A Risk Evaluation Index System for Infrastructure PPP Modelbased on FAHP Method

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September 11, 2023

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ABSTRACT: The upsurge in demand for infrastructure construction due to increasing urbanization and economic growth has prompted governments to invest more in infrastructure and public utilities. However, the high cost of infrastructure construction requires the inclusion of market mechanisms to attract social capital, leading to the innovative Public-Private-Partnership (PPP) model as a public service investment mechanism. Although the PPP model can effectively alleviate the debt burden of local governments, it also poses a variety of risks and complexities in decision-making. Thus, it is crucial to identify and evaluate the primary risks throughout the project lifecycle. This study constructs a risk index system from ten dimensions for infrastructure PPP projects and further adopts the fuzzy analytic hierarchy (FAHP) process to evaluate the identified risk factors. The study examines the Huzhou South Taihu New Area PPP project and identifies the project design stage risk as the most important. The findings in general could provide valuable insights for PPP project stakeholders to effectively manage key risks.

Keywords: Public-Private Partnerships, Fuzzy Analytic Hierarchy, Risk, Government, Case Study, China

1 INTRODUCTION

Infrastructure is a fundamental facility, and it plays a key role in economic development. At present, it is difficult to meet the requirements of infrastructure development by relying solely on the government in terms of funding and technology (Jayasena et al., 2021). The government urgently needs to introduce a new model to alleviate the funding problem of infrastructure construction, and the public-private partnership (PPP) project cooperation model is considered to be a potential solution.

The PPP is an emerging model of project financing and project management (Koul et al., 2021), which encourages private enterprises to participate in the construction of public infrastructure and public service projects. It not only utilizes the advantages of government in terms of policies and resources, but also takes advantage of private enterprises in terms of technology, management, and capital (Liu, 2021). However, due to the complexity of the financing structure of PPP projects, there are a variety of risk factors that could affect the success of PPP projects. Therefore, it is necessary to identify the risk factors throughout the PPP project life cycle and develop a comprehensive system to evaluate the identified risk factors to ensure the successful implementation of PPP projects.

Accordingly, this paper aims to establish a risk evaluation index system for infrastructure PPP projects and to further prioritize the identified risk factors by using the Fuzzy Analytic Hierarchy Process (FAHP). The results of the study could help practitioners in assessing, prioritizing, and managing risks for PPP infrastructure projects. In addition, recommendations are also provided for practitioners to address important risks in PPP projects in conclusion.

2 METHODOLOGY

This study employed a mixed method, integrating both qualitative and quantitative approaches to evaluate the risks associated with PPP projects. Specifically, this paper utilized a combination of AHP and fuzzy comprehensive evaluation (FCE) techniques to rank the degree of influence of various risk factors on PPP projects.

2.1 *Development of infrastructure PPP project risk index system*

A risk index system for infrastructure PPP project was established based on the results of the literature review and expert interviews. It includes ten level-I risk factor indicators at the macro, medium and micro levels, which are further subdivided into 25 level-II risk factor indicators, as shown in Table 1.

Table 1. Infrastructure PPP project risk assessment and analysis system

The target level	First-level indicator	Secondary indicator	Descriptions
Macro level	Political risk (C1)	Government stability X11	Government political stability of the project
		Government credit X12	Failure or refusal of the government to fulfill its contractual responsibilities and obligations
		Fiscal risk X13	The surge in demand for PPP projects due to urbanization led to excessive government guarantees and over-investment
		Legal environment X14	Changes in relevant laws and regulations
	Economic risk (C2)	Inflation X21	Increase in prices, decrease in purchasing power of currency
		Foreign exchange risk X22	Changes in foreign exchange rates affecting foreign exchange payments
		Interest rate risk X23	Risk of changes in market interest rates
		Financing environmentX24	The national economic situation related to PPP project financing
	Social risk (C3)	Public attitude X31	Public support for the project
Medium level	Project selection stage risk (C4)	Other competing projects X41	Competition from fellow projects
		Degree of project demand X42	The level of demand for the project in the market
	Project financing stage risk (C5)	Project attractiveness X51	Investor interest in the project
		Cost of financing X52	Financing costs outweigh returns resulting in project losses
	Project design stage risk (C6)	Project approval X61	Delays in approval due to complex approval process
		Project design issues X62	Risk of project design quality issues and design changes
	Project construction stage risk (C7)	Construction quality X71	Losses caused by quality of construction
		Contract variations X72	Compensation due to contractual changes
		Budget overrun X73	Budget overruns
	Project operation stage risk (C8)	Operating costs X81	Increased operating costs due to economic and other factors in the project operation
		Maintenance costs X82	High cost of equipment replacement and maintenance
		Security risks X83	Risk incidents arising from the safety of project
Micro level	Participant relationship risk (C9)	Contracts between participants X91	Credit risk resulting from inadequate communication and information asymmetry between participants

		Sharing of responsibilities, powers, and risks between participants X92	Inappropriate allocation of powers, responsibilities, and risks among participants
	Third-party risks (C10)	Third-party infringement indemnity risk X101 Personnel risk X102	Agent conducts prejudicial to the interests of the participant Problems arising from human resources management

2.2 *Survey design based on Delphi Method*

After constructing the above risk indicator system, this study used the Delphi survey method to evaluate and prioritize the identified risks to obtain the preliminary results of risk evaluation.

The experts being surveyed are selected based on the following criteria: (1) in-depth understanding of PPP project risk management; and (2) direct involvement in risk management of PPP projects in practice. A total of 30 experts participated in the Delphi study, of whom 10 were from government departments, 15 from project companies, and 5 from technical staff. The profiles of these experts are summarized in Table 2. A total of 60 questionnaires (two rounds to the same group of experts) were distributed by email and 55 valid questionnaires were returned, representing a 92% return rate.

The questionnaire is composed of three parts: the first part is to collect the basic information of participants; the second part is an overview of the Huzhou South Taihu New Area project; the third part is the main body of the questionnaire, in which the relative importance of the first-level and secondary risk indicators can be obtained through Delphi method. The survey data were analyzed by following the steps of Section 2.3.

Table 2. Survey respondent profiles

Basic information	Category	Number of people	Proportion
Expert Category	Government manager	10	33%
	PPP project manager	15	50%
	Technical staff	5	17%
Years of involvement in PPP	1-3	9	30%
	4-6	14	47%
	> 6	7	23%
Number of PPP projects involved	1-3	13	43%
	4-6	15	50%
	> 6	2	7%

2.3 *Fuzzy analytic hierarchy process*

The fuzzy integrated evaluation method is a system analysis method developed based on the AHP risk evaluation method, which uses the principles of fuzzy mathematics to make an overall comprehensive evaluation of the impact of various factors. The specific steps are as follows:

Step 1: Establish a Hierarchical Structure

The AHP hierarchical structure is a hierarchical structure that decomposes a complex problem into simple elements, which can be roughly divided into three levels: target level, criterion level and scheme level. The hierarchy proposed for this study is shown in Figure 1.

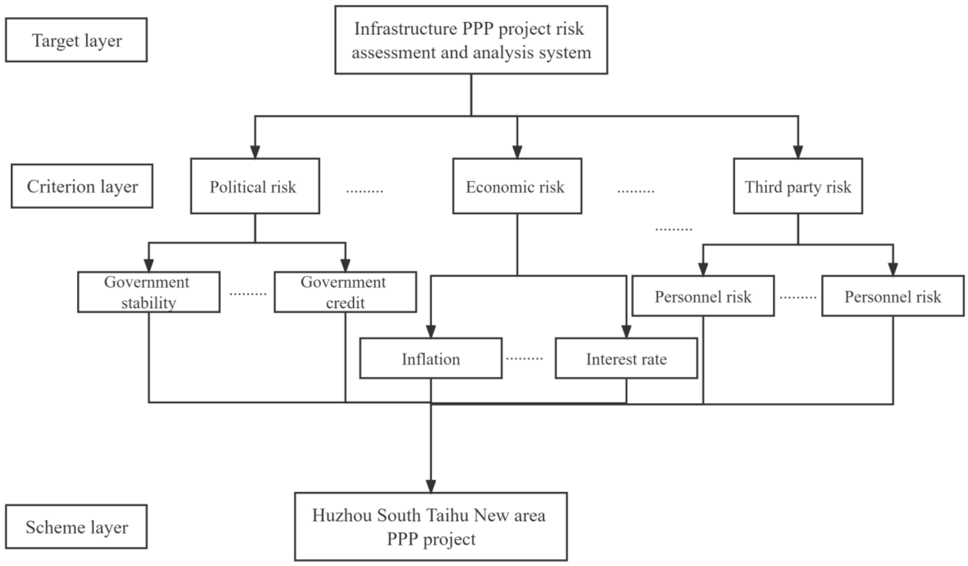

Figure 1. Hierarchy structure chart of AHP

The set of primary risk factors is set as $C= \{C_1, C_2, C_3...Cn\}$, and it is assumed that there is no correlation among the risk factors, and the set of secondary risk factors is set as $Xi=\{Xi1, Xi2, \ldots Xin\}$.

Step 2: Construct the Judgment Matrix

Firstly, a pairwise comparison is made between the importance of each element at the first level, and a comparative judgment matrix is established based on the degree of influence between the two; secondly, a comparative matrix is further constructed for the importance of each element at the second level. The quantitative scale of the two-by-two comparison method adopted here is shown in Table 3. Then SPSS software is adopted to derive the risk indicators weight. The first set of risk weights is $A=\{a1,a2, ...an\}$, $ai(i=1,2, ...,n)$ satisfies $\sum_{i=1}^{n} a_i=1$, $(i=1,2, ...,n)$; the second level of $Ai=\{ai1,ai2, ...ain\}$, $aij(j=1,2, ...,n)$ satisfies $\sum_{j=1}^{n} a_{ij}=1$, $(j=1,2, ...,n)$.

Table 3. The scale of the judgement matrix and the meaning of *aij* value(Saaty & Kearns, 1985)

Scale	Meaning
1	i and j are equally important
3	i is slightly more important than j
5	i is significantly more important than j
7	i is strongly more important than j
9	i is extremely more important than j
2,4,6,8	It represents the intermediate value of the above adjacent judgement

Step 3: Judgement Matrix Consistency Check

At this stage, the judgement matrix random consistency is checked according to the following equations:

$$CI = \frac{\lambda_{max}-n}{n-1};\ CR = \frac{CI}{RI} \tag{1}$$

Where CI=consistency index; CR=consistency ratio; RI=random consistency index

When the judgment matrix is of order n > 2, the ratio CR is obtained by dividing CI by RI, and the value of CR is the random consistency ratio of the judgment matrix. If CR is less than 0.1, the judgment matrix is judged to have satisfactory consistency, as presented in Table 4.

Table 4. Average random consistency index

Matrix order	1	2	3	4	5	6	7	8	9

RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Step 4: Determine the Evaluation Factor Set

This step requires that the risk level of each factor is evaluated by experts through a questionnaire method. Here the risk evaluation set is constructed by using the fuzzy evaluation language method to obtain the risk assessment experts evaluation of the risk factors, and the risk indicator system is evaluated into five levels: V_5- very low, V_4- low, V_3- medium, V_2- high, V_1- very high: $V= \{V_1, V_2, V_3, V_4, V_5\}$. Here, each risk factor of the secondary risk indicator set is first evaluated as a single factor, and R is the fuzzy evaluation matrix.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}, 0 \leqslant rij \leqslant 1 \tag{2}$$

Step 5. Fuzzy comprehensive evaluation

By combining the weight vectors of the derived set of secondary risk factor indicators with the resulting fuzzy evaluation set Ri of the set of secondary risk factor indicators, a comprehensive evaluation set of secondary risk factor indicators can be obtained.

$$R = \begin{pmatrix} C_1 \\ C_2 \\ \cdots \\ C_P \end{pmatrix} \begin{pmatrix} C_{11} & C_{12} & \cdots & C_{1m} \\ C_{21} & C_{22} & \cdots & C_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ C_{P1} & C_{P2} & \cdots & C_{pm} \end{pmatrix} \tag{3}$$

The R evaluation set is then evaluated in combination with the weight vector W of the C matrix to obtain a level 1 risk indicator evaluation set.

$$C = A * R = (a_1 \quad a_2 \quad \cdots \quad a_p) \begin{pmatrix} C_1 \\ C_2 \\ \cdots \\ C_p \end{pmatrix} = (C_1 \quad C_2 \quad \cdots \quad C_n) \tag{4}$$

3 CASE APPLICATION

3.1 *Case Introduction*

The Huzhou South Taihu New Area Changdou Harbor Comprehensive Improvement and Changdong Area Supporting Facilities PPP Project, hereafter referred to as the Huzhou South Taihu New Area PPP Project, is composed of two sub-projects. The total investment included in this PPP cooperation is 951,721,500 RMB. The project cooperation period is 23 years, including a construction period of 3 years and an operation period of 20 years. A full process partnership has been established to ensure the smooth implementation of the project. This project is selected because it is a typical example of an infrastructure PPP project, which can provide valuable insights for decision-makers in managing similar projects.

3.2 *Fuzzy evaluation results of the case study*

The proposed risk indicator system (refer to Table 1) is further confirmed with experts, which is deemed to be appropriate and thus applied in this case project for further evaluation.

The pairwise comparison matrix is constructed according to the risk evaluation model described in the previous section. In accordance with the AHP method, the mean of the experts' scores is taken, and the judgement matrix A can be obtained, and the weights of the first-level risk indicators can be calculated, as shown in Table 5.

Table 5. Fuzzy judging matrixes for A level indexes relative to C level indexes

A	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Wi
C1	1	0.5	3	2	4	0.333	5	5	6	3	0.14823
C2	2	1	5	4	3	0.5	6	6	7	4	0.21065
C3	0.333	0.2	1	0.333	0.333	0.167	3	2	2	0.5	0.04289
C4	0.5	0.25	3	1	2	0.25	3	5	5	2	0.09779
C5	0.25	0.333	3	0.5	1	0.2	2	3	4	1	0.06656
C6	3	2	6	4	5	1	8	7	7	5	0.28864
C7	0.2	0.167	0.333	0.333	0.5	0.125	1	3	2	0.333	0.03251
C8	0.2	0.167	0.5	0.2	0.333	0.143	0.333	1	0.25	0.25	0.01983
C9	0.167	0.143	0.5	0.2	0.25	0.143	0.5	4	1	0.333	0.02635
C10	0.333	0.25	2	0.5	1	0.2	3	4	3	1	0.06656

After SPSS software measurement, the above judgment matrix obtained through the expert survey has a CITC value greater than 0.5 and a Cronbach's alpha coefficient greater than 0.7 for the judgment criteria (see Table 6). Therefore, the validity and reliability of the questionnaire for risk evaluation are good and basically meet the requirements of the study. The normalized weight values and ranking of each risk indicator are shown in Table 7.

Table 6. Consistency test results summary

Maximum characteristic root	CI	RI	CR	Consistency test result
10.693	0.077	1.49	0.052	Pass

Table 7. Normalized weight and rank for risk indexes

First-level indicator and weight	Secondary indicator	Weight	Category sorting	Overall ranking
Political risk (C_1) 0.14823	Government stability X_{11}	0.08271	1	3
	Government credit X_{12}	0.04359	2	8
	Fiscal risk X_{13}	0.01096	3	17
	Legal environment X_{14}	0.01096	3	17
Economic risk (C_2) 0.21065	Inflation X_{21}	0.03136	3	11
	Foreign exchange risk X_{22}	0.01280	4	16
	Interest rate risk X_{23}	0.03729	2	10
	Financing environment X_{24}	0.12919	1	2
Social risks (C_3) 0.04289	Public attitude X_{31}	0.04289	1	9
Project selection stage risk (C_4) 0.09779	Other competing projects X_{41}	0.07823	1	4
	Degree of project demand X_{42}	0.01956	2	14
Project financing stage risk (C_5) 0.06656	Project attractiveness X_{51}	0.04992	1	5
	Cost of financing X_{52}	0.01664	2	15
Project design stage risk (C_6) 0.28864	Project approval X_{61}	0.24053	1	1
	Project design issues X_{62}	0.04811	2	6
Project construction stage risk (C_7) 0.03251	Construction quality X_{71}	0.00484	2	22
	Contract variations X_{72}	0.00198	3	25
	Budget overrun X_{73}	0.00576	1	21
Project operation stage risk (C_8) 0.01983	Operating costs X_{81}	0.00925	1	19
	Maintenance costs X_{82}	0.00199	3	24
	Security risks X_{83}	0.00859	2	20
Participant relationship risk (C_9) 0.02635	Contracts between participants X_{91}	0.00376	2	23
	Sharing of responsibilities, powers, and risks between participants X_{92}	0.02259	1	12

Third-party risks (C_{10}) 0.06656	Third-party infringement indemnity risk X_{101}	0.02219	2	13
	Personnel risk X_{102}	0.04437	1	7

According to the above-constructed risk factor index system, the next step is to ask experts to evaluate the risk level of each factor through the questionnaire. The fuzzy evaluation matrix of risk factors is then obtained by counting the specific results, as shown in Table 8.

Table 8. Evaluation of risk levels by experts

First-level indicator and weight	Secondary indicator	V5	V4	V3	V2	V1
Political risk (C1)	Government stability X11	0.00	0.35	0.50	0.15	0.00
	Government credit X12	0.00	0.12	0.22	0.32	0.34
	Fiscal risk X13	0.00	0.14	0.22	0.35	0.29
	Legal environment X14	0.00	0.10	0.40	0.48	0.02
Economic risk (C2)	Inflation X21	0.00	0.00	0.42	0.50	0.08
	Foreign exchange risk X22	0.00	0.10	0.45	0.26	0.19
	Interest rate risk X23	0.08	0.22	0.23	0.25	0.22
	Financing environment X24	0.20	0.25	0.20	0.30	0.05
Social risks (C3)	Public attitude X31	0.15	0.30	0.38	0.17	0.00
Project selection stage risk (C4)	Other competing projects X41	0.00	0.15	0.30	0.48	0.07
	Degree of project demand X42	0.00	0.18	0.20	0.35	0.27
Project financing stage risk (C5)	Project attractiveness X51	0.06	0.24	0.35	0.35	0.00
	Cost of financing X52	0.00	0.22	0.26	0.25	0.27
Project design stage risk (C6)	Project approval X61	0.10	0.20	0.40	0.29	0.01
	Project design issues X62	0.10	0.22	0.30	0.28	0.10
Project construction stage risk (C7)	Construction quality X71	0.00	0.00	0.15	0.29	0.56
	Contract variations X72	0.00	0.10	0.20	0.30	0.40
	Budget overrun X73	0.00	0.00	0.00	0.40	0.60
Project operation stage risk (C8)	Operating costs X81	0.12	0.20	0.38	0.10	0.20
	Maintenance costs X82	0.00	0.18	0.22	0.42	0.18
	Security risks X83	0.00	0.10	0.25	0.48	0.17
Participant relationship risk (C9)	Contracts between participants X91	0.00	0.00	0.22	0.38	0.40
	Sharing of responsibilities, powers, and risks between participants X92	0.00	0.25	0.40	0.28	0.07
Third-party risks (C10)	Third-party infringement indemnity risk X101	0.16	0.38	0.22	0.18	0.06
	Personnel risk X102	0.18	0.40	0.10	0.25	0.07

The calculation by SPSS software is given:

$P=C*V^T= (0.046,0.176,0.279,0.314,0.185) *(0.10,0.35,0.6,0.75,1.00)^T$

$P=0.654$

The overall risk assessment score for the South Taihu New Area is 0.654; therefore, the overall risk of the project is judged to be moderate.

4 DISCCUSION

Based on the weights obtained in Table 7, the top five risk factors affecting the PPP project in Huzhou South Taihu New Area are project design stage risk, economic risk, political risk, project selection stage risk and financing risk, which need to develop response mechanisms.

Project design stage risks are objective and complex, which include the project approval risk and design issues risk. Project quality assurance is the most fundamental element of design management objective control (Rasheed et al., 2022). The proper treatment of the technical and economic dichotomy is an important principle in controlling investment.

The most important risk factor among economic risk is the financing environment risk, ranking 2nd out of all 25 risk indicators. The financing environment risk is generally borne by the social capital, and the government is only obliged to assist, so the social capital needs to raise the necessary funds for the project as agreed in the contract (Roumboutsos & Pantelias, 2015).

It is inevitable to encounter adjustments to national political policies and regulations, which may affect amendments or supplements (Sarvari et al., 2019). Government departments should amend the relevant laws according to practice to ensure smooth project operation.

Project selection stage risk refers to the possibility and uncertainty of project profit or loss faced by the participants (Sarvari et al., 2019). The uncertainty includes the market demand for the PPP project, the timing of market reception, and the speed of market diffusion of the product.

With domestic financing channels relatively concentrated in commercial bank loans, the main ways to hedge financing risks are to obtain syndicated loans and low-interest policy loans (Zhang et al., 2019). The Huzhou South Taihu New Area project is reasonably controlled through the loan agreement system and the lower interest rate.

5 CONCLUSION AND FUTURE DIRECTIONS

This study proposes a risk evaluation index system for infrastructure PPP projects by incorporating the characteristics of China's urbanization. The Huzhou South Taihu New Area project is selected as a case study where the project risks are further assessed by using the proposed risk evaluation index system and analyzed by using the FAHP method.

The results of this study could be served as guidance for practitioners to evaluate and manage the risks of infrastructure PPP project. This paper carries out risk identification through the literature review and Delphi method, but it cannot reflect the risk factors faced by all PPP projects. Therefore, for further study, the PPP project risk index evaluation system should be adjusted according to the actual operation process, and methods such as TOPSIS can be used to make risk evaluation more comprehensive.

6 ACKNOWLEDGEMENT

This work was supported by Xi'an Jiaotong-Liverpool University under the research project REF-21-01-006.

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