Research on Financing Risks of PPP+EPC Engineering Projects Based on the Triangular Fuzzy Analytic Hierarchy Process

Hongwen Zhou[a], Wei Zhu[*]

School of Urban Construction and Safety Engineering, Shanghai University of Applied Technology, Shanghai, China

[a]sitzhw@sina.com, *1654263592@qq.com

Abstract. Highway engineering projects face a complex financing risk environment due to their large construction scale, long financing cycle, and numerous influencing factors. This article takes PPP+EPC mode engineering projects as the research object, based on grounded theory and literature analysis method, a financing risk influencing factor index system is constructed. The large-scale civil engineering project of Hangzhou Quzhou Railway in PPP+EPC mode is selected as a practical case. The financing risk of the project is analyzed and evaluated through the triangular fuzzy analytic hierarchy process, and the key financing risk factors of the project are clarified. The research conclusion shows that the most significant risk factors affecting the financing of engineering projects under the PPP+EPC model are financing sources and financing costs, followed by credit ratings of financial institutions and social capital, government supervision and regulatory capabilities of the project, and the ability to bear risks, providing reference for the development of PPP+EPC engineering projects.

Keywords: PPP+EPC; Civil engineering; Engineering risks; Financing influencing factors; TFAHP

1 Introduction

In order to solve the investment difficulties of infrastructure projects and alleviate the financial pressure on the government[1], China vigorously advocates the construction of PPP (Public Private Partnership) projects and promotes the EPC (Engineer Procedure Construct) engineering general contracting model, which is conducive to overcoming key problems such as information fragmentation and mutual constraints among various participants in the traditional engineering management model[2]. The PPP+EPC model is an infrastructure engineering project model that combines public-private partnerships (PPP) and engineering procurement and construction (EPC)[3]. In this model, the public sector collaborates with private enterprises, with private enterprises undertaking the financing, design, construction, and operation of projects, while the public sector is responsible for supervision and guidance[4]. This model can effectively utilize private

H. Bilgin et al. (eds.), *Proceedings of the 2024 6th International Conference on Civil Engineering, Environment Resources and Energy Materials (CCESEM 2024)*, Advances in Engineering Research 253,
https://doi.org/10.2991/978-94-6463-606-2_22

sector funds and professional technology to accelerate the pace of infrastructure construction. However, this model also brings a series of financing risks, which affect the implementation of engineering projects and lead to project failure[5]. PPP+EPC is not a specific model of PPP, but rather a combination of social capital and EPC model in solving financial problems[6]. This model provides an operational approach that unifies project investors and general contractors into a consortium. The PPP+EPC model, as a new financing and construction model, started relatively late in China, and the relevant theoretical research and practice are not yet sufficient. Most experts and scholars' research on risks is mainly focused on a single PPP or EPC model, and risk research under the PPP+EPC model still needs to be explored[7]. Therefore, the simple addition of risk lists under both PPP and EPC models is no longer fully applicable to PPP+EPC models, and a suitable risk assessment index system needs to be reconstructed based on the specificity of this model.

For the literature published from 2014 to December 2024, on the CNKI platform, when entering "PPP-EPC risk" in the theme or keywords, a total of 47 relevant literature were screened. At the same time, 6 relevant articles were found by entering "PPP AND EPC AND risk" in the topic on the Web of Science literature indexing platform. It can be seen that the research on the project risks of the PPP+EPC model in the academic and engineering fields is still in its infancy. Through the review and analysis of these literature, it is found that most of the existing research is limited to the development origin and connotation definition of the PPP+EPC model, and there is still relatively little research on risk assessment, risk control, and formation mechanism under this model. There is little research on the financing risks that will inevitably arise from the integration of PPP and EPC models in related risk studies. The focus is more on summarizing macro risks, and the weighting method of risk factors is single, without considering the ambiguity of judgment. At the same time, it is greatly influenced by subjectivity, which affects the accuracy and comprehensiveness of the final evaluation results. The large-scale civil engineering project of Hangzhou Quzhou Railway in PPP+EPC mode is selected as a practical case. The financing risk of the project is analyzed and evaluated through the triangular fuzzy analytic hierarchy process, and the key financing risk factors of the project are clarified, filling the gap in the research on financing risks that will inevitably arise from the integration of PPP and EPC models in related risk studies. The effectiveness and feasibility of the triangular fuzzy analytic hierarchy process were verified, providing a new perspective and method for the development research of PPP+EPC model engineering projects and theoretical basis and practical guidance for highway financing risk management.

2 PPP+EPC Model Project Financing Risk Factor Indicator System

2.1 Identification of Risk Factors in PPP+EPC Model Project Financing

To ensure the rationality and accuracy of the evaluation results, this article is based on grounded theory, combined with literature analysis method. Following the principles of system and hierarchy, simplicity and completeness, science and operability, and combined with the opinions of experts with PPP or EPC project experience in the engineering industry, four primary indicators of financing risk and twelve secondary indicators of financing risk have been determined, ultimately forming a PPP+EPC model project financing risk evaluation index system with differences and applicability. As shown in the Table 1.

Table 1. PPP+EPC Model Project Financing Risk Factor Indicators

First level risk indicators	Secondary indicators
B1: Financing structure risk	C1: Financing source C2: Financing Term C3: Financing cost
B2: Credit and management level of financial institutions and social capital	C4: Credit rating of financial institutions and social capital parties C5: Financial status of financial institutions and social capital parties C6: Management capabilities of financial institutions and social capital providers
B3: Risk responsibility allocation among government, financial institutions, and social capital parties	C7: The government's ability to regulate and supervise projects, as well as its ability to bear risks C8: Financing conditions of financial institutions, risk assessment and risk-taking ability for projects C9: Social capital's own funds and risk bearing capacity for the project
B4: exchange rate risks	C10:The amplitude and frequency of exchange rate fluctuations C11:Currency types and amounts involved in the project C12:Does the contract include clauses regarding exchange rate fluctuations and corresponding solutions

2.2 PPP+EPC Model Project Financing Risk Indicator Evaluation Set

This model adopts a three-level classification method to scientifically and reasonably evaluate the financing risk status of PPP+EPC projects. Based on the weight determination results, it is divided into five weight interval values corresponding to five risk levels. The risk evaluation levels of the corresponding interval risk factors are represented by 1, 2, and 3, respectively: high risk, moderate risk, and low risk. Therefore, the determined evaluation set is

$$H = \{H1, H2, H3\} = \{1,2,3\} \tag{1}$$

2.3 PPP+EPC Model Project Financing Risk Assessment Model

At present, most research in the field of highway financing risk is based on the Analytic Hierarchy Process to construct project risk assessment models. The traditional Analytic Hierarchy Process ignores the fuzziness of human judgment when constructing judgment matrices, and the consistency check of judgment matrices is too complex and computationally intensive, making it difficult to deal with multi criteria decision-making problems [7]. The Triangular Fuzzy Analytic Hierarchy Process Method can compensate for the ambiguity that traditional Analytic Hierarchy Process cannot fully consider when experts compare the importance of pairwise factors. By integrating triangular fuzzy numbers with Analytic Hierarchy Process, The triangular fuzzy analytic hierarchy process is a decision analysis method that combines fuzzy mathematical theory with the analytic hierarchy process, particularly suitable for dealing with uncertainty and fuzziness problems in risk assessment. The following is the basic principle of the triangular fuzzy analytic hierarchy process in the risk assessment of highway financing: firstly, a multi-level evaluation index system for financing risk factors needs to be constructed. Secondly, judgment moments need to be constructed. Experts need to compare each factor pairwise and use triangular fuzzy numbers to represent the evaluation results. The weights of risk factors are determined through weight calculation, consistency testing, and other steps. Finally, the risk factors are sorted based on the comprehensive weight value to determine their priority. The factors with the highest weights are considered as key financing risk factors. The triangular fuzzy analytic hierarchy process takes into account the uncertainty and fuzziness of the evaluation process in risk assessment, effectively solving the problem of strong subjectivity in expert scoring and difficult consistency in judgment matrices, and improves the reliability of weights, and making the risk assessment results more scientific and reasonable.

2.4 Definition of Triangular Fuzzy Numbers

Let F be a fuzzy number on the real number field R, if the membership function of F $\mu_F^{(y)}$ (a continuous mapping from R to [0,1]) satisfies

$$u_F^{(y)} = \begin{cases} \frac{y-x}{z-x}, x \le y < z \\ \frac{s-y}{s-z}, z \le y \le s \end{cases} \tag{2}$$

Then F is a triangular fuzzy number, denoted as F=(x, z, s), where $x$is the lower limit, z is the median, and s is the upper limit.

2.5 Triangle Fuzzy Number Operation Rule

If it is a triangular fuzzy number $F_i = (x_i, z_i, s_i)$and $F_j = (x_j, z_j, s_j)$, the operation rule is as follows:

$$F_i + F_j = x_i + x_j, z_i + z_j, s_i + s_j \tag{3}$$

$$F_i \times F_j = x_i \times x_j, z_i \times z_j, s_i \times s_j \tag{4}$$

$$\frac{F_i}{F_j} = \left(\frac{x_i}{x_j}, \frac{z_i}{z_j}, \frac{s_i}{s_j}\right) \tag{5}$$

$$kF_i = (kx_i, kz_i, ks_i) \tag{6}$$

2.6 Construct a Fuzzy Judgment Matrix

Invite experts to compare n indicators pairwise using the 1-9 scale method, as shown in Table 2, and compare the results using triangular fuzzy numbers. When the experts provide $\frac{n(n-1)}{2}$ fuzzy judgments, a fuzzy judgment matrix can be constructed:

$$A = (a_{ij})_{n\times n} \tag{7}$$

Explain: $i = 1,2,\cdots,n; a_{ij} = (x_{ij}, z_{ij}, s_{ij})$,Among them, x_{ij}, z_{ij}, s_{ij} are the lower limit, median, and upper limit values of triangular fuzzy numbers, respectively. For the judgment results of multiple experts, the average value can be taken as the comprehensive triangular fuzzy number through the algorithm of triangular fuzzy numbers.

Table 2. Scale Method for Assigning Values of r_k from 1 to 9

r_k scale value	importance of indicators
5	r_i is equally important than r_j
6	r_i is slightly more important than r_j
7	r_i is significantly more important than r_j
8	r_i is stronger and more important than r_j
9	r_i is extremely more important than r_j
1,2,3,4,	the ratio of the importance of r_i to r_j is a_{ij} the ratio of the importance of r_j to r_i is a_{ji}

2.7 Calculate the Comprehensive Fuzzy Value

Di represents the comprehensive fuzzy value of each risk indicator in the fuzzy judgment matrix. The calculation formula is:

$$D_i = \sum_{j=1}^{n} k_{ij} \times \left(\sum_{i=1}^{n}\sum_{j=1}^{n} k_{ij}\right)^{-1} = \left(\sum_{j=1}^{n} x_{ij}, \sum_{j=1}^{n} y_{ij}, \sum_{j=1}^{n} z_{ij}\right) / \left(\sum_{i=1}^{n}\sum_{j=1}^{n} x_{ij}, \sum_{i=1}^{n}\sum_{j=1}^{n} y_{ij}, \sum_{i=1}^{n}\sum_{j=}^{n} z_{ij}\right) = \left(\sum_{j=1}^{n} x_{ij} / \sum_{i=1}^{n}\sum_{j=1}^{n} z_{ij}, \sum_{j=1}^{n} y_{ij} / \sum_{i=1}^{n}\sum_{j=1}^{n} y_{ij}, \sum_{j=1}^{n} z_{ij} / \sum_{i=1}^{n}\sum_{j=1}^{n} x_{ij}\right) \tag{8}$$

$$i = 1,2,\cdots,n; j = 1,2,\cdots,n.$$

2.8 Remove Blurring

The comprehensive fuzzy value cannot represent the fully deterministic state of indicator weight information, so the possibility degree method is used to compare the comprehensive fuzzy value pairwise. The two comprehensive fuzzy values $D_i = (\widetilde{x_i}, \widetilde{y_i}, \widetilde{z_i}), D_j = (\widetilde{x_j}, \widetilde{y_j}, \widetilde{z_j}), F(D_i \geq D_j)$ represent the possibility that the comprehensive fuzzy value $D_i \geq D_j$. The rule for determining the value of possibility is:

$$F(D_i \geq D_j) = \begin{cases} 1, & \widetilde{y_i} \geq \widetilde{y_j} \\ \frac{(\widetilde{x_j} - \widetilde{z_i})}{(\widetilde{y_i} - \widetilde{z_i}) - (\widetilde{y_j} - \widetilde{x_j})}, & \widetilde{x_i} < \widetilde{y_j}, \widetilde{z_i} \geq \widetilde{x_j} \\ 0, & \text{others} \end{cases} \tag{9}$$

Explain: f_g represents the weight of the indicator after deblurring,$f_g = F(D_g \geq D_1, D_2, \cdots D_n)$,among them,$i = 1,2,\cdots,n; k = 1,2,\cdots,n; j \neq k$.

2.9 Determine the Weight

Normalize the indicator weight vector after deblurring to obtain the final weight.

3 Example of PPP+EPC Model Project Financing Risk Engineering

3.1 Project Introduction

The Hangzhou Quzhou Railway Project, a large-scale civil engineering project, is contracted by the Fourth Survey and Design Institute of China Railway Construction Bureau and constructed by China Railway 11th Bureau Group. It starts from the Hangzhou Huangshan Railway in the east, ends at Jiangshan Station of the Shanghai Kunming High speed Railway in the west, and connects with the Jiujing Quzhou Railway in the middle. The total length is about 132.28 kilometers, with a design speed of 350 kilometers per hour. It is one of the landmark projects in the construction of the Zhejiang Jiangsu Provincial Expressway. This project is the first high-speed railway project in China to operate under the "PPP+EPC" mode and an important part of the Yangtze River Delta rapid transit network. After completion, the travel time from Hangzhou to Quzhou will be shortened to 40 minutes, which is of great significance for improving the layout of the Zhejiang railway network, alleviating the transportation pressure of the Shanghai Kunming high-speed railway, and driving the economic and social development and development opening up along the project line.

3.2 Construct a Fuzzy Complementary Judgment Matrix

In the form of a survey questionnaire, a total of 3 important construction personnel, as well as 5 professors and graduate students in engineering risk related majors, who were invited to undertake the project at the Fourth Survey and Design Institute of China

Railway Construction Bureau, were invited to score. By taking the average, a complementary judgment matrix was constructed using triangular fuzzy numbers as as shown in Table 3-7:

Table 3. B1-B4 Fuzzy Discriminant Matrix of Indicators

index	B1	B2	B3	B4
B1	(5,5,5)	(4.9,5.1,5.4)	(4.8,5.1,5.6)	(5.15.3,5.5)
B2	(4.6,4.9,5.1)	(5,5,5)	(4.8,5.0,5.4)	(4.9,5.2,5.6)
B3	(4.4,4.9,5.2)	(4.6,5.0,5.2)	(5,5,5)	(4.9,5.1,5.3)
B4	(4.5,4.7,4.9)	(4.4,4.8,5.1)	(4.7,4.9,5.1)	(5,5,5)

Table 4. C1-C3 Fuzzy Discriminant Matrix of Indicators

index	C1	C2	C3
C1	(5,5,5)	(5.0,5.1,5.3)	(4.9,5.0,5.2)
C2	(4.7,4.9,5.0)	(5,5,5)	(4.8,4.9,5.0)
C3	(4.8,5.0,5.1)	(5.0,5.1,5.2)	(5,5,5)

Table 5. C4-C6 Fuzzy Discriminant Matrix of Indicators

index	C4	C5	C6
C4	(5,5,5)	(5.0,5.1,5.2)	(4.9,5.1,5.3)
C5	(4.8,4.9,5.0)	(5,5,5)	(5.0,5.0,5.1)
C6	(4.7,4.9,5.1)	(4.9,5.0,5.0)	(5,5,5)

Table 6. C7-C9 Fuzzy Discriminant Matrix of Indicators

index	C7	C8	C9
C7	(5,5,5)	(5.0,5.1,5.2)	(4.9,5.0,5.2)
C8	(4.8,4.9,5.0)	(5,5,5)	(4.9,5.0,5.1)
C9	(4.8,5.0,5.1)	(4.9,5.0,5.1)	(5,5,5)

Table 7. C10-C12 Fuzzy Discriminant Matrix of Indicators

index	C7	C8	C9
C10	(5,5,5)	(5.0,5.1,5.3)	(4.9,5.0,5.1)
C11	(4.7,4.9,5.0)	(5,5,5)	(4.8,4.9,5.0)
C12	(4.8,5.0,5.1)	(5.0,5.1,5.2)	(5,5,5)

3.3 Calculation Results of Risk Indicator Weights

The calculation results of risk indicator weights and risk levels are shown in Table 8:

Table 8. Weight Calculation of PPP+EPC Financing Risk Factors

First level indicator	weight	Secondary indicators	weight	comprehensive weight	Weight sorting	Risk level
B1	0.38	C1	0.47	0.179	1	1
		C2	0.10	0.038	11	3
		C3	0.43	0.163	2	1
B2	0.3	C4	0.5	0.150	3	1
		C5	0.27	0.081	6	2
		C6	0.23	0.069	8	2
B3	0.23	C7	0.44	0.132	4	1
		C8	0.22	0.051	9	3
		C9	0.33	0.076	7	2
B4	0.09	C10	0.43	0.099	5	2
		C11	0.10	0.009	12	3
		C12	0.47	0.042	10	3

4 Conclusions

This article combines literature analysis to identify 12 project financing risk factors with differences and applicability under the PPP+EPC model, and establishes an index system for financing risk influencing factors. Taking the Hangzhou Quzhou Railway project under the PPP+EPC model as an actual case, the TFAHP method is used to calculate the weights of various influencing factors, fully considering the fuzziness in the comparison of the relative importance of each factor, making the formation of the judgment matrix more operable, and the establishment of weights more scientific and reasonable. It is concluded that the risk factors that have the greatest impact on the financing of engineering projects under the PPP+EPC model are the financing source and financing cost, followed by the credit rating of financial institutions and social capital, the government's supervision and supervision ability of the project, and the ability to bear risks, in order to provide reference for the financing development of engineering projects under the PPP+EPC model. The TFAHP method has limitations in dealing with the dynamic changes of financing risk factors over time. Future research can consider dynamic analysis methods such as system dynamics to more comprehensively evaluate the dynamic changes of financing risk factors.

Acknowledgment

This research is supported by the Henan Provincial Transportation Science and Technology Project (2021-2-21), and is held by Professor Zhou Hongwen.

References

1. Love., Peter, E.D., et al. (2011) Risk/reward compensation model for civil engineering infrastructure alliance projects. Construction engineering and management., 137(2): 127-136. 10.1061/ (ASCE)CO.1943-7862.0000263.
2. Siraj, N.B., Aminah, R.F. (2019) Risk identification and common risks in construction: Literature review and content analysis. Construction engineering and management., 145(9).10.1061/(ASCE) CO.1943-7862.0001685.
3. Ullah, S., Xiaopeng, D., Anbar, D.R., et al. (2024) Risk identification techniques for international contracting projects by construction professionals using factor analysis. Ain Shams Engineering., 15(4): 102655.10.1016/J.ASEJ.2024.102655.
4. Álvarez, J.R. (2023) Urban Building Energy Modelling for the Renovation Wave: A Bespoke Approach Based on EPC Databases. Buildings., 13(7). 10.3390/ BUILDINGS13071636.
5. bo, L., Ying, Y. (2024) Research on Cost Management Evaluation of Urban Renewal Projects under EPC Mode. Economics Studies., 6(2).10.22158/IBESV6N2P266.
6. Xin Guohua, Z.S. (2023) Research on EPC Construction Mode of China Informatization Project. Pacific International., 6(3).10.55014/PIJV6I3.428.
7. Chen, Y., Ren, Z., Hu, B., et. (2023) Investigation of the Critical Factors Influencing Multi-Stakeholders' Participation in Design Optimization of EPC Projects. Buildings., 13(7). 10.3390/BUILDINGS13071654.