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Risk Analysis of Project Financing and Optimization of Engineering Construction Financing Based on Fuzzy Comprehensive Evaluation

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Keywords: Project financing risks; Fuzzy comprehensive evaluation; Analytic Hierarchy Process; Risk management framework; Optimization of Engineering Construction Financing

***Abstract*：** This study focuses on the application of fuzzy comprehensive evaluation in project financing risk analysis and engineering construction financing optimization, using large-scale highway projects as empirical evidence to construct a risk management framework. With the expansion of large-scale project investment scale, project financing has become the core means due to its characteristic of using future cash flow as the repayment source. However, its long cycle, large scale, and multiple participants lead to complex financing risks, and traditional qualitative methods are difficult to meet scientific decision-making needs. Combining literature review and case analysis, using Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) to construct a multi-level risk assessment system consisting of 2 first level, 8 second level, and 30 third level indicators, quantifying risk levels through expert scoring, identifying external (policy, market) and internal (funding, technology) risks, and proposing targeted response strategies. Result: Land acquisition and demolition, construction safety, etc. are relatively high risks, while policy adjustments and interest rate changes are general risks; Three dimensional strategy optimizes fund allocation, enhances fund flow stability, reduces financing default risk, and achieves multi-party benefit coordination among project management, investors, and government departments. Enriched the quantitative analysis methods for risk management in large-scale engineering project financing, providing a replicable practical path for optimizing engineering construction financing. In the future, it is necessary to optimize the indicator system in combination with the new situation, explore more scientific evaluation models, and further verify some viewpoints.

1. Introduction

With the accelerated advancement of global infrastructure construction, large-scale engineering projects have become an important engine for promoting economic development due to their large investment scale, long construction period, and diverse participating parties. Such projects typically rely on project financing models[1-3], with future cash flows as the core repayment source. However, their long cycle and high complexity also result in multidimensional, dynamic, and uncertain financing risks, making traditional qualitative analysis difficult to meet scientific decision-making needs. Although project financing has significant advantages in addressing funding gaps, its risk management has become a key challenge in project management due to multiple factors such as policy changes, market fluctuations, technical feasibility, and liquidity of funds.Existing research has conducted multidimensional exploration on the financing risks of engineering projects. Early scholars emphasized the impact of regional policies, project management quality[4-5], and socio-economic environment on financing risks, pointing out that risks run through the entire project lifecycle and manifest in various forms[6-8]. Subsequent research further validated the core role of macroeconomic factors such as economic environment, political stability, and labor costs through statistical analysis. Some scholars focus on the cultural, policy, and tax risks of emerging market enterprises, and propose that the existing risk management mechanisms need to adapt to the new situation. In terms of risk identification and evaluation, some studies have constructed risk systems through regression analysis or financial instruments, but they mostly focus on international projects or specific industries (such as BOT models), lacking universality. Methodologically[9-11], Analytic Hierarchy Process (AHP), Fuzzy Comprehensive Evaluation (FCE), and intelligent algorithms such as neural networks and cloud models have been applied to risk quantification, but there are limitations such as complex calculations, high data requirements, or strong subjectivity[12-14]. However, current research still faces three core issues: firstly, Western theories are difficult to directly adapt to emerging market projects due to differences in policy and legal environments; Secondly, some studies focus on theoretical models while neglecting empirical verification, especially lacking dynamic analysis combined with specific cases[15-17]; Thirdly, although complex methods such as system dynamics and grey relational analysis improve accuracy, their high operational threshold limits their practical application. Based on this, this study takes a large highway project as a case study and combines the Analytic Hierarchy Process and Fuzzy Comprehensive Evaluation Method to construct a multi-level financing risk evaluation index system (including 2 primary indicators, 8 secondary indicators, and 30 tertiary indicators). Through expert scoring and quantitative calculation[18-19], key risk factors are identified and response strategies are proposed, aiming to provide a framework that combines theoretical depth and practical feasibility for financing risk management of large engineering projects.The research contribution is reflected in three aspects: firstly, innovative methods, balancing subjective and objective analysis through the AHP-FCE combination model, and improving the accuracy and operability of risk assessment; Secondly, practice oriented, validate the effectiveness of the model through real cases[20-22], and clarify the priority of core risks such as land acquisition and demolition, construction safety, etc; Thirdly, framework optimization, proposing a comprehensive management plan covering risk identification, evaluation, and response, to help stabilize project funding flow and promote multi-party interest coordination[23-25].

2. Correlation Theory

2.1. Definition of Financing Risks for Large scale Engineering Projects

Large scale engineering projects usually refer to infrastructure projects with large investment scale, complex technology, and long implementation cycle. In practice, the total investment amount (such as over 500 million yuan) is often used as the classification standard, which has the characteristics of high efficiency variability and high financing risk. Project financing is a model in which the fund user raises funds from financial institutions by establishing a project company, using project assets as collateral and future cash flows as repayment sources. It is widely used in large-scale public facilities such as power generation facilities and highways[26-27].

As the fund user, the project investor faces financing risks that include both internal (such as construction risks, schedule risks, quality risks, safety risks) and external (such as policy changes, market fluctuations) uncertainties, which may result in impaired repayment ability. Existing research often constructs risk systems from a macro perspective, involving multidimensional factors such as financial risks, policy and regulatory risks, production risks, and market risks.

This study is based on the fuzzy comprehensive evaluation method, combined with the Analytic Hierarchy Process (AHP) to construct a multi-level risk assessment system consisting of 2 primary indicators, 8 secondary indicators, and 30 tertiary indicators. Through expert scoring and quantitative calculation, it identifies major risks such as land demolition and construction safety, as well as general risks such as policy adjustments and interest rate changes, and proposes targeted response strategies. Its advantages lie in balancing subjective and objective analysis through the AHP-FCE combination model, improving the accuracy of risk assessment; Validate the effectiveness of the model with real cases and clarify the priority of risks; Covering the full process management of risk identification, evaluation, and response, it helps to stabilize project funding flow and promote multi-party benefit coordination. Limitations include the impact of subjectivity on project specificity, the need for dynamic optimization of indicator systems in conjunction with new situations, and the operational threshold issues of complex methods in practical applications.

2.2. Identification of Financing Risk Characteristics for Large-Scale Engineering Projects

This study analyzes financing risks in large-scale engineering projects, characterized by objective universality, dynamic variability, and complex hierarchy. Risks stem from external environmental fluctuations (e.g., exchange rates, policy changes) and internal project complexity (e.g., multi-stakeholder coordination, technological integration). Utilizing fuzzy comprehensive evaluation (FCE) and analytic hierarchy process (AHP), a multi-level assessment system (2 primary, 8 secondary, 30 tertiary indicators) was constructed. Through expert scoring and quantitative analysis, major risks (e.g., land demolition, construction safety) and general risks (e.g., policy adjustments, interest rate changes) were identified, with targeted strategies proposed. The AHP-FCE model balances subjective-objective analysis, enhancing accuracy, while case validation clarifies risk priorities and supports full-cycle management. Limitations include subjectivity in project-specific contexts, the need for dynamic indicator optimization, and operational complexity in practice.

The risk management of financing for large-scale engineering projects runs through the entire life cycle of the project, covering three core links: risk identification, evaluation, and response. Risk identification adopts expert judgment method and Delphi method, and selects key risk factors through group intelligence; Risk assessment combines Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) to construct a multi-level evaluation system consisting of 2 primary indicators, 8 secondary indicators, and 30 tertiary indicators. The system is evaluated through expert scoring and weight calculation, such as the consistency test formula for judgment matrices

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{1}$$

Synthesize the fuzzy relationship matrix (B=WR) and quantify the risk level; Risk response is based on evaluation results, proposing strategies for risk avoidance, mitigation, prevention, retention, and transfer. The research results clearly indicate that land acquisition and demolition, construction safety, etc. are relatively high risks, while policy adjustments, interest rate changes, etc. are general risks, and targeted response plans should be formulated. Its advantages lie in balancing subjective and objective analysis through the AHP-FCE combination model, improving evaluation accuracy; Validate the effectiveness of the model with real cases and clarify the priority of risks; Covering the entire process management, assisting in stable capital flow and multi-party benefit coordination. Limitations include: subjective impact on project specificity, dynamic optimization of indicator system, and high threshold for application of complex methods.

3. Research Method

3.1. Systematic Response Strategy Framework for Major Risk Factors

To address the core risks faced in the financing process of large-scale projects, such as land acquisition and demolition, construction safety, cost overruns, project delays, and operational cost overruns, it is necessary to establish a full cycle risk control system. Specific measures include: strengthening communication and compensation transparency among villagers, enhancing project recognition through diversified publicity, optimizing construction layout to reduce disturbance to residents, and establishing a rapid compensation dispute resolution mechanism in conjunction with local governments; Implement special safety control and enhance the awareness of all staff, including expert investigation of high-risk operations in the early stage, establishment of professional safety supervision teams, setting up graded isolation areas and violation prohibition mechanisms, and regularly conducting customized safety training; Establish a budget reservation and risk transfer mechanism, transfer price fluctuation risks through fixed total price contracts, set up special emergency funds to cope with material price fluctuations, strictly control equipment and material entry acceptance, optimize construction plans to improve the first acceptance pass rate; Strengthen dynamic progress control and resource guarantee, select strong construction units and develop scientific construction plans, establish a daily progress comparison and adjustment mechanism, reserve key equipment molds in advance, introduce efficient construction equipment to shorten process time; Implement quality source control and technology cost reduction and efficiency improvement, reduce post maintenance needs through strict quality control, promote mechanized operations to reduce labor cost fluctuations, build an information management platform to achieve standardized operation and maintenance, and apply low-cost technology to optimize maintenance processes. This system forms a closed-loop management through publicity coordination, special control, cost transfer, dynamic scheduling, and technological empowerment, effectively reducing the impact of major risks on financing goals and providing a replicable risk prevention and control framework for similar projects.

3.2. Multi-dimensional Control Framework for Major Risks

To address core risks such as policy adjustments, interest rate fluctuations, design changes, and engineering quality, it is necessary to establish a response system that combines agreement constraints, dynamic adjustments, and quality control. In terms of policy risks, by strengthening the terms of government enterprise agreements and clarifying government default responsibilities, we will promote the sharing of policy change risks; The interest rate risk adopts a combination of fixed and floating interest rates, sets an upper limit on interest rate fluctuations, and relies on government coordination to stabilize financing costs for commercial banks. The risk of design changes is reduced by integrating the design procurement construction process through the EPC general contracting model, combined with multi drawing review and on-site collaboration mechanisms to minimize rework; The engineering quality risk relies on a three-level quality inspection system (team self inspection, special inspection, joint inspection) and a quality guarantee deposit system to ensure controllable quality throughout the entire cycle.

3.3. Systematic Response Strategies for Secondary Risks

In response to secondary risks such as unclear technical disclosure, quality defects, and operational errors, it is necessary to improve the responsibility traceability and capacity building mechanism. The risk of technical disclosure is addressed by establishing a document revision and re disclosure process, clarifying the responsibility of the design and construction parties for information transmission; Quality risks are reduced by prohibiting overloaded vehicles and signing force majeure exemption clauses to mitigate the impact of external factors. For general operational risks, enterprises need to cultivate specialized teams, optimize partner screening criteria, and rely on dynamic policy monitoring and joint regulatory mechanisms to achieve rapid response to market changes and collaborative resolution of potential problems. This framework covers multiple dimensions such as technology, quality, and collaborative management, providing a practical path for achieving financing goals.

4. Results and Discussion

4.1. Risk assessment of coastal BOT cross sea high-speed financing based on AHP-FCE model

In order to promote regional economic integration and alleviate the problem of uneven development between new and old urban areas, a coastal city plans to construct a BOT model highway project that connects the two urban areas across the sea. The franchise period of the project is 30 years (construction period of 3 years, operation period of 27 years), and the private partner is responsible for investment, construction, and operation. The revenue is realized through a return mechanism combining operating income (including vehicle tolls, advertising revenue) and feasibility gap subsidies, and a traffic flow guarantee (80% of the feasibility study forecast) and a 1:1 sharing mechanism for excess revenue are set. The project design has a total length of 12.226km, with six lanes in both directions, including complex projects such as super large bridges and interchanges. It involves large-scale land occupation (1038.14 acres of sea area and 442.11 acres of land area) and demolition (57722m ^{2}), with high technical standards. The construction content covers bridge (prefabricated pier caps and piers), roadbed (mechanized construction+drainage protection), and pavement (asphalt concrete mechanized paving) engineering. The geographical location connects the old and new urban areas, with abundant rainfall along the coast but stable seabed and low wind and waves. The supply of building materials (granite, sand and gravel) is sufficient, and the transportation system is mature.

The total investment is approximately 11.483 billion yuan, with a financing structure of 80% bank loans (9.186 billion yuan, interest rate of 4.05%)+20% self owned funds. The private party has obtained an AA+credit rating and has cooperated with Construction Bank and others to set up a 1 billion yuan credit line to cope with loan delays. The financing cost is calculated based on the actual cost rate. The risk management adopts the AHP-FCE model to construct a two-level indicator system that includes external environmental risks (political, economic, natural, social) and internal risks (project pre stage, construction period, acceptance period, operation period, handover period), further refining three-level risk indicators such as policy adjustments, interest rate changes, land acquisition and demolition, and construction safety. By using expert scoring and weight calculation to synthesize a fuzzy relationship matrix (B=WR), quantifying risk levels, identifying core risks, and proposing response strategies. In the evaluation process, the first level risk factor set U is defined as {U1, U2} (external risk U1, internal risk U2), the second level factor set includes external environmental risk U1={U11, U12, U13, U14} (political U11, economic U12, natural U13, social U14) and internal risk U2={U21, U22, U23, U24} (project pre stage U21, construction period U22, operation period U23, handover period U24), and the third level factor set covers specific indicators such as geological environment, land acquisition and demolition, and construction safety. The risk evaluation set is divided into five levels: high risk (extremely high probability of occurrence), high risk (high probability of occurrence), moderate risk (average probability of occurrence), low risk (low probability of occurrence), and low risk (unlikely to occur), represented by V={V1, V2, V3, V4, V5}. The project standard cross-sectional diagram shows a two-way six lane design that balances functionality and safety.

4.2. Model Experiment

This study uses Analytic Hierarchy Process (AHP) combined with Delphi method to construct a financing risk weight calculation model. Through multiple rounds of expert scoring and consistency testing, the relative importance of each risk indicator to project financing is quantified. The process of model construction is as follows: Firstly, based on the risk assessment index system (including 2 primary indicators, 8 secondary indicators, and 30 tertiary indicators), an expert team composed of project managers, university professors, etc. is organized to obtain the "1-9 proportional scale" scores of pairwise comparisons of each indicator through anonymous questionnaires. After 3 rounds of iterative correction, a unified judgment matrix is formed (as shown in Tables 1 and 2)

Table 1. Internal Risk U2 Judgment Matrix Data Table

Risk Indicator	Project Pre-construction Risk U21	Project Construction Period Risk U22	Project Acceptance Period Risk U23	Project Operation Period Risk U24	Project Handover Period Risk U25
Project Pre-construction Risk U21	1	1/4	1/2	1/3	1/2
Project Construction Period Risk U22	4	1	3	2	3
Project Acceptance Period Risk U23	2	1/3	1	1/2	1
Project Operation Period Risk U24	3	1/2	2	1	2
Project Handover Period Risk U25	2	1/3	1	-	-

Table 2 Risk U24 Judgment Matrix during Project Operation Period

Risk Indicator	Construction Management Risk U221	Construction Safety Risk U222	Engineering Quality Risk U223	Construction Cost Overrun Risk U224	Construction Schedule Delay Risk U225	Construction Environment Risk U226	Technical Risk U227	Technical Clarification Risk U228

Construction Management Risk U221	1	1/3	1/2	1/3	1/5	2	2	2
Construction Safety Risk U222	3	1	2	1	1/2	5	5	5
Engineering Quality Risk U223	2	1/2	1	1/2	1/3	3	3	3
Construction Cost Overrun Risk U224	3	1	2	1	1/2	5	5	5
Construction Schedule Delay Risk U225	5	2	3	2	1	7	7	7
Construction Environment Risk U226	1/2	1/5	1/3	1/5	1/7	1	1	1
Technical Risk U227	1/2	1/5	1/3	1/5	1/7	1	1	1
Technical Clarification Risk U228	1/2	1/5	1/3	1/5	1/7	1	1	1

For example, in the first level risk assessment matrix, the relative importance ratio of external risk (U1) to internal risk (U2) is 1:3, and the normalized weight is 0.2:0.8 (formula W=(0.2000, 0.8000)). The weight calculation adopts normalization processing and eigenvalue method. For each judgment matrix A, the normalized vector W and the maximum eigenvalue are calculated, and the validity of the results is verified through consistency index and random consistency ratio (as shown in Figure 1)

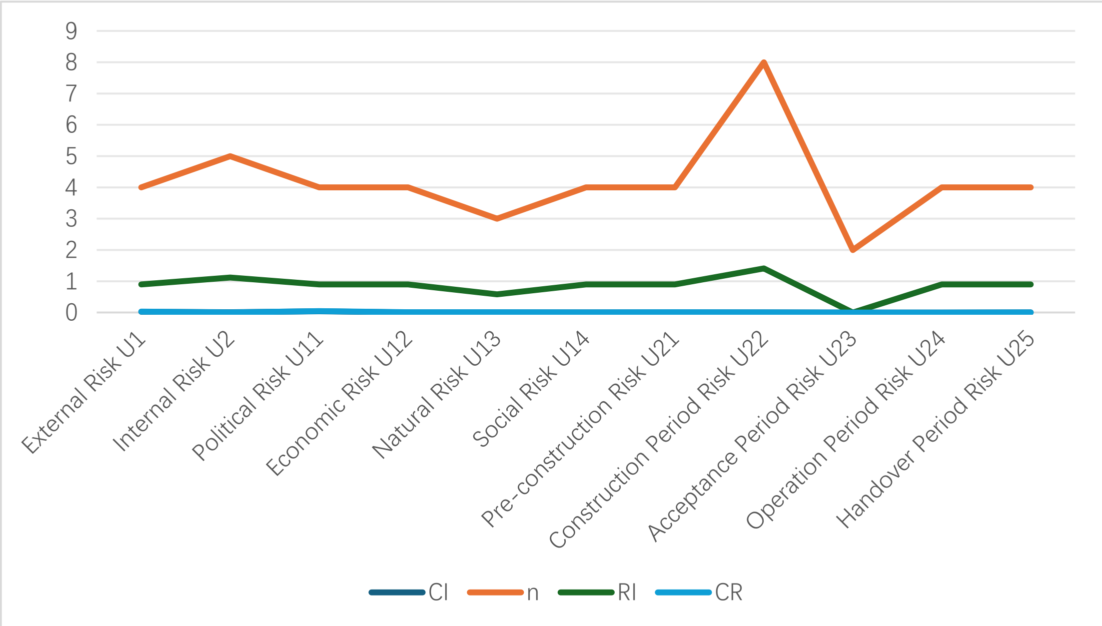

Figure 1. Consistency check results of risk assessment matrix

For example, the normalized weight of the judgment matrix for external risk (U1) is W1=(0.0626, 0.3093, 0.1362, 0.4919), corresponding to, CR=0.0295<0.1， Through consistency testing. Finally, the weighted summary of risk weights at each level shows that internal risk (U2) is the dominant factor with a weight of 0.8, followed by the risk of construction period exceeding the deadline (U225) with a weight of 0.319 and the risk of construction cost overruns (U224) with a weight of 0.1926, indicating that project construction period risk is the core focus. Traditional AHP often relies on a single round of expert scoring, which is subjective. However, this study uses the Delphi method for multiple rounds of correction (3 iterations), combined with statistical feedback to adjust expert scoring, to improve the consistency of the judgment matrix (such as the CR=0.0074 for internal risk U2, far below the threshold of 0.1), and pays more attention to the convergence of expert opinions. Some studies have introduced fuzzy AHP or ANP (Network Analysis Method) to handle the dependency relationship between indicators, but the computational complexity has significantly increased. This study adopts classical AHP to achieve a balance between operability and accuracy, which is suitable for scenarios where new engineering data is lacking. The "combination weight method" (subjective AHP+objective entropy weight method) proposed in the literature is more objective, but it requires a large amount of historical data support, and this model has lower dependence on data. The limitation lies in the individual experience differences in expert scoring. In the future, BIM technology can be used to dynamically adjust the judgment matrix based on real-time collection of construction parameters (such as schedule and cost consumption), or interval AHP can be introduced to handle the uncertainty of expert judgment, further improving the objectivity of weight calculation. In summary, the model effectively quantifies the relative importance of financing risks in large-scale engineering projects through multiple rounds of Delphi correction and strict consistency testing, providing key inputs for subsequent fuzzy comprehensive evaluation and a reusable method framework for calculating risk weights in similar projects.

4.3. Effect Analysis

This study constructed a large-scale engineering project financing risk assessment model based on fuzzy comprehensive evaluation method, quantifying the risk level through a three-level fuzzy evaluation system, and providing data support for investment decision-making. The model calculation process follows the following framework: the three-level fuzzy evaluation adopts the expert scoring method to obtain the membership vector. The formula is: 10 experts (including project managers, university professors, etc.) score 30 three-level risk indicators such as policy adjustments and construction safety to form a membership matrix. For example, the membership vector of a certain land acquisition and demolition risk is (0.1, 0.4, 0.3, 0.2, 0), corresponding to a probability of 0.4 for "higher risk"; The membership vector of construction safety risk is (0.1, 0.3, 0.2, 0.2, 0.2), and the maximum value of 0.3 corresponds to "general risk". The weight vector determined by the two-level fuzzy evaluation combined with the Analytic Hierarchy Process (AHP) and the results of the three-level evaluation are used to calculate the comprehensive evaluation vector of the two-level risk. The formula is $B=W \times R$, where W is the weight vector and R is the membership matrix. For example, the weight vector of external risk is (0.0626, 0.3093, 0.1362, 0.4919), and its fuzzy matrix is composed of the membership degrees of four level indicators such as natural risk and political risk. The final comprehensive evaluation vector of external risk is calculated as (0.0882, 0.2084, 0.3164, 0.2078, 0.1794), and the maximum value of 0.3164 corresponds to "general risk". The first level fuzzy evaluation integrates the results of the second level evaluation of external and internal risks, weighted by W=(0.2, 0.8), to obtain the overall risk evaluation vector of the project (0.1095, 0.2165, 0.3129, 0.2452, 0.1157). The maximum value of 0.3129 corresponds to "general risk", indicating that the project financing risk is controllable but key areas need to be focused on. According to the principle of maximum membership degree, the "major risks" in the third level of risk include 5 items such as land acquisition and demolition, construction safety, etc. (probability>0.3); The 'general risk' covers 6 items, including policy adjustments, interest rate changes, etc. (probability 0.2-0.3). In the second level risk, the risk during the project construction period is classified as "relatively high risk" (probability 0.3341), while social and economic risks are classified as "general risks". Compared with the traditional method of AHP or single fuzzy evaluation, this study combines AHP (determination of weight) and fuzzy evaluation (quantitative uncertainty), gives consideration to subjective experience and objective data, and reduces evaluation bias; Compared to the current research that introduces machine learning (which requires a large amount of historical data) or cloud models (which have high computational complexity), this model strikes a balance between operability and accuracy, providing a suitable evaluation framework for new construction projects. In the future, BIM technology can be combined to adjust membership degrees in real time or introduce interval fuzzy sets for further optimization.

5. Conclusion

This article starts from the perspective of project investors, uses risk models as research tools, and combines fuzzy comprehensive evaluation method to systematically study the financing risks of large-scale engineering projects, focusing on the three core links of risk identification, evaluation, and response. The research first clarifies the background and significance of the topic, sorts out the research progress in the field of financing risk management for large-scale engineering projects at home and abroad, and clarifies the research content and methodological framework; Subsequently, the core concepts and theoretical foundations were defined, with a focus on explaining the definition of large-scale engineering projects, financing risk characteristics, and risk management theories, providing theoretical support for subsequent analysis. Taking a typical highway project as a case study, a financing risk evaluation index system is constructed from two dimensions: external environmental risks and internal risks. It includes 2 primary indicators, 8 secondary indicators, and 30 tertiary indicators, forming a multi-level analysis framework. In the risk assessment stage, quantitative analysis methods were used to determine the weights of various risk indicators through the Analytic Hierarchy Process (AHP), and the risk level was evaluated using the Fuzzy Comprehensive Evaluation method. The results showed that the risks of land acquisition and demolition, construction safety, construction cost overruns, construction period delays, and operation and maintenance cost overruns were relatively high risks; Policy adjustment risk, interest rate change risk, design change risk, engineering quality risk, unclear technical disclosure risk, and quality condition risk are classified as general risks. Based on different risk levels, targeted response strategies are proposed from three dimensions: significant risk, general risk, and other risks, providing practical reference for financing risk management of similar projects. Research has pointed out that in recent years, with the global and regional economic development entering a new stage, relevant laws and regulations have been continuously adjusted and optimized. Against the backdrop of economic development model transformation, the factors affecting project financing risks are dynamically changing, requiring the financing risk evaluation index system to be continuously updated and optimized in conjunction with new external situations and technological management changes; Meanwhile, although the combination of Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) used in the study integrates the advantages of both methods, subjective factors may still affect the universality of the results. In the future, more scientific evaluation models can be explored to enhance their practical guidance value. In addition, due to the experience and level of researchers, some viewpoints may be biased and need further verification and improvement.

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