSR Methods: A Study in 7 Provincial Laboratories of China,” Front. Public Health, vol. 10, p. 883551, Jul. 2022, doi: 10.3389/fpubh.2022.883551.

[44] Minxue Shen, “[Weighted TOPSIS method and weighted RSR method in the construction of drug supervision and supply networks in rural areas of Hunan] | Request PDF,” ResearchGate, Oct. 2024, Accessed: Mar. 20, 2025. [Online]. Available: https://www.researchgate.net/publication/236097019_Weighted_TOPSIS_method_and_weighted_RSR_method_in_the_construction_of_drug_supervision_and_supply_networks_in_rural_areas_of_Hunan

[45] J. Liu, Z. Du, L. Ma, and C. Liu, “Identification and Assessment of Subway Construction Risk: An Integration of AHP and Experts Grading Method,” Adv. Civ. Eng., vol. 2021, no. 1, p. 6661099, Jan. 2021, doi: 10.1155/2021/6661099.

[46] “Occupational safety and health risk assessment methodologies - OSHwiki | European Agency for Safety and Health at Work.” Accessed: Mar. 20, 2025. [Online]. Available: https://oshwiki.osha.europa.eu/en/themes/occupational-safety-and-health-risk-assessment-methodologies?utm_source=chatgpt.com

[47] D. Wikoff, R. J. Lewis, N. Erraguntla, A. Franzen, and J. Foreman, “Facilitation of risk assessment with evidence-based methods – A framework for use of systematic mapping and systematic reviews in determining hazard, developing toxicity values, and characterizing uncertainty,” Regul. Toxicol. Pharmacol., vol. 118, p. 104790, Dec. 2020, doi: 10.1016/j.yrtph.2020.104790.

[48] G. Peng, L. Han, Z. Liu, Y. Guo, J. Yan, and X. Jia, “An Application of Fuzzy Analytic Hierarchy Process in Risk Evaluation Model,” Front. Psychol., vol. 12, p. 715003, Sep. 2021, doi: 10.3389/fpsyg.2021.715003.

[49] Z. Wang, S. Dang, Y. Xing, Q. Li, and H. Yan, “Applying Rank Sum Ratio (RSR) to the Evaluation of Feeding Practices Behaviors, and Its Associations with Infant Health Risk in Rural Lhasa, Tibet,” Int. J. Environ. Res. Public. Health, vol. 12, no. 12, pp. 15173–15181, Dec. 2015, doi: 10.3390/ijerph121214976.

[50] N. H. Kim, “Sensitivity Analysis,” in Encyclopedia of Aerospace Engineering, 1st ed., R. Blockley and W. Shyy, Eds., Wiley, 2010. doi: 10.1002/9780470686652.eae497.

[51] Z. Wang, C. Zhao, and W. Zhang, “Multi-objective design and optimization of squeezed branch pile based on orthogonal test,” Sci. Rep., vol. 13, no. 1, p. 22508, Dec. 2023, doi: 10.1038/s41598-023-49936-y.

[52] K.-Y. Zhou and W. R. Sheate, “EIA application in China’s expressway infrastructure: Clarifying the decision-making hierarchy,” J. Environ. Manage., vol. 92, no. 6, pp. 1471–1483, Jun. 2011, doi: 10.1016/j.jenvman.2010.12.011.