Highway Projects in Four Different Regions of China under Risk Perspective: Modeling Assessment and Management Strategies

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Abstract. This paper examines the construction risks of four highway construction projects in mainland China. The paper divides risks into two main categories, macro risks and micro risks. Macro risk is the risk that the company itself faces in the project, and micro risk is mainly the risk in the construction of the project itself. Again, the risk is divided into several aspects. First, this paper describes the background of China's highway construction, and explains the significance of studying the risk of highway construction and the purpose of this paper. Then it delves into the characteristics of each project and identifies the risks. In order to study the ranking of various types of risks, the expert scoring method is first used to score different projects. Experts are asked to give the judgment matrix of each aspect of risk. After collating the results of the expert scoring, the risk value of each risk is calculated using the fuzzy hierarchical analysis calculation model. Prior to this, the risk values were categorized into four levels, with the two most serious levels requiring special attention The empirical results of this study show that political risk has the highest average weight of 0.5196 at the macro level, while financial risk follows with 0.2336 At the micro level, uncertainty of emerging technology and resource risk with an average weight of 0.2492 and 0.2098, respectively, top the top of the list, highlighting the importance of technological innovation and resource management in project execution. Through model validation, the risk assessment method in this study shows up to 93% accuracy, proving its validity and reliability in risk assessment, and the model can also be used as a ranking tool to prioritize highway construction projects based on risk magnitude.

Keywords: construction risk, risk analysis, model analysis, highway construction, fuzzy hierarchical analysis

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1 Introduction of 4 Projects

China's expressway construction began in the late 1980s. After decades of rapid development, it has become one of the largest and most complete highway networks in the world. Since 1998, China's expressway construction has entered a phase of rapid growth. In the past five years, China has built an average of 8,000 to 9,000 km of expressways per year, with a basic compound annual growth rate of about 9% in total mileage. As of 2021, China's total highway mileage has exceeded 160,000 kilometers, ranking first in the world." During the 13th Five-Year Plan period, China enters a new era of public infrastructure construction, with highway projects entering a period of large-scale construction. During this period, more advanced tools for risk assessment are needed. This is relevant to improve risk decision making in enterprises and projects, reduce accidents, and prevent worker fatalities and property damage.[1]

For this reason, the article selected four highway projects as the subject of risk management investigation, and by using hierarchical analysis to study in depth the degree of influence of macro and micro risks in the project operation process, and based on the results obtained from the study to provide corresponding risk management measures for other highway construction companies, the following is the overall overview for the four highway construction projects.

1.1 JQ Highway Expansion Project

The JQ Highway Expansion Project is located in Shandong Province, starting from Qingdao, and is an important hub connecting cities in the east and west of Shandong. The JQ Highway passes through 17 cities in the central and western part of Shandong Province, with a total length of about 309.172 kilometers. The highway was originally a standard two-way four-lane road with a designed and planned travel speed of about 120 km/h. [1] On the political side, there is the risk of uncertainty in the approval procedures. The construction of the project requires the supervision of relevant functional departments. On the economic side, there are not enough funds. The funds of the project-related units will be jointly used as the source of funding for the construction of the project. Insufficient funds of any subject or link will certainly directly affect the liquidity of project funds, resulting in risky results such as project stoppage and schedule delay. In terms of natural risks, the area where the JQ Highway renovation and expansion project is located has a high probability of heavy rainfall every summer, which will cause flooding and affect the normal construction of the project. From the technical aspect, there is a design risk. Under the combined influence of tight schedule, material shortage and program changes, the content of the project design process is often modified, resulting in the procurement plan not being determined in time, which also adversely affects the subsequent construction and trial operation.

Politically, uncertainties in approval procedures and regulatory oversight pose a risk to timely progression. Economically, inadequate funding, crucial for the project's diverse stakeholders, threatens liquidity, potentially halting construction and delaying schedules. Natural hazards, notably recurrent summer downpours leading to floods, disrupt construction activities. Technologically, the project grapples with design modifications necessitated by schedule constraints, material scarcity, and evolving plans, which hamper timely procurement and undermine construction efficiency and testing phases. These interconnected risks underscore the necessity for meticulous planning and adaptive risk management strategies to ensure the project's successful execution.

1.2 LH Highway Construction Project

The starting point of LH highway is docked with Lugu highway and the ending point is docked with Xipan highway. The total length of the main line is about 69.9 km, which is an important traffic artery in Liangshan Prefecture, Sichuan Province. The project is being carried out against the backdrop of the resumption of construction due to the epidemic. [2] The political risk of the highway construction in Liangshan Prefecture under the resumption of work due to the epidemic is mainly reflected in the government's intervention in the construction of the project, which requires all-out measures to prevent the epidemic. Due to the high flow of people and goods at the construction site, all personnel must be regularly quarantined and tested. The implementation of this policy led to several suspensions of the construction period and increased construction costs. At the construction level, less than 50% of migrant workers and construction workers from construction units returned to the construction site after resuming work due to the impact of the new crown epidemic. LH highway construction site faced a crisis of mass suspension of work. At the same time, migrant workers and construction workers returning from across the country may be carrying the virus, which could pose a significant threat to the project. The LH highway construction project faces serious economic risks. For example, raw material prices have soared, wages have risen due to staff shortages, and many constructions equipment cannot be supplied in a timely manner, which has led to higher unit prices for construction equipment rentals. Due to insufficient cash flow from suppliers, short-term supply capacity was unable to meet site demand, resulting in delays in site installation works. In terms of natural risks, the LH Highway is located in an area with a high incidence of landslides and geological subsidence areas, thus the natural risk level of the project is high.

Firstly, stringent government interventions for epidemic prevention, mandating regular quarantines and tests amidst high traffic, have disrupted timelines and escalated costs. With only half of the workforce returning post-lockdown, work suspensions loom large, compounded by the potential viral transmission risk from returning workers. Economically, soaring material costs, wage hikes due to labor scarcity, and delayed equipment provisions escalate rental expenses, while cash flow inadequacies from suppliers hinder timely installations. Naturally, the region's susceptibility to landslides and geological instability escalates project risks significantly. Collectively, these factors necessitate vigilant risk management to safeguard the project's progress.

1.3 SD Highway Construction Works

The SD highway is a major north-south highway in the southern part of China's GanZhou region and provides a great deal of help in transporting these areas as it connects to the GuiXin, KangDa and XiaLong highways with a large road planning. It is much more difficult to build than a normal road because of the proximity to streams and rivers and the number of ditches, which can cause significant changes in the water level of the road when rainfall occurs. Due to the hilly terrain in the construction area of the SD Highway, the topography is complex, and the slope of the highway rises gradually from north to south, with the lowest elevation being about 200 meters and the highest being about 300 meters [3]. A large area of the construction section is covered by the accumulated soil of the mountain, therefore, during the construction process, it is necessary to cut and fill a large amount of earth to make the slope angle of the road meet the construction requirements. The environmental risk of this project is high. Due to the large amount of geological works, large-scale cutting and filling are required, and the construction is susceptible to weather and environmental im-pacts. Secondly, the cultural risk is prominent, which requires coordination of eco-nomic disputes and cultural disputes between the construction party and local government and surrounding residents in construction. The quality risk of the project, due to the large scale of construction of this project, involves a lot of technical work in different fields, which requires advance planning of the construction sequence and good monitoring during the construction process to ensure that the quality of the project meets expectations. Besides, the SD highway project is accompanied by great technical risks in the difficult construction of bridges and tunnels, which may have a significant impact on the progress of the whole project.

Because the elevations ranging from 200 to 300 meters and extensive earthmoving necessities, environmental risks escalate due to extensive excavation and filling activities that are sensitive to weather fluctuations. Moreover, cultural sensitivities compound the risk landscape, necessitating delicate negotiations between constructors, local authorities, and residents to mitigate economic and cultural frictions. Quality assurance is paramount given the project's vast scale, involving intricate multidisciplinary engineering that demands meticulous planning and vigilant oversight to uphold standards. Furthermore, the ambitious bridge and tunnel constructions introduce substantial technical risks, threatening to impede the project timeline significantly. Hence, the SD Highway venture must navigate a precarious balance of environmental, cultural, quality, and technical risks, requiring robust management strategies to ensure successful delivery.

1.4 SY Highway Construction Project

The SY highway reconstruction project is located in the northern area of L. The previous generation of the highway was built in 1974, with a total length of 41.79 km, and is a major traffic route between L and the surrounding counties. over the past 40 years, the old SY highway has made a great contribution to the economic development and town construction of the city. Due to the gradual increase of passing vehicles and the negative impact of the surrounding factories on the road, the asphalt layer of the road surface has cracked and spalled extensively, resulting in a serious deterioration of the performance of the SY road, which eventually could not meet the mutual traffic between the towns [4]. In recent years, the local government decided to renovate the SY road in order to enhance the development of the town. According to the specific situation of this project, the reconstruction of SY road will cause long time travel disturbance to the surrounding residents, and the large engineering equipment used in the construction will have a certain negative impact on the normal life of the residents, thus bringing a certain cultural risk to this project. The pollution of water and air during the operation of the project, as well as the interference of the noise from the construction environment to the surrounding residents, will bring certain environmental and cultural risks to the SY project. There are also technical and safety risks during the operation of the project. As there are many safety hazards in the previous generation of highway, it will bring certain technical problems to the construction team, which may threaten the lives of the construction workers.

This renovation, however, introduces a suite of challenges. Prolonged disruptions to local residents' mobility and disturbances from heavy machinery operation pose cultural risks, impacting community life. Environmental concerns arise from potential pollution of water and air resources, alongside noise intrusion affecting residents' wellbeing. Technical and safety risks loom large, given the inherited highway's numerous hazards, presenting intricate challenges to the construction crew and jeopardizing worker safety. Thus, the SY project must carefully navigate these environmental, cultural, technical, and safety risks to ensure a successful and sustainable upgrade. [5]

2 The Nature of Risks in Highway Projects

Within each phase of road construction, there is a need for significant capital investment and a long construction cycle. These stages include advanced planning, design, tendering, construction, monitoring, acceptance and maintenance of the road after completion of construction, all of which require the sufficient investment of cost, time and manpower to make the project run smoothly. The construction of roads covers a large area of land and requires not only adequate construction technology, construction equipment and technical personnel but also the cooperation of various departments to improve efficiency. As sufficient funds are required at each stage of the construction process to support the smooth running of the project, it is necessary to strengthen the risks management of the project to keep the construction processes smoothly.

2.1 Establishment of the Risk Hierarchy

The model used in this paper is the fuzzy analytic hierarchy process (FAHP), which is a method that combines qualitative and quantitative analysis. The FAHP is particularly suitable for dealing with complex decision-making problems with uncertainty or subjective judgment, and is usually used to measure, sort, rank and evaluate decision choices. The FAHP combines the analytic hierarchy process and fuzzy set theory, which allows uncertainty or ambiguity to be handled in the evaluation process.[6]

Among them, the analytic hierarchy process (AHP) has been widely used to solve multi-criteria decision-making (MCDM) problems in practical situations, that is, decision-making problems involving multiple conflicting criteria or goals. The AHP method estimates the criterion weights through pairwise comparisons. It is a reliable method for mathematically converting the decision maker's judgment into numerical results. From top to bottom, they are the target layer, the criterion layer, and the solution layer, as shown in Figure 1.[7][8]

Fuzzy logic (FL) is one of the tools used to develop artificial intelligence (AI) systems. FL is a reasoning method that imitates human cognition by capturing intermediate possibilities between numerical values. Fuzzy logic solves many problems of dealing with imprecise and uncertain data. Fuzzy logic allows some rules to contain very complex problems. Like other AI methods, it has some advantages over the AHP and other MCDM methods in uncertain, imprecise, and ambiguous contexts; it is similar to human judgment.

Merging the strengths of fuzzy methods with AHP is one way to overcome the limitations of the AHP. Fuzzy AHP allows decision makers to evaluate their preferences within reasonable time intervals. These intervals produce a fuzzy judgment matrix that corresponds to the rigid-valued judgment matrix of the classical AHP [6][15].

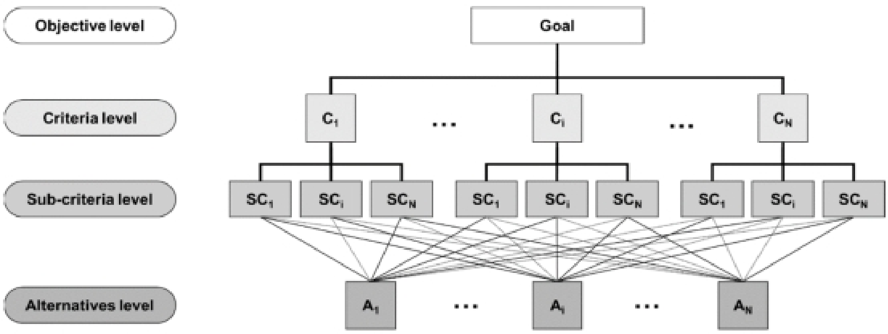

Fig. 1. Structural diagram of hierarchical analysis method

The main objective of the way in which the hierarchical analysis is applied in this report is to construct a set of risk indicators to make a detailed classification of the macro and micro risks present in the four Chinese highway construction projects according to the risk classification of road construction projects discussed above, and then to judge the rank order of each risk from the questionnaires filled out by experts and to quantify the risk level, and finally, by comparing the overall risk of the four projects This gives management a deeper understanding of the overall risk of each project. Table 1 and Fig. 2 provide a macro and micro analysis of the potential risks in each of the four projects.[9][10]

In the highway construction project, macro risks mainly include financial risks, political risks, market risks and cultural risks. Financial risk mainly refers to the impact of financial market instability, cost shortage and interest rate fluctuations on road construction projects; political risk mainly refers to the impact of instability of political environment on road construction projects; market risk mainly refers to the impact of market demand and competition on road construction projects; cultural risk mainly refers to the impact of cultural differences on road construction projects. [11] In order to reduce macro risks, investors and managers need to carefully consider these risks and take appropriate risk management measures to ensure the smooth implementation and successful completion of the project.[12][13][14]

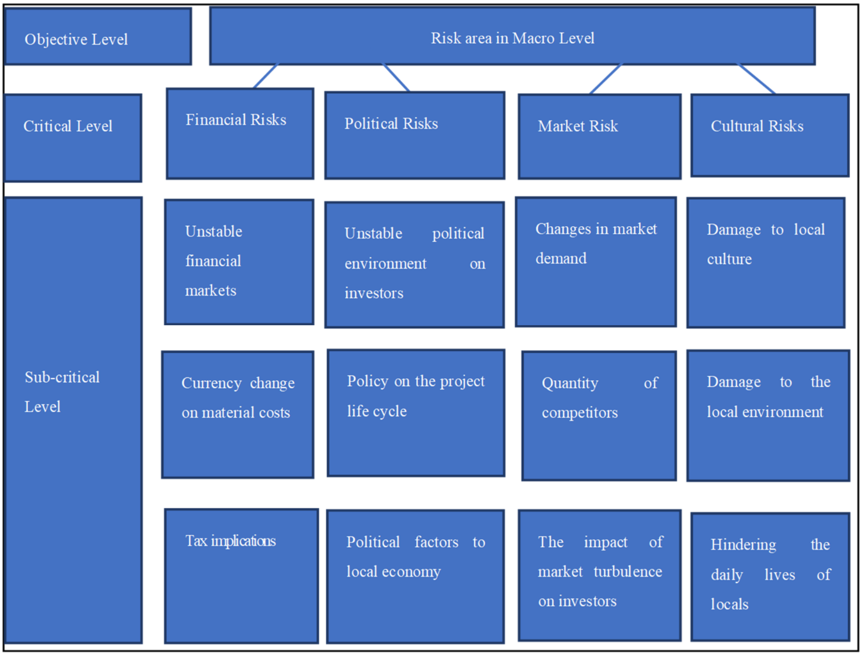

Fig. 2. Risk area in Macro Level

Table 1. Risk area in Micro Level

Sub-critical Level	Critical Level	Objective Level	Critical Level	Sub-critical Level
Inadequate management of finance Embezzlement of project finance Gaps in the engineering budget	Risk of financial management	Risk area in Micro Level	Project quality risk	Use of low-quality or substandard materials Flawed design solutions Inappropriate acceptance criteria
Consumes a lot of energy and resources Excessive carbon emissions Project damage to natural ecosystem	Environment Risk		Technical risk	The technical difficulty of the project Adoption of immature technology Insufficient technical
occupational hazard Lack of proper health and safety facilities Unsafe work environment	Safty Risk		Project management risk	Inexperience of management staff Insufficient level of management Inadequate management system
Change of contract The contract has loopholes Inability of the contracting unit to perform	Contract dispute risk			

In highway construction projects, micro risks mainly include technical risks, project management risks, financial management risks, project quality risks, environmental risks, safety risks, and contract dispute risks. These risks may be caused by a variety of factors, such as technical problems, inadequate management, improper cost control, and inadequate environmental and safety management. To reduce these risks, effective management and monitoring measures are needed to ensure that projects are completed on time and to quality, and to reduce the impact on the social environment and people.

3 Methodology

3.1 Algorithm Simulation

This first step will apply the risk hierarchy shown above, where risk factors within the same hierarchy are assigned and ranked. In this study 1-9, as shown in Table 1, and its inverse will be used to develop the risk hierarchy. Matrix $A=(a_{ij}\, n*n)$, where a_{ij} represents the risk factors in the different hierarchies and n*n represents the hierarchy of the matrix, which needs to satisfy several conditions: $a_{ij}>0$; $a_{ji}=1/a_{ij}$; $a_{ii}=1$. [16].

Table 2. Scale of AHP

Scale	Definition	Explanation
1	Equally Important	Factor **i** is as important as factor **j**
3	Moderately important	Factor **i** is slightly more important than factor **j**
5	Highly important	Factor **i** is more important than factor **j**
7	Very Highly important	Factor **i** is very important than factor **j**
9	Extremely important	Factor **i** is highest important than factor **j**
2, 4, 6, 8	Intermediate value	The scale between the above two elements
Inverse	Opposite of the meaning with the above scales	Comparison scale of element **j** with element **i**

$$A = \begin{bmatrix} \frac{W_1}{W_1} & \cdots & \frac{W_1}{W_n} \\ \cdots & \cdots & \cdots \\ \frac{W_n}{W_1} & \cdots & \frac{W_n}{W_n} \end{bmatrix}$$

A is the judgement matrix and W represents the risk factors in the same stratum. Expanding the content of the operations of matrix A gives the following algorithm in Table 3.

Table 3. Expanding the content of the matrix, A

A	a_1	a_2	...	a_n
a_1	1	a_{12}	...	a_{1n}
a_2	$1/a_{12}$	1	...	a_{2n}
...	...	...	...	...
a_n	$1/a_{1n}$	$1/a_{2n}$	...	1

The second step is calculating the eigenvectors by comparing the importance of any two risk factors can be obtained from the above matrix. The weighting relationship between different risk factors can be quantified by calculating the eigenvectors, and the quantification process mainly consists of the following.

$$\begin{cases} Mi = \prod_{j=1}^{n} a_{ij} & (i = 1,2\ldots n) \\ \overline{W_i} = \sqrt[n]{M_i} & (i = 1,2\ldots n) \\ W_i = \overline{W_i} / \sum_{i=1}^{n} W_i & (i = 1,2\ldots n) \\ W = (W_1, W_1 \ldots W_n)^T \end{cases}$$

M_i is the result of the risk factors after quantification; W_i scales the resulting quantification results so that the importance ratio between the risk factors is <1; and W is the quantified result of the eigenvectors of this matrix.

The third step is testing consistency to determine the validity of the matrix so that the final calculated results are accurate. The formulae included in the consistency test include.

$$\begin{cases} \lambda_{max} = \sum_{i=1}^{n} \frac{(AW)_I}{nW_I} \\ CI = \frac{\lambda_{max} - n}{n-1} \\ CR = \frac{CI}{RI} \end{cases}$$

Where λmax denotes the maximum value of the feature vector, CI denotes the consistency index parameter, RI (random consistency index) denotes the random consistency index shown in Table 4; CR denotes the consistency ratio, and when CR < 0.1, the matrix is proved to have validity and normal logical relationship [12].

Table 4. RI value

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.52	0.89	0.12	1.24	1.32	1.41	1.46

3.2 Expert Assessment of Risks

When conducting risk assessment studies, especially when using the fuzzy ana-lytic hierarchy process (FAHP), the selection of appropriate experts and the quantification of their inputs are key steps to ensure the validity and credibility of the analysis. First, the qualifications and experience that the experts should have should be clarified based on the research topic and the required expertise. In the risk assessment of highway construction projects, the ideal expert should have extensive practical experience in related fields such as engineering management, project implementation, and risk control. Second, ensure that the expert team includes members from different backgrounds, such as academia, government departments, construction units, consulting agencies, etc., to obtain a comprehensive and diverse perspective. Potential experts can be nominated through academic networks, professional associations, project history records, etc., and then screened through resume review, peer recommendation, etc. to ensure the authority and representativeness of each expert.

The assessment model verifies the consistency of expert judgment by sending questionnaires to 50 experts in China and Malaysia, collecting expert scoring data, and applying consistency tests (calculation of CI and CR values). If the CR value is less than the preset threshold (usually 0.1), the expert judgment matrix is considered to be consistent and the next step of analysis can be continued. If the consistency test fails, the expert can communicate with to discuss the reasons for the inconsistency, and some comparisons may need to be readjusted until a satisfactory level of consensus is reached.

Each questionnaire consists of three parts: first, information about the expert's unit, address and contact information; second, effect score information, using the scale shown in Table 2; pairwise comparison matrix information. Each risk factor (field) needs to be compared with other risk factors (fields) to form a pairwise com-parison matrix of risk fields and their subfields. Third, Tables 4 and 5 are used to evaluate the factors affecting highway construction risks from 1 to 5 levels.

Below are the evaluation results of sub-critical level risks of four projects, and the risk hazard level (very light; light; medium; heavy; very heavy) and probability of occurrence (very low; low; medium; high; very high) are statistically analyzed. Frequency P and hazard level C are indicators of the possibility and degree of risk occurrence, and are divided into 5 levels, as shown in Tables 5 and 6.

Table 5. Risk probability classification

Level	Likelihood	Range	Value
1	Very High	$4.0 < P < 5.0$	5
2	High	$3.0 < P < 4.0$	4
3	Moderate	$2.0 < P < 3.0$	3
4	Low	$1.0 < P < 2.0$	2
5	Very Low	$0 < P < 1.0$	1

Table 6. Hazard degree classification

Level	Likelihood	Range	Value
1	Very Heavy	$4.0 < C < 5.0$	5
2	Heavy	$3.0 < C < 4.0$	4
3	Moderate	$2.0 < C < 3.0$	3
4	Light	$1.0 < C < 2.0$	2
5	Very Light	$0 < C < 1.0$	1

According to the probability of occurrence of project construction risk and the level of loss, the project risk level is divided into four levels, and the risk classification matrix is established, as shown in Table 7.

Table 7. Risk classification matrix

		1	2	3	4	5
		Catastrophic	Major	Moderate	Minor	Insignificant
1	Certain	Level I	Level I	Level II	Level II	Level III
2	Likely	Level I	Level II	Level II	Level III	Level III
3	Moderate	Level I	Level II	Level III	Level III	Level IV
4	Unlikely	Level II	Level III	Level III	Level IV	Level IV
5	Rare	Level III	Level III	Level IV	Level IV	Level IV

Project risk includes the probability of occurrence of risk and the level of loss, therefore, the valuation of the probability of occurrence of risk is multiplied by the standard valuation of the possible loss to the project if this risk occurs, using $R=P*C$ where P represents the probability of occurrence of the risk factor and C represents the severity of the occurrence of the risk. Among them, each level of risk has different response measures and corresponding response departments, as shown in Table 8.

Table 8. Valuation and response plan of each risk level

Level	Value	Acceptability
I	16 ~ 25	Unacceptable
II	10 ~ 16	Unwilling to accept
III	4 ~ 10	Acceptable
IV	1 ~ 4	Negligible

3.3 Data Collection and Arrangement

After the questionnaire was sent out, 32 valid questionnaires were collected, with a response rate of 64%. Next, through the risk index analysis of the four projects, the average value of each secondary risk of the four projects can be compared with the overall risk level of each project. The results are shown in Tables 9 and 10.

From the perspective of macro risk, the evaluation results of the secondary macro indicators of highway reconstruction projects are shown in Table 9. Among them, the risks of Tax implications, Unstable political environment on investors, the impact of market turbulence on investors, and Changes in market demand belong to Level II, that is, avoid as much as possible, and need to strengthen monitoring. The risks of the remaining risk indicators belong to Level III, which are acceptable risks and do not require key monitoring.

Table 9. The Average Risk Index Table of Macro Secondary

Category	What is the risk?	Likelihood	Severity	Risk factor (L*S=)	Priority
		1=Unlikely 5=Very likely	1=Little impact 5=Major impact		Level IV 1-4 Level III 4-10 Level II 10-16 Level I 16-25
Financial Risks	Unstable financial markets	3.265	3.050	9.958	Level III
	Currency change on material costs	3.180	2.995	9.524	Level III
	Tax implications	3.410	2.990	10.196	Level II
Political Risks	Unstable political environment on investors	3.360	3.075	10.332	Level II
	Policy on the project life cycle	3.315	3.000	9.945	Level III
	Political factors to local economy	3.275	2.925	9.579	Level III
Market Risk	Changes in market demand	3.480	2.945	10.249	Level II
	Quantity of competitors	3.130	2.980	9.327	Level III
	The impact of market turbulence on investors	3.375	3.050	10.294	Level II
Cultural Risks	Damage to local culture	3.110	2.685	8.350	Level III
	Damage to the local environment	3.200	2.795	8.944	Level III
	Hindering the daily lives of locals	3.295	3.000	9.885	Level III

Table 10. The Average Risk Index Table of Micro Secondary

Category	What is the risk?	Likelihood	Severity	Risk factor (LxS=)	Priority
		1=Unlikely 5=Very likely	1=Little impact 5=Major impact		Level IV 1-4 Level III 4-10 Level II 10-16 Level I 16-25
Project quality risk	use of low-quality or substandard materials	3.705	2.540	9.411	Level III
	flawed design solutions	3.385	2.780	9.410	Level III
	Inappropriate acceptance criteria	3.300	2.230	7.359	Level III
Technical risk	The technical difficulty of the project	3.415	3.135	10.706	Level II
	Adoption of immature technology	3.390	3.000	10.170	Level II
	Insufficient technical capabilities	3.290	2.715	8.932	Level III
Project management risk	Inexperience of management staff	3.220	2.590	8.340	Level III
	Insufficient level of management	3.335	2.595	8.654	Level III
	Inadequate management system	3.245	2.595	8.421	Level III
Risk of financial management	Inadequate management of finance	3.295	2.575	8.485	Level III
	Embezzlement of project finance	3.130	2.900	9.077	Level III
	Gaps in the engineering budget	3.280	2.670	8.758	Level III
Environmental risk	Consumes a lot of energy and resources	3.530	2.860	10.096	Level II
	Excessive carbon emissions	3.365	2.865	9.641	Level III
	Project damage to natural ecosystem	3.555	3.260	11.589	Level II
Safety risk	occupational hazard	3.285	2.850	9.362	Level III
	Lack of proper health and safety facilities	3.325	2.765	9.194	Level III

	unsafe work environment	3.205	2.735	8.766	Level III
Contract dispute risk	Change of contract amount	3.093	2.347	7.259	Level III
	The contract has loopholes	3.287	2.600	8.545	Level III
	Inability of the contracting unit to perform	3.180	2.807	8.925	Level III

From the micro risk point of view, the evaluation results of the macro secondary indicators of highway reconstruction projects are shown in Table 10. Among them, the risks of the technical difficulty of the project, Adoption of immature technology, consumes a lot of energy and resources, and Project damage to natural ecosystem belong to Level II. The risks of the remaining risk indicators belong to Level III.

4 Results of Qualitative Risks in Projects

By constructing the data obtained from the single-element fuzzy evaluation into an index matrix and then carrying out a multi-element fuzzy evaluation, the quantitative impact of multiple risk factors on the project can be obtained. The macro risk and micro risk hazard levels and hazard probability for other projects, resulting in the Table 11 and Table 12.

Table 11. Multi-element fuzzy evaluation in Macro Risks

	Macro Risks									
	Hazard Degree					**Probability**				
	Very Heavy	**Heavy**	**Moderate**	**Light**	**Very Light**	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
JQ	0.048	0.177	0.316	0.296	0.163	0.085	0.239	0.399	0.222	0.055
LH	0.022	0.059	0.272	0.470	0.177	0.095	0.225	0.390	0.249	0.042
SD	0.051	0.132	0.307	0.349	0.161	0.078	0.165	0.342	0.322	0.094
SY	0.146	0.274	0.373	0.135	0.072	0.111	0.217	0.350	0.235	0.087

Table 12. Multi-element fuzzy evaluation in Micro Risks

	Micro Risks									
	Hazard Degree					**Probability**				
	Very Heavy	**Heavy**	**Moderate**	**Light**	**Very Light**	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
JQ	0.039	0.159	0.335	0.363	0.104	0.351	0.316	0.225	0.080	0.028
LH	0.071	0.196	0.335	0.306	0.092	0.055	0.152	0.363	0.336	0.094
SD	0.023	0.112	0.300	0.400	0.164	0.108	0.286	0.349	0.204	0.054
SY	0.042	0.191	0.319	0.327	0.122	0.096	0.266	0.344	0.234	0.059

5 Analyze Based on Macro Risks Level

Based on the risks and the corresponding serial numbers in the Table 13, the macro risk index shown in Table 14 and a line graph of the macro-risk indices for the four projects was constructed as shown in the Fig. 3. The lowest risk factor ‘Currency change on material costs’, has an overall risk index of 6.505, which is more than twice the risk of SY compared to LH. The second lowest risk factor ‘Quantity of competitors’ has a composite risk index of 6.810, which is also the second highest risk for the LH project, while the SY project has a composite macro risk index of 8.055, which is less than 9.0 and is within the acceptable range.

The graph also shows that the JQ highway construction project is not the best choice for political risk and market risk, with an overall macro risk index of 9.782 that has a low-risk hazard and probability of occurrence, due to the unstable market and political environment in the region, which leads to a lack of investor interest in the project and therefore reluctance to be accepted by investors.

The overall macro-risk index for the LH project is 10.856, which is a high macro-risk project. The overall risk of the project is increased due to the development of the LH region, which has been severely affected by the epidemic, leading to a decline in the city’s economic development, and the spread of the epidemic as a result of the project being carried out.

The SD highway project has a similar overall risk index to the LH project, with the SD road construction project having a higher overall macro risk index of 10.954, mainly due to the deeper financial and political influence, which is mainly due to the poor economic conditions in these areas and the lack of required equipment and talent, while the unstable political environment leads to reduced investor interest in the construction of these areas, which may be hindered in the bidding The bidding process is hampered.

Overall, the SY highway construction project is likely to be less affected by macro risks, as the specific content of the project is the renovation of old roads, the workload is much less than other projects, and the area is located between urban and suburban areas, where the overall level of economic development is high, making it easier to carry out the project.

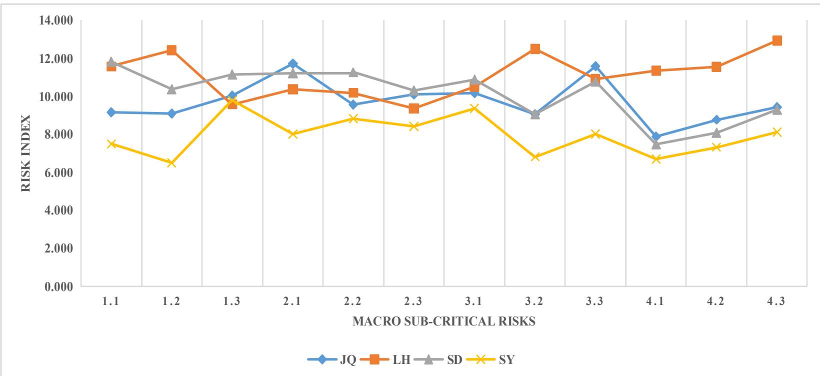

Fig. 3. Macro sub-critical risks

Table 13. Macro Sub-critical risk numbers

Macro Risks	No.	Sub-Critical Risks
	1.1	Unstable financial markets
Financial Risks	1.2	Currency change on material costs
	1.3	Tax implications
	2.1	Unstable political environment on investors
Political Risks	2.2	Policy on the project life cycle
	2.3	Political factors to local economy
	3.1	Changes in market demand
Market Risks	3.2	Quantity of competitors
	3.3	The impact of market turbulence on investors
	4.1	Damage to local culture
Cultural Risks	4.2	Damage to the local environment
	4.3	Hindering the daily lives of locals

Table 14. Macro risk Index of four projects

Macro Risk									
Critical Level	Risk Index				Sub-Critical Level	Risk Index			
	JQ	LH	SD	SY		JQ	LH	SD	SY
					1.1	9.152	11.567	11.832	7.488
1.0 Financial Risks	9.409	11.111	11.396	7.966	1.2	9.082	12.417	10.368	6.505
					1.3	10.037	9.574	11.150	9.780
					2.1	11.721	10.378	11.220	8.001
2.0 Political Risks	10.867	10.053	10.956	8.254	2.2	9.562	10.182	11.264	8.821
					2.3	10.098	9.370	10.296	8.406
					3.1	10.162	10.508	10.862	9.362
3.0 Market Risk	10.015	11.061	10.380	8.545	3.2	9.058	12.483	9.043	6.810
					3.3	11.584	10.921	10.757	8.009
					4.1	7.882	11.334	7.470	6.702
4.0 Cultural Risks	8.278	11.559	7.820	7.009	4.2	8.765	11.556	8.074	7.315
					4.3	9.429	12.934	9.296	8.118

6 Analyze Based on Micro Risks Level

Based on the micro risks corresponding serial numbers in the Table 15, the micro risk index shown in Table 16 and a line graph of the micro-risk indices for the four projects was constructed as shown in the Fig. 4. From the micro-risk perspective, it can be seen that the overall micro-risk of the JQ Highway project is lower than the other three projects, especially in the areas of engineering quality risk, project management risk, environmental risk and safety risk, where the risk index is less than 9 and is significantly lower than the other projects. However, the more prominent micro-risks of the JQ project are in the technical and financial management areas, where the risk indices for "the technical difficulty of the project" and "Embezzlement of the project The technical difficulty of the project" and "Embezzlement of the project finance" risk indices are 9.005 and 9.018 respectively, which are in the reluctance range. Overall, the micro-risk index for the JQ project is 7.167, which is low and manageable overall, making it an acceptable project.

The LH project has a much higher quantitative valuation in a number of micro-risk areas, particularly in the engineering quality risk; technical risk and environmental risk, with the highest risk indices of 12.954, 12.744 and 12.740 respectively that reaching the high-risk range. While the risk indexes in engineering management risk; financial management risk and contract dispute risk are lower, most of the risk indices are greater than 9, which is in the higher risk range. Therefore, the overall micro-risk of the LH Highway project has a risk index of 10.282, which is a high risk and is not recommended to be selected.

The SD project has a slightly lower overall micro-risk than the LH project, with the highest risk index of 12.934 under the risk of ‘Project damage to natural ecosystem’. The SD project is therefore in the higher risk range of the micro-risk profile and is not recommended for acceptance.

Finally, the SY Highway project has the highest risk index in the ‘Project damage to natural ecosystem’ risk category (12.716), and is in between the SD and JQ projects. Under the safety risk stratum, the index for each specific risk is more than 9, which is an acceptable range, but in the other safety areas, the risk index is between 9 and 12, which is a high-risk hazard. Overall, with a micro risk index of 9.537, the SY project is less risky compared to the SD and LH projects, but still not the best choice.

In summary, the JQ project has the lowest risk index among the micro-risks and is within the acceptable range of micro-risks except for some technical difficulties and financial vulnerability to corruption. The JQ project is also the most likely to be accepted out of the four projects.

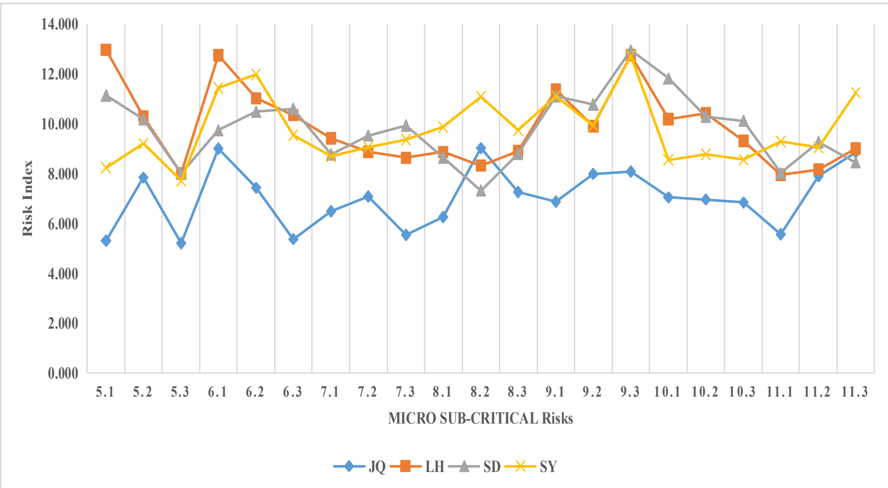

Fig. 4. Micro sub-critical risks

Table 15. Micro Sub-critical risk numbers

Micro Risks	No.	Sub-Critical Risks
5.0 Project quality risk	5.1	Use of low-quality or substandard materials
	5.2	Flawed design solutions
	5.3	Inappropriate acceptance criteria
6.0 Technical risk	6.1	The technical difficulty of the project
	6.2	Adoption of immature technology
	6.3	Insufficient technical capabilities
7.0 Project management risk	7.1	Inexperience of management staff
	7.2	Insufficient level of management
	7.3	Inadequate management system
8.0 Risk of financial management	8.1	Inadequate management of finance
	8.2	Embezzlement of project finance
	8.3	Gaps in the engineering budget
9.0 Environmental risk	9.1	Consumes a lot of energy and resources
	9.2	Excessive carbon emissions
	9.3	Project damage to natural ecosystem
10.0 Safety risk	10.1	Occupational hazard
	10.2	Lack of proper health and safety facilities
	10.3	Unsafe work environment
11.0 Contract dispute risk	11.1	Change of contract amount
	11.2	The contract has loopholes
	11.3	Inability of the contracting unit to perform

Table 16. Macro risk Index of four projects

Micro Risk									
Critical Level	Risk Index				Sub-Critical Level	Risk Index			
	JQ	LH	SD	SY		JQ	LH	SD	SY
					5.1	5.311	12.954	11.130	8.226
5.0 Project quality risk	5.743	10.938	10.088	8.253	5.2	7.835	10.292	10.173	9.194
					5.3	5.216	8.006	8.000	7.710
					6.1	9.005	12.744	9.734	11.430
6.0 Technical risk	7.854	11.917	10.055	10.995	6.2	7.426	11.016	10.478	11.970
					6.3	5.372	10.343	10.597	9.546
					7.1	6.490	9.408	8.770	8.686
7.0 Project management risk	6.504	9.177	9.104	8.869	7.2	7.085	8.874	9.523	9.053
					7.3	5.542	8.634	9.926	9.360
					8.1	6.256	8.861	8.638	9.860
8.0 Risk of financial management	7.544	8.766	8.425	10.104	8.2	9.018	8.320	7.322	11.077
					8.3	7.258	8.904	8.784	9.744
					9.1	6.880	11.356	11.100	11.098
9.0 Environmental risk	7.305	11.110	11.206	10.967	9.2	7.986	9.894	10.774	9.920
					9.3	8.071	12.740	12.934	12.716

		10.1	7.04210.17511.808 8.549
10.0 Safety risk	6.901 9.624 10.539 8.574	10.2	6.96310.41910.282 8.777
		10.3	6.839 9.315 10.110 8.556
		11.1	5.568 7.946 8.016 9.280
11.0 Contract dispute risk	8.224 8.688 8.582 10.499	11.2	7.889 8.165 9.264 9.048
		11.3	8.856 9.005 8.449 11.241

7 Conclusion & Recommendation

In conclusion, the employment of the integrated fuzzy hierarchical analysis methodology enabled the derivation of a comprehensive risk index for each of the studied highway projects, encapsulating both micro and macro risks. As depicted in Fig. 5, the calculated indices revealed JQ project's risk score at 8.475, LH at 10.574, SD at 10.494, and SY at 8.796. It is imperative for the company to favor projects with a lower risk profile; in this context, while JQ encounters heightened macro risks—owing to an unpredictable political and market milieu leading to cumbersome approval procedures, funding scarcities, and intense competition—SY project grapples with elevated micro risks, particularly concerning technical complexities and environmental challenges. These micro-risks in SY could potentially delay project completion, inflict environmental harm, and provoke public and governmental resistance.

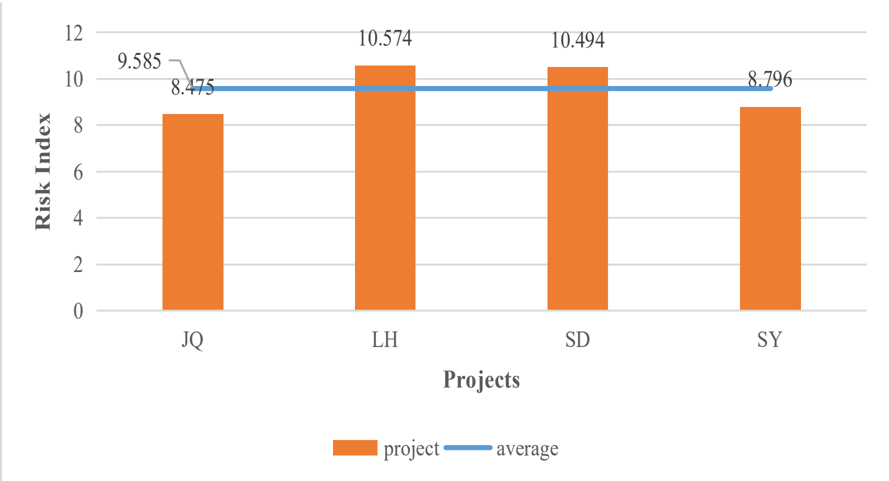

Fig. 5. Total risk indexes of 4 projects

The crux of a successful and enduring highway construction endeavor hinges on the proficient management and mitigation of both macroscopic and microscopic risks. Firms must base their decisions on a holistic evaluation of these risks vis-a-vis their developmental stage. Notably, JQ project emerges as a frontrunner in terms of overall risk metrics, warranting a meticulous reevaluation to ascertain its suitability for selection. Future research avenues could explore strategies for enhancing risk resilience in highway projects, considering the nuanced dynamics between macro and micro risks, and further refine risk assessment methodologies to better inform corporate strategies and ensure sustainable infrastructure development.

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