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USING FUZZY ANALYTIC NETWORK PROCESS AND ISM METHODS FOR RISK ASSESSMENT OF PUBLIC-PRIVATE PARTNERSHIP: A CHINA PERSPECTIVE

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Abstract. The public-private partnership (PPP) has been adopted globally to meet intensifying demands for public facilities and services. However, PPP projects contain a variety of risks which may lead to project failure. Many researchers have explored risk factors associated with PPP projects in developing countries. However, these investigations have limited their aim to understanding risk impact without considering the interactions of these factors. Hence, to fill this gap, this study proposes a risk assessment method, addressing vital interrelationships and interdependencies. Two methodologies, fuzzy analytic network process (F-ANP) and interpretive structural modeling (ISM), were applied to avoid vagueness and data inaccuracies. The primary contributions of this paper were considering the relationships among risk factors and risk priority; and offering a risk analysis approach based on linguistic scales and fuzzy numbers to reflect different neutral, optimistic and pessimistic viewpoints from expert respondents' judgments. Results from this analysis showed that legal and policy risk was the most influential and interdependent risk, and interest rate risk was the most essential risk in Chinese PPP projects. The ISM structure diagram demonstrated that most of 35 identified risk factors had high driving and dependence power. This study proposed a systematic and practical method to identify and assess PPP risk factors, utilizing an integrated approach consisting of F-ANP and ISM, which has not been used for risk assessment in the construction field. This paper provides a new risk assessment tool and a basis for risk management strategies in the construction engineering and management field.

Keywords: public-private partnership, fuzzy analytic network process (F-ANP), interpretive structural modeling (ISM), risk assessment.

Introduction

The public-private partnership (PPP) has been adopted in developed and developing countries such as the US, Australia, South Africa, France, Singapore, Brazil, and China. McKinsey (2013) predicted that, as the world's largest investor in infrastructure, China will spend more than $16 trillion on infrastructure from 2013–2030. According to the Chinese State Council Development Research Center, the urban populations in China will increase by at least 550 million people, if the urbanization rate reaches 70% by 2050. Accordingly, capital investment on urbanization construction could reach 50 trillion (Liu, 2014). Fiscal investment by the Chinese government has long played a dominant role in the construction of urban infrastructure in China. Therefore, taking into account expected economic growth and the new pattern for urbanization in China, there is a huge demand for infrastructure investment. According to the Finance and Economics Strategic Research Institute of the Chinese Academy of Social Sciences, China's local government debt exceeded 16 trillion RMB at the end of 2015, and local government debt will continue to rise in the next few years.

PPP was regarded as a favorable option to meet infrastructure demands, reduce pressure on government finances, and improve the operational efficiency of projects. The Ministry of Finance of the People's Republic of China (2018) indicated that there were approximately 14,424 PPP projects, with 18.2 trillion RMB investments, from 2013 through 2017. However, participants in PPP projects differ in terms of values, goals and socioeconomic interests. These factors should be considered simultaneously. Risk factors lie in the root of diversification of interests and

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objectives. PPPs usually have various risk factors which may affect implementation. Due to these complex risks, some unsuccessful PPPs have occurred in China, including Shanghai Dachang Waterworks, Jiangsu Sewage Treatment Plant, Shandong Zhonghua Power Plant, Hangzhou Bay Bridge, Quanzhou Citong Bridge, and Minjiang River Bridge 4 (Ke, Wang, Chan, & Lam, 2010). Projects may be delayed and undergo bankruptcy due to various factors. Thus, risk management is very important for ensuring the successful operation of PPP projects. Additionally, understanding the significance of risk factors and driving and dependence power among the risks, are critical for risk management in PPP projects.

Construction organizations are focusing on risk assessment techniques and the prediction of potential risks for effective risk management. PPP risks cannot be analyzed with existing risk assessment tools due to the lack of historical data and risk uncertainty. Uncertainty makes assessments of the degree of risk exposure difficult (Kirchsteiger, 1999). The lack of historical data may prevent the risk assessment tool from providing plausible outcomes in the decision-making process (Salah & Moselhi, 2015).

These problems can be solved using the fuzzy logic method, which introduces approximate or vague description rather than precise data. Unlike traditional sets where variables are represented by a single crisp value, fuzzy numbers can give a value with different degrees and may present imprecise concepts by linguistic variables, such as very high, high, moderate, low, and very low. This dynamic makes fuzzy numbers applicable in assessing risks when there is insufficient historical data and uncertain/imprecise expert knowledge. Fuzzy logic can evaluate risks based on current data from a PPP project. Because fuzzy numbers address vagueness, imprecision, and subjectivity, by using linguistic variables, fuzzy numbers can adopt linguistic variables in risk assessment (Salah & Moselhi, 2015). Moreover, previous studies have assumed mutual independence rather and neglected potential interaction effects among risks, leading to risk assessment results which may be inaccurate. F-ANP and ISM can be applied in complex interdependence and interactions among the risks (Govindan, Diabat, & Shankar, 2015).

The rest of this paper is organized as follows: The section entitled "Knowledge gap, research objectives and value" critically examines gaps in the current literature on risk assessment in PPP projects. The "Research method" section describes F-ANP and ISM for risk assessment and outlines differences with existing risk assessment methods. Discussion of the results is presented in "Results and discussion" section. The final section presents conclusions and future work opportunities.

1. Knowledge gap, research objectives and value

At present, risk evaluation methods mainly include qualitative and quantitative analysis. Lyons and Skitmore (2004) obtained risk qualitative analysis results based on expert judgments and subjective evaluations captured through questionnaires, a common risk assessment method in engineering projects. Additionally, Songer, Diekmann, and Pecsko (1997) used the Monte Carlo simulation method, a quantitative method relying on historical data (Ye & Tiong, 2000; Salah & Moselhi, 2015), for risk assessment of toll roads. Further, the sensitivity analysis method is used by most PPP project managers to make financial evaluations of capital investment in the risk management process (Woodward, 1995). Liu, Wang, Yao, and Li (2017) constructed the system dynamics model of PPP project risk evolution and their results, gathered using sensitivity analysis, showing that market risk had the greatest cumulative effect on the overall entropy of risk system. The AHP analysis method is another approach. Due to the lack of historical data on PPP projects, many scholars have tried to build F-AHP risk evaluation models through Delphi Expert Investigation and Fuzzy mathematics methods (Ebrahimnejad, Mousavi, & Seyrafianpour, 2010). In addition, Fault tree analysis, Failure mode and effect analysis are used. Fault tree analysis identifies and presents visual events and root causes which leads to risks (Abdelgawad & Fayek, 2010). Failure mode and effect analysis represent another method for evaluating the consequences of event failures to minimize the impacts; however, this approach uses more energy to select input and output variables (Abdelgawad & Fayek, 2010; Elbarkouky, MagdyAbouShady, & Marzouk, 2014).

The most widely used method of risk evaluation for PPP projects in China are AHP and ANP methods. He (2008) established a multi-level fuzzy risk evaluation model for hydropower infrastructure projects to determine the weight of risk factors based on a combination of hierarchical analysis and fuzzy evaluation theory. W. Zhang and W. D. Zhang (2012) used the Network Layer Method (ANP) to evaluate main risk factors, using hydropower PPP projects in Southeast Asian countries as an example. Liu and Sun (2018) established the evaluation model of project risk using the DEMATEL-ANP model. Other scholars have tried to combine fuzzy mathematics, neural network technology and analytic hierarchy process to construct risk evaluation models.

Several studies have applied fuzzy logic using a traditional approach, which can effectively deal with problems mentioned in the previous classical risk assessment techniques (Wu et al., 2017). Fuzzy logic does not depend on historical data, and provides imprecision and subjectivity in risk estimation, which can overcome the limitations of classic technologies. Some researchers have studied risk evaluation for PPP projects using the fuzzy Monte Carlo simulation (MCS) method to handle random and fuzzy uncertainties (Shaheen, Fayek, & AbouRizk, 2007; Sadeghi, Fayek, & Pedrycz, 2010; Kumar, Jindal, & Velaga, 2018). However, fuzzy MCS only estimates the combined effect of risks rather than the individual effect of each risk. Fuzzy logic method is always used in combination with AHP and ANP methods which facilitate risk decision making in PPP projects. Many researchers have adopted the F-AHP method to evaluate risks for PPP projects to achieve vague expert judgment and improve risk evaluation accuracy (Zhang & Zou, 2007; Fayek, Young, & Duffield, 1998; Li & Zou, 2011; Li, Phoon, Du, & Zhang, 2013; Feizi, Karbalaeiramezanali, & Mansouri, 2017). F-AHP can identify relationships in the probability of risk occurrence and the level of importance of risk events (Abdelgawad & Fayek, 2010; She & Tang, 2017). Valipour et al. (2015) applied a fuzzy analytical method process (F-ANP) to risk prioritization with a focus on interdependencies among risk factors for PPP freeway projects. Guneri, Cengiz, and Seker (2009) proposed the F-ANP address shipyard location selection. Additional applications of F-ANP have targeted decision-making problems (Karsak, Sozer, & Alpteki, 2003; Kahraman, Cebeci, & Ruan, 2004; Chung, Lee, & Pearn, 2005; Toosi & Samani, 2017; Zhao, Chen, Pan, & Lu, 2017).

Review of the existing literature reveals that there are studies which have evaluated risk factors in Chinese PPP projects. Researchers have attempted to identify and evaluate risks for PPP projects using various perspectives and methods. F-AHP and ANP are widely applied and more suitable than Monte Carlo simulation and sensitivity methods for complex, group decision-making problems. F-AHP assumes that each element in the same hierarchy is independent, thus not considering potential internal relationships and interdependence among these risks. ANP introduces interdependence among various factors and the interaction path but is stymied by inherent uncertainty and ambiguity from respondents' judgments. F-ANP and ISM have good ability addressed the aforementioned matters (Jajarmizadeh & Eslamloo, 2017; P. Zhang, Wang, P. Zhang, & Wu, 2017). However, such studies paid more attention to the identification of risk factors and ranking of impact degree under the hypothetical condition of an independent relationship among risk factors. Because of disconnect in application, it is problematic to rank risk factors without considering the correlation among risk factors and expert emotional responses. Hence, to appropriately address this gap, this paper proposed an integrated approach of F-ANP and ISM that has not been previously used for risk assessment in the construction field. This paper proposes an integrated approach of F-ANP and ISM to assess PPP project risks. The proposed method overcomes the limitations of existing research to provide risk management measures to ensure smooth project implementation. The objective of this paper is to propose a systematic and practical method for identifying and assessing PPP project risk factors. This method uses an integrated approach of F-ANP and ISM while considering complex interdependence and interactions among the risks, an approach which has not been previously used for risk assessment in the construction field.

The contributions of this study are as follows: (1) considering complex interdependence and interactions among the risks using ANP and ISM; (2) dealing with problems of measurement imprecision and subjective uncertainty of respondents' results, and reflecting different neutral, optimistic and pessimistic viewpoints from expert respondents' judgments with fuzzy numbers; (3) providing a framework to evaluate the driving and dependence power among risk factors with ISM method. This study will enable greater clarity and provide PPP managers with information on the impact of different risks. This paper will help risk managers identify the most influential and interdependence risk as well as the most essential risk in PPP projects. Further, this analysis could help PPP managers determine the sequences of risk management assignments and optimize risk management schemes according to rankings of different risk factors' impacts. In turn, this may aid developing countries in modifying their approaches, taking into account their respective economy, politics, culture, and social environment. In its present application, this work demonstrates how effective risk management measures may ensure smooth implementation of PPP projects in China.

2. Research method

The risk assessment process involves identifying risk factors, assessing risks, monitoring risks, and controlling risks. Risk assessment consists of a systematic analysis to determine how often specific events may occur and the magnitude of events' likely consequences. Risk assessment, which aims to establish proactive strategies for ensuring smooth project operation, is a key component in the risk management process. Risk assessment reveals risk factors more efficiently than conventional safety management. An appropriate risk assessment technique is required for risk management measures. It is vital to select the risk assessment method among several methods which have different steps and outputs. Risk evaluation method determines the validity of the analytic results. To evaluate the PPP project risks, this paper used fuzzy ANP and ISM approaches. The application of these two approaches is presented below.

2.1. ISM

Mandal and Deshmukh (1994) introduced ISM, considering the interrelationship among the evaluation objects. ISM became a popular analytical tool among researchers studying interdependence and factor interactions. This methodology helps decision makers understand the elements' relationships, priorities and their importance (Yin, Wang, Teng, & Hsing, 2012; Govindan, Shankar, & Kannan, 2016). Moreover, this methodology has been applied in various fields such as for policy analysis, supply chains, and other areas (Govindan, Palaniappan, Zhu, & Kannan, 2012; Kannan, Diabat, & Shankar, 2014; Tyagi, P. Kumar, & D. Kumar, 2015). ISM is effective in obtaining the structure of the elements (Tazaki & Amagasa, 1979). Therefore, this paper selected the ISM method to analyze the interrelationships among PPP project risk factors. Detailed application steps are as follows (Kannan & Haq, 2007; Govindan et al., 2015):

Step 1. Risks involved in the PPP projects are identified, and the risk index system is presented.

Step 2. Relationships among risks is developed based on Step 1.

Step 3. A structural self- interaction matrix is formed through pair-wise comparison of the risks.

Step 4. A reachability matrix is presented based on Step 3; this paper considered transitivity, such that X_1 is related to X_3 if X_1 is related to X_2 and X_2 is related to X_3.

Step 5. Reachability matrix from Step 4 is partitioned into different levels.

Step 6. An ISM structure diagraph is drawn according to the relationship shown by the reachability matrix.

Step 7. With the ISM structure diagraph, the influence and interrelationships among the risks are analyzed.

2.2. Fuzzy analytic network process (F-ANP)

Analytic network process (ANP) is a multi-criteria decision-making (MCDM) tool, which is used to calculate the weights of elements. ANP is the extended method of AHP, which does not consider interdependencies among elements. Furthermore, ANP is a network structure which can make results more accurate by considering the interdependencies of the factors (Jharkharia & Shankar, 2007). Therefore, ANP is widely used in many fields (Sipahi & Timor, 2010; Nixon, Dey, Ghosh, & Davies, 2013; Dou, Zhu, & Sarkis, 2014; Govindan et al., 2015). However, ANP depends on the maximum accuracy and least vagueness of experts' judgments to avoid potential biases related to the results. Fuzzy logic is applied with ANP to address this dynamic, potentially improving the results' precision (Govindan et al., 2015). Another issue is that ANP has difficulty addressing the complex interrelationships of a large number of factors (Dou & Sarkis, 2010). The integration of ANP and ISM can address the interdependence and interactions of factors, and can enable researchers to obtain more accurate feedback on complex problems (Govindan et al., 2016). This paper integrates ISM and ANP to analyze critical risk factors for Chinese PPP projects. Below, the steps of the F-ANP approach are discussed.

Step 1. Network model with dependencies

This approach constructs a network model presenting the relationship between the clusters (see Figure 1). Inner and outer dependence among the risks are shown in the model; the interdependencies among the criterion are also identified by ISM method.

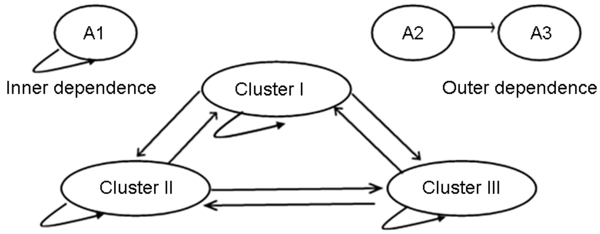

Figure 1. Network model with dependence

Table 1. The fuzzy linguistic scale for the experts' judgments

Linguistic terms	Triangular fuzzy numbers	Mean value
IVL	(1/4, 1/3, 1/2)	0.3611
IL	(1/6,1/5,1/4)	0.2056
IH	(1/8,1/7,1/6)	0.1448
IVH	(1/10,1/9,1/8)	0.1121
EQ	(1,1,1)	1
VH	(8,9,10)	9
H	(6,7,8)	7
L	(4,5,6)	5
VL	(2,3,4)	4
N	(0,0,0)	0

Step 2. Pair-wise comparison with fuzzy numbers

The interdependencies and the pair-wise comparison matrix are identified from the experts and decision makers based on their opinions about the factors. The fuzzy linguistic scale for the experts' judgments is converted into a triangular fuzzy scale, which reflects optimistic, neutral, and pessimistic judgments (Table 1).

Step 3. Defuzzification of triangular fuzzy numbers

This step is to convert the triangular fuzzy numbers into crisp numbers using the centroid defuzzification method.

Step 4. The relative weights of the criterion

The relative weights of the criterion and interdependencies are obtained based on Step 3.

Step 5. The super-matrix and limit matrix

The super matrix and limit matrix are completed using the weights from Step 4. The final priority weights of factors are obtained by raising the super matrix to the limit matrix. This step can be carried out using super decision software (Govindan et al., 2015).

Fuzzy logic is a way of transforming the vagueness of individuals' emotional feedback into a mathematical formula. The fuzzy analytic network process (F-ANP) technique is used to obtain the ranking of risk factors and may help risk managers understand the most essential risk. In this paper, the F-ANP approach is used for triangular fuzzy scale, which reflects optimistic, neutral, and pessimistic judgments for evaluating two risk factors. This method could deal with a shortcoming of crisp risk calculation, to decrease the inconsistency of decision-making. After a group of experts identifies risk factors, a pair-wise comparison matrix is constructed, and F-ANP is utilized to determine the weights of the risk factors. Then, the ranking of the risk factors was obtained by using experts' linguistic evaluations of each risk factor. Second, through the F-ANP technique, the ISM model is constructed to

Table 2. Survey respondent profiles

Characteristic	Categorization	Number of people	Ratio (%)
Expertise	Construction company (China Huadian Corporation)	30	25.00
	Local government department (Hebei Provincial Finance Department)	25	20.83
	Academic organizations (China University of Mining and Technology, Financial Research Institute of Training Center of Chinese Postal Service Group)	33	27.50
	Financial institutions (Hebei branch of China construction bank, Jianxin Insurance Asset Management Company Limited)	32	26.67
Working experience	Less than 6 years	34	28.33
	6–11 years	35	29.17
	12–15 years	25	20.83
	More than 15 years	26	21.67
Years involved in PPP projects	None	31	25.83
	Less than 3 years	34	28.33
	3–5 years	30	25.00
	More than 5 years	25	20.83
Number of PPP projects	None	27	22.50
	Less than 3 projects	37	30.83
	3–5 projects	31	25.83
	More than 5 projects	25	20.83

analyze the influence and interdependence of each risk. ISM structure diagram shows six risk hierarchy levels. Subsequently, a Cross impact matrix multiplication applied to classification (MIMAC) method was used. The risk factors were classified into these four clusters: Cluster I, Cluster II, Cluster III, and Cluster IV. The different dependence and driving power of risk factors are displayed. In the final step, the most influential and interdependent risk is determined, and the most essential risk is identified.

3. A risk index system for PPP Projects

3.1. Risk identification and classification

According to the *Guidelines for Successful Public and Private Partnerships* (European Commission, 2003), risk can be defined as "any factor, event or influence that threatens the successful completion of a project in terms of time, costs or quality". Because of the particularity of the infrastructure and the cooperation relations among different stakeholders in PPP projects, the risks are much more complicated. Participant cognizance regarding the conditions, the characteristics of risk factors, and the consequences of risk will directly affect willingness to share risk. Risks have been classified from different points of view. Li, Akintoye, Edwards, and Hardcastle (2005) proposed macro, medium, and micro levels for PPP risks. Other researchers have classified PPP project risks into internal risk and external risk (Shen, Platten, & Deng, 2006; Ng & Loosemore, 2007). To analyze the impact of each risk on other risks, and to determine their priorities for risk management, we followed the risk classification method of Li et al. (2005), which can comprehensively reflect risks in the total life cycle of PPP projects. Thus, risks for PPP projects were classified into three levels in terms of risk sources: i.e., macro, medium, and micro risks. We established a risk index system according to the characteristics of China's urbanization history. This approach will help public and private stakeholders formulate suitable risk management measures and implement risk identification, evaluation, sharing, and monitoring strategies.

3.2. Participants

With the finalized risk factors, we approached PPP experts to get their opinions regarding the risk factors. A total of 130 Chinese experts in PPP projects were invited to participate in our questionnaire investigation. A. P. C. Chan, Lam, D. W. M. Chan, Cheung, and Ke (2010) analyzed critical success factors for PPPs in infrastructure developments through 87 experts' completed questionnaires. Govindan et al. (2015) evaluated the factors and barriers in automotive parts remanufacturing with a F-ANP method based on 35 experts' responses. Therefore, the sample of this paper is adequate. This study's experts were from different professional fields in China, including construction companies participating in PPP projects, local government departments involved in or managing PPP projects (finance bureaus), academic organizations (researchers who have published books or reviewed papers on the PPP field), and financial institutions (loan institutions and insurance companies). Of the 130 questionnaires distributed, 120 valid questionnaires were collected: 30 from construction companies, 25 from local govern-

Table 3. Risk index system for PPP projects

First-level indexes	Second-level indexes	Third-level indexes
Macro risk	Political policy risk (C_1)	Government stability (X_{11})
		Expropriation and nationalization (X_{12})
		Legal and policy risk (X_{13})
		Poor political decision-making risk (X_{14})
		Government credit risk (X_{15})
		Fiscal risk (X_{16})
	Economic risk (C_2)	Inflation risk (X_{21})
		Foreign exchange and convertibility (X_{22})
		Interest rate risk (X_{23})
		Financing environment risk (X_{24})
	Social risk (C_3)	Public opposition risk (X_{31})
	Natural risk (C_4)	Environment risk (X_{41})
		Ground/weather conditions (X_{42})
		Force majeure (X_{43})
Medium risk	Project selection risk (C_5)	Market demand change (X_{51})
		Other project competition (X_{52})
		Land acquisition (X_{53})
	Financing stage risk (C_6)	Financial feasibility (X_{61})
		Project attraction (X_{62})
		Financial cost (X_{63})
	Design stage risk (C_7)	Delay in project (X_{71})
		Technical risk (X_{72})
	Construction stage risk (C_8)	Cost overruns (X_{81})
		Contract change (X_{82})
		Project quality (X_{83})
	Operation stage risk (C_9)	Operating costs overruns (X_{91})
		Maintenance charge overruns (X_{92})
		Operation revenue risk (X_{93})
		Pricing risk (X_{94})
		Government subsidies risk (X_{95})
		Security risk (X_{96})
Micro risk	Cooperation risk (C_{10})	Organization and coordination risk (X_{101})
		Rights, responsibility, and risk allocation between the cooperative parties (X_{102})
	Third-party risk (C_{11})	Third-party tort compensation risk (X_{111})
		Personnel risk (X_{112})

ment departments, 33 from academic organizations, and 32 from financial institutions. The distribution of experts' professional fields is shown in Table 2. We selected expert respondents according to the following standards: (1) familiar with ISM and fuzzy ANP approaches; (2) published papers or books on this topic; and (3) had been involved in PPP projects. The experts mainly included government officials, project company staff, scientific research personnel, and financial institutions.

3.3. Construction of a risk index system for PPP projects

Based on the existing literature and experts' opinions, the risk factors were identified. Using a hierarchy structure (Figure 1) after the results validation, we constructed a risk index system for PPP projects that included three first level risk factors, 11 second level risk factors, and 35 third level risk factors (Table 3). The collected risk factors were validated by an external professional team which ensured that the critical risks had been included.

The first level indices were macro, medium, and micro risks. The second level indices were $C = \{C_1, C_2, \cdots C_n\}$ and the third level indices were $X_k = \{X_{k1}, X_{k2}, \cdots X_{kn}\}$. It should be noted that the number of layers was determined by a system analysis of the hierarchy structure and the degree of relevance among indexes.

4. Application of a proposed method for risk assessment of PPP projects in China

4.1. Experts' opinion on risk factors

Using the risk index system from the previous step, the expert respondents' judgments were obtained. The fuzzy data collection method followed the approach of Dyer and Forman (1992). The pair-wise judgments from a specific number of experts can be correlated through mean calculation, consensus, vote or compromise, and specific model (Horenbeek & Pintelon, 2014). Consensus method was selected to combine the responses of the expert respondents; and pair-wise judgments could be correlated according to Table 1. The relative importance of the risk factors was identified using the linguistic scale in Table 1, based on the decision-makers' responses through the questionnaires. The questionnaire responses demonstrated the relative importance of risks. Each risk was compared to the other risks. Through repeated discussions on the questions, the experts provided their consensus responses regarding risks in the linguistic scale. In turn, these data were analyzed using the F-ANP and ISM methodologies in the following sections.

4.2. Application of ISM

In this section, ISM was applied to analyze the interrelationships among the risks.

Step 1. To develop SSIM

According to Govindan et al. (2015), with the assistance of the data from the experts, the SSIM was formed (Table 4), presenting the relationship among the risks. Four symbols are displayed to explain the interrelationships. Regarding the risk i and j, the assessments are as follows:

"O" – risk *i* and *j* are unrelated;
"X" – risk *i* and *j* influence each other;
"A" – risk *j* influences risk *i*;
"V" – risk *i* influences risk *j*.

Step 2. To obtain the reachability matrix

Based on the SSIM, the reachability matrix was formed. First, an initial reachability matrix was converted from the SSIM. If the interrelationship in the SSIM was "O" regarding (*i*, *j*), the value of (*i*, *j*) in the reachability matrix was set to 0 and (*j*, *i*) was set to 0. If the interrelationship in the SSIM was "X" regarding (*i*, *j*), the value of (*i*, *j*) in the reachability matrix was set to 1 and (*j*, *i*) was set to 1. If the interrelationship in the SSIM was "A" regarding (*i*, *j*), the value of (*i*, *j*) in the reachability matrix was set to 0 and (*j*, *i*) was set to 1. If the interrelationship in the SSIM was "V" regarding (*i*, *j*), the value of (*i*, *j*) in the reachability matrix was set to 1 and (*j*, *i*) was set to 0. The final reachability matrix was derived from the initial reachability matrix using *Matlab*.

Step 3. Partition of different levels

The reachability set, the antecedent set, and the intersection set were developed from the final reachability matrix. The reachability set contained the risk itself and the other risks which this risk influenced. The antecedent set contained the risk itself and the other risks which influenced this risk. The intersection set contained the common risks gathered in the reachability set and the antecedent set. Comparing the reachability set and the antecedent set for any risk, if the two sets were the same, the risk level was designated as Level I.

Step 4. Formation of ISM structure figure

The ISM structure figure was formed, presenting the interrelationships among the risks of PPP projects in China shown in Figure 2. The impact path among the risks can be clearly seen.

4.3. Application of F-ANP

After the analysis of the interrelationships among the risks, the F-ANP method was used in relation to the priority levels of risks.

Step 1. ANP model

The risk index system consisted of three levels: the objective level, criterion level, and alternative level. The objective level was the first level, which reflected the goal of the research. The criterion level was the second level, which explained the main risk factors. The alternative level was the third level, which showed the sub-risk factors. In accordance with the study aims, we focused on the alternative level of hierarchy to assess the priorities of risk factors of PPP projects.

Step 2. Pair-wise comparison in fuzzy numbers and defuzzification

The experts' responses, in linguistic form, were converted into triangular fuzzy numbers, and the pair-wise comparisons were formed. Then, crisp numbers were calculated from the fuzzy numbers using the centroid defuzzification method. The linguistic, fuzzy, and defuzzified pair-wise comparisons regarding X_{11} are presented in Tables 6–8. The pair-wise comparisons regarding X_{12}–X_{112} were similarly obtained.

Step 3. Super matrix and limit matrix

Here, we developed the super matrix and limit matrix with the super decision software. The priorities of risk factors could be obtained by raising the super matrix to the limiting matrix. The results are shown in Table 9.

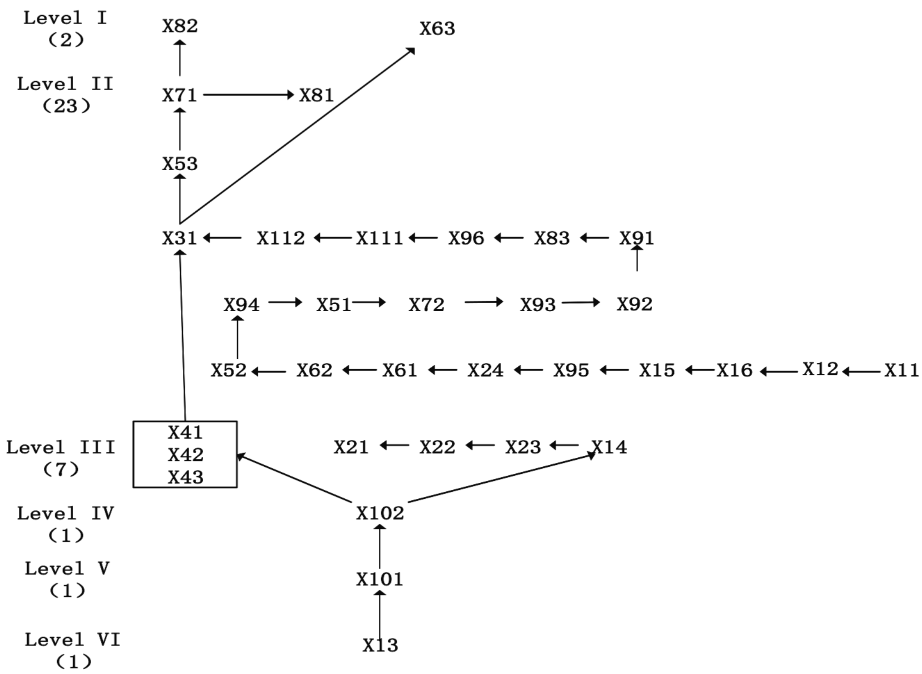

Figure 2. ISM model for risk factors of PPP projects

5. Analysis of results, and discussion

From the ISM structure diagram in Figure 2, the Legal and policy risk was located in the lowest level of the hierarchy, suggesting that this risk factor had more influence than other PPP project risks. Laws and regulations for PPP projects in China are still in their infancy, and projects can be affected by this risk. For example, Jiangsu Sewage Treatment Plant, Shanghai Dachang Waterworks and the Yanan East Road Tunnel encountered this risk, and the projects were eventually purchased by the government. Additionally, this risk factor' location was next to the organization and coordination risk, which held the second lowest level. Lack of training and coordination was also an important factor influencing completion of PPP projects in China. A proper tender prequalification system was necessary to encourage the training of contractors. The risk factors of the highest level were contract change and financial cost, which affirmed that two risks did not sufficiently influence PPP projects. Different levels of other risks were presented by the ISM model.

Figure 2 shows the ISM structure diagram for risks with six levels of hierarchy. To get a clear analysis of the interdependencies, a Cross impact matrix multiplication applied to classification (MIMAC) method was used. The risk factors were classified into these four clusters: Cluster I, Cluster II, Cluster III, and Cluster IV. Cluster I contained the elements with low dependence and low driving power. Figure 3 shows that no risk appears in Cluster I, which meant that no risk had low dependence and low driving power. Cluster II had elements with low driving power and high dependence. Only two risks, financial cost and contract change, held this location. Cluster III had risks with high driving power and dependence, which contained government stability, expropriation and nationalization, poor political decision-making risk, government credit risk, financing environment risk, public opposition risk, force majeure, market demand change, other projects competition, land acquisition, financial feasibility, project attraction, project quality, operating cost overruns, maintenance charge overruns, operation revenue risk, pricing risk, government subsidies risk, security risk, third-party tort compensation risk, and personnel risk. Cluster IV risks were in the status with high driving power and low dependence, which contained legal and policy risk, fiscal risk, inflation risk, foreign exchange and convertibility, interest rate risk, environment risk, ground/weather conditions, delay of project, technical risk, cost overruns, organization and coordination risk and rights, and responsibility and risk allocation between the cooperative parties.

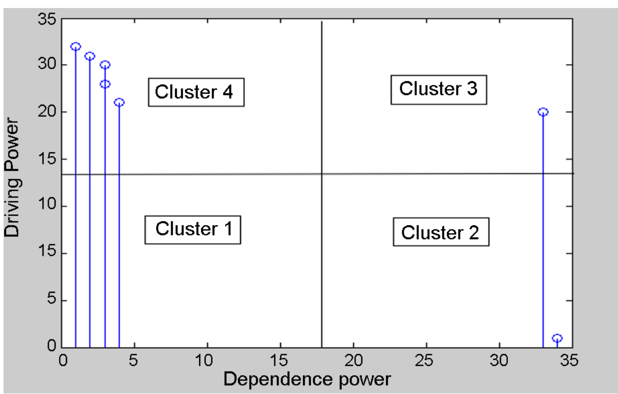

Figure 3. Driving and dependence power diagram (MICMAC analysis)

Table 4. Structural self-interaction matrix (SSIM)

	X_{112}	X_{111}	X_{102}	X_{101}	X_{96}	X_{95}	X_{94}	X_{93}	X_{92}	X_{91}	X_{83}	X_{82}	X_{81}	X_{72}	X_{71}	X_{63}	X_{62}	X_{61}	X_{53}	X_{52}	X_{51}	X_{43}	X_{42}	X_{41}	X_{31}	X_{24}	X_{23}	X_{22}	X_{21}	X_{16}	X_{15}	X_{14}	X_{13}	X_{12}
X_{11}	X	O	O	O	V	V	O	O	O	O	O	O	A	O	V	V	O	V	V	O	O	O	O	O	V	V	A	A	A	X	X	O	O	V
X_{12}	V	V	O	O	O	V	O	O	O	O	O	O	O	O	A	O	O	O	A	A	O	O	O	O	A	O	O	O	O	A	X	O	O	
X_{13}	O	O	V	V	O	V	V	O	O	O	O	O	O	O	O	O	O	O	V	O	O	O	O	O	O	V	O	O	O	O	O	O		
X_{14}	V	V	A	A	O	O	O	V	V	V	V	O	V	O	V	V	V	O	O	O	O	O	O	O	V	O	O	O	O	O	O			
X_{15}	V	O	A	O	O	X	O	V	O	O	O	O	O	O	V	V	O	V	O	O	O	O	O	O	V	O	O	O	A	A				
X_{16}	V	O	O	O	O	V	O	O	O	O	O	O	O	O	O	V	O	V	O	O	O	O	O	O	V	O	O	O	O					
X_{21}	V	O	O	O	O	V	V	V	V	V	V	O	V	O	V	V	V	V	O	O	V	O	O	O	O	V	X	X						
X_{22}	O	O	O	O	O	V	V	V	V	V	V	O	V	O	V	V	V	V	O	O	V	O	O	O	O	V	X							
X_{23}	O	O	O	O	O	V	V	V	V	V	V	O	V	O	V	V	V	V	O	O	V	O	O	O	O	V								
X_{24}	O	O	O	O	O	O	O	O	O	O	O	O	V	O	V	V	V	X	O	A	O	O	O	O	O									
X_{31}	X	V	A	A	A	A	O	O	O	O	A	V	V	A	X	V	X	O	V	O	O	A	A	A										
X_{41}	V	V	A	O	O	O	O	O	O	O	O	O	O	O	V	O	V	V	V	O	O	O	O											
X_{42}	O	V	A	O	O	O	O	O	O	O	O	O	O	O	0	O	O	O	O	O	O	O												
X_{43}	O	O	A	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O													
X_{51}	O	O	O	O	A	O	X	O	X	X	A	O	X	O	O	O	O	O	O	O														
X_{52}	O	O	O	O	O	O	X	V	V	V	V	O	V	V	V	V	X	V	V															
X_{53}	A	O	O	O	O	O	V	V	O	O	O	O	O	O	V	V	X	V																
X_{61}	A	O	O	A	O	O	X	O	O	O	O	O	V	O	V	V	A																	
X_{62}	A	O	A	O	A	A	X	O	O	O	O	O	O	O	V	V																		
X_{63}	A	O	O	O	O	A	A	O	O	O	O	O	O	O	O																			
X_{71}	A	V	A	A	O	V	O	O	V	V	O	V	V	O																				
X_{72}	O	O	O	O	V	O	O	V	V	V	V	O	V																					
X_{81}	A	O	A	A	O	O	V	V	V	V	V	O																						
X_{82}	O	O	A	O	O	A	A	O	O	O	O																							
X_{83}	V	V	O	O	V	O	V	V	V	V																								
X_{91}	O	O	O	O	O	O	V	V	O																									
X_{92}	O	O	O	O	O	O	V	V																										
X_{93}	A	O	A	A	O	O	A																											
X_{94}	O	O	O	O	O	O																												
X_{95}	V	O	O	O	O																													
X_{96}	V	V	A	O																														
X_{101}	V	O	V																															
X_{102}	V	O																																
X_{111}	O																																	

Table 5. Final reachability of F-ANP

	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{21}	X_{22}	X_{23}	X_{24}	X_{31}	X_{41}	X_{42}	X_{43}	X_{51}	X_{52}	X_{53}	X_{61}	X_{62}	X_{63}	X_{71}	X_{72}	X_{81}	X_{82}	X_{83}	X_{91}	X_{92}	X_{93}	X_{94}	X_{95}	X_{96}	X_{101}	X_{102}	X_{111}	X_{112}
X_{11}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{12}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{13}	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
X_{14}	1	1	0	1	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{15}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{16}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{21}	1	1	0	0	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{22}	1	1	0	0	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{23}	1	1	0	0	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{24}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{31}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{41}	1	1	0	0	1	1	0	0	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{42}	1	1	0	0	1	1	0	0	0	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{43}	1	1	0	0	1	1	0	0	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{51}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{52}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{53}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{61}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{62}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{63}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
X_{71}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{72}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{81}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{82}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
X_{83}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{91}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{92}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{93}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{94}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{95}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{96}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{101}	1	1	0	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
X_{102}	1	1	0	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
X_{111}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
X_{112}	1	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1

Finally, most risk factors were located in Cluster III, which had high driving and dependence power.

As Table 9 shows, interest rate risk held the first position, and organization and coordination risk followed. The last position was financial cost (X_{63}), contract change (X_{82}), operation revenue risk (X_{93}), and third-party tort compensation risk (X_{111}). In fact, there was a relationship between the influential and essential risks. From the ISM results, legal and policy risk, and organization and coordination risk, were more influential and interdependent risks; however, using the F-ANP method, these risks ranked in the fourth and second positions, respectively. It was clear that organization and coordination risk in the ISM structure and using the F-ANP method were located in the same position. Nevertheless, there was not complete consistency; this was because of the indirect influence of the other risks. For example, interest rate risk caused cost increase in the financing stage, construction stage and operation stage, such as increases in material prices, labor costs, and tax and loan cost. These dynamics may influence project benefit, which was ultimately related to project success or failure. Interest rate risk resulted from the legal and policy risk. In developing countries like China, monetary and fiscal policy is usually applied to economic regulation. Furthermore, interest rate is shown to be an important monetary policy tool in macroeconomic regulation and control.

Table 6. Pair-wise comparison with linguistic scale

X_{11}	X_{15}	X_{16}	X_{21}	X_{22}	X_{23}	X_{81}	X_{112}
X_{15}	EQ	VL	L	H	H	VH	VH
X_{16}	IVL	EQ	VL	L	L	H	VH
X_{21}	IL	IVL	EQ	VL	VL	L	H
X_{22}	IH	IL	IVL	EQ	VL	L	H
X_{23}	IH	IL	IVL	IVL	EQ	VL	L
X_{81}	IVH	IH	IL	IL	IVL	EQ	L
X_{112}	IVH	IVH	IH	IH	IL	IL	EQ

Table 7. Pair-wise comparison with fuzzy scale

X_{11}	X_{15}	X_{16}	X_{21}	X_{22}	X_{23}	X_{81}	X_{112}
X_{15}	(1,1,1)	(2,3,4)	(4,5,6)	(6,7,8)	(6,7,8)	(8,9,10)	(8,9,10)
X_{16}	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(4,5,6)	(4,5,6)	(6,7,8)	(8,9,10)
X_{21}	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(2,3,4)	(4,5,6)	(6,7,8)
X_{22}	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(4,5,6)	(6,7,8)
X_{23}	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(4,5,6)
X_{81}	(1/10,1/9,1/8)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(4,5,6)
X_{112}	(1/10,1/9,1/8)	(1/10,1/9,1/8)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)

Table 8. Pair-wise comparison with crisp number

X_{11}	X_{15}	X_{16}	X_{21}	X_{22}	X_{23}	X_{81}	X_{112}
X_{15}	1	3	5	7	7	9	9
X_{16}	0.3611	1	3	5	5	7	9
X_{21}	0.2056	0.3611	1	3	3	5	7
X_{22}	0.1448	0.2056	0.3611	1	3	5	7
X_{23}	0.1448	0.2056	0.3611	0.3611	1	3	5
X_{81}	0.1121	0.1448	0.2056	0.2056	0.3611	1	5
X_{112}	0.1121	0.1121	0.1448	0.1448	0.2056	0.2056	1

Table 9. Priorities of risk factors

Third-level indexes	Weight	Rank
Government stability (X_{11})	0.014827	22
Expropriation and nationalization (X_{12})	0.00557	27
Legal and policy risk (X_{13})	0.066986	4
Poor political decision-making risk (X_{14})	0.038635	10
Government credit risk (X_{15})	0.029144	12
Fiscal risk (X_{16})	0.046654	8
Inflation risk (X_{21})	0.060869	5
Foreign exchange and convertibility (X_{22})	0.03852	11
Interest rate risk (X_{23})	0.148656	1
Financing environment risk (X_{24})	0.027122	13
Public opposition risk (X_{31})	0.009765	23
Environment risk (X_{41})	0.008945	24
Ground/weather conditions (X_{42})	0.000145	30
Force majeure (X_{43})	0.000145	30
Market demand change(X_{51})	0.000266	29
Other projects competition (X_{52})	0.051404	6
Land acquisition (X_{53})	0.008238	25
Financial feasibility (X_{61})	0.017714	20
Project attraction (X_{62})	0.020711	17
Financial cost (X_{63})	0	32
Delay of project (X_{71})	0.025042	14
Technical risk (X_{72})	0.017499	21
Cost overruns (X_{81})	0.046178	9
Contract change (X_{82})	0	32
Project quality (X_{83})	0.019639	18
Operating costs overruns (X_{91})	0.02341	15
Maintenance charge overruns (X_{92})	0.018503	19
Operation revenue risk (X_{93})	0	32
Pricing risk (X_{94})	0.069633	3
Government subsidies risk (X_{95})	0.021926	16
Security risk (X_{96})	0.004047	28
Organization and coordination risk (X_{101})	0.102833	2
Rights, responsibility and risk allocation between the cooperative parties (X_{102})	0.049288	7
Third-party tort compensation risk (X_{111})	0	32
Personnel risk (X_{112})	0.007687	26

In China, government financial capital plays a central role in the provision of public infrastructure and services. In the early stages of the PPP application, the private sector's enthusiasm may not be high due to the limited profits in the public infrastructure and services. The financing environment is crucial to PPP projects. Financing difficulties can be caused by unreasonable financing structures, imperfect financial markets, financing accessibility, and other factors. Participants in PPP projects normally sign a franchise agreement after the winning bidder has been determined. The franchise agreement is valid if the bidder meets the financing plan deadline. Otherwise, the bidder is disqualified, and the bid guarantee is removed, as in the case of the Hunan Power Plant. Therefore, a better financing environment is favorable for PPP projects. Details on rights, responsibility and risk allocation between the cooperative parties are central in contract clauses. Vague or unclear contract clauses can lead to disputes at a later stage and expose the project to risk. The success of the Dalian Life Garbage Incineration project was attributed to detailed terms included in the franchise agreement regarding project implementation.

Government credit risk for PPP projects in China also warrants attention. The lack of specialized management institutions tends to increase financial risk in the future. Many PPP projects have become unattractive to private investors because of government credit problems. Government failure to act responsibly and fulfill contract obligations can pose a direct or indirect risk to projects. For example, Changchun Huijin Sewage Treatment Plant was started in 2000. The government department stopped paying cooperative enterprises any sewage disposal charges, and the project was repurchased by the government in 2005 after a nearly 2-year dispute. Another example was the Lianjiang Sino-French Water Supply Plant. The project contract required that Lianjiang Tap Water Company purchase not less than 60,000 m^3 of water daily in the first year. However, the actual daily amount purchased in Lianjiang was approximately 20,000 m^3. At the same time, the water price in Lianjiang was lower than the price agreed upon in the contract. Therefore, the Lianjiang municipal government and the Lianjiang Tap Water Company refused to fulfill the contract obligations, and the project failed. Additional cases involving government credit risk are the Jiangsu Sewage Treatment Plant and the Hunan Power Plant.

PPP projects' development in the UK, Australia and Russia are more mature than Chinese PPP projects. China has an imperfect legal apparatus for PPP. At present, local governments mainly formulate relevant laws and regulations about PPP according to regulation measures of the state council. Because of the complexity and long-term nature of PPP projects, current laws and regulations are insufficient in supporting sustainable development of PPPs. In particular, the lack of the provisions about project procurement, project evaluation, risk allocation, and project compensation mechanism, may give rise to obstacles to

PPP projects. Additionally, few PPP project participants in China are aware of design stage risks and always focus on maximizing their profit. The Tangxun Lake Sewage Treatment Plant of China is a typical case of equipment service problems, in which supporting facilities did not reach the design goals. In this case, the project was ultimately transferred to the water group of Wuhan City. Finally, the results from the ISM and F-ANP method were presented to the PPP experts. The experts disregarded that China has a certain gap compared with the countries with mature PPP operation experiences. The development of PPP in China requires various supports from the government, financial institutions, project enterprises, insurance institutes, and other participants, through incentives, compensation, distribution, rewards, and punishment mechanisms. Risk management will be a challenge in ensuring the smooth completion of PPP projects. Participants must abide by the principle of “interest-sharing and risk-sharing” with full enthusiasm and passion. This study can help PPP participants have a comprehensive understanding of project risks and rank the degree of risk influence, rather than use a crude approach based on preferences and biases.

6. Risk response strategy

This paper explored the risk evaluation of PPP projects in China and identified risk levels using ISM and F-ANP methods. Chinese scholars and researchers are striving to smooth the completion of PPP projects through effective risk management. This study provides a thorough understanding of PPP projects’ risks and offers support to construction managers in the form of a risk assessment tool. With the results of this paper, these individuals can ascertain critical risks and evaluate the influence degree of risks. In addition to this, this paper has societal contributions given that PPP projects can satisfy the sharply increasing demand for public facilities and services associated with further urbanization in China. With the intense demand for public facilities and services, and the huge debt burden on local government in China, PPP is regarded as a favorable option to meet infrastructure demands, reduce pressure on government finances, and improve the operational efficiency of projects. Moreover, the wide application of PPP projects may create more job opportunities, which would be beneficial to China. In light of the risk factors discussed above, the following risk response strategies are suggested to reduce the probability of risk occurrence and negative impacts of risks in PPP projects in China. Risk factors differ from one project to another. Thus, any risks identified are related to personal, project-related, and external factors. Risk assessment should be ongoing and dynamic because the impact of risks may change in different stages of a project. In consideration of the results, there are some prominent problems related to the risks of PPP projects in China, such as imperfect laws and regulations, ambiguous allocation of right, responsibility and risk, unstable national policy, and other risk factors. Therefore, some risk response strategies are recommended for project managers to help ensure smooth completion of PPP projects in the China.

First, government should promote laws and regulations of PPP projects, especially risk allocation, project evaluation, compensation, and a rewards and punishment mechanism.

Second, specific terms regarding the design details, ownership float, information sharing, material non-availability, technique application, response to price variation, delay damages, participants’ role, and government compensation, should be clearly defined in the contract. Participants should formulate appropriate contract clauses to clarify the allocation of right, responsibility and risks, thereby making the project attractive and raising participants’ enthusiasm.

Third, PPP projects should identify a suitable partner via an appropriate method instead of selecting the lowest tender which tends to involve higher risk. PPP managers should promote electronic tendering and online contract bidding for transparent bidding.

Fourth, government should implement credit promotion measures and financial supervision to reduce government credit risk. The key audit points for a PPP project are overall profitability, management ability, financial status, cash flow, and corresponding credit promotion measures. In practice, promotion measures such as equity pledges, accounts receivable usufruct, project company assets, and other social capital guarantees can be used to manage financing risk; PPP projects have diverse funding sources.

Conclusions

The importance of risk assessment is a matter of consensus among many researchers and PPP project practitioners. Risk assessment could help project managers establish suitable contractual terms that clearly define the rights and responsibilities of participants throughout the franchise cycle to avoid future crises. PPP projects are always plagued by risk, and successful operation depends on effectively managing and controlling risks. However, conventional methods in previous studies have failed to consider internal relationships and interdependence among the risks, inherent uncertainty, and ambiguity related to respondents’ judgments; this leads to inaccurate results. Hence, this paper proposed a systematic and practical method to evaluate risk factors of PPP projects in China using F-ANP and ISM, with ISM having the ability to address the above-stated problems. The results of the study are as follows:

1. The most influential and interdependent risk among 35 risk indices of PPP projects in China was legal and policy risk (see ISM structure diagram). This is consistent with previous research; for example, J. Song, D. Song, Zhang, and Sun (2013) identified 10 key risks, including legal and policy risk, of PPP waste-to-energy incineration projects, using in-

terviews and surveys. Chan et al. (2010) explored critical factors through an empirical questionnaire survey administered to Chinese experts, and legal framework risk was ranked first among eighteen critical factors in Chinese PPP projects. Of course, not all prior literature shows legal risk to be ranked first; for example, risk impact level of legal risk was ranked fourth in a piece by Li and Zou (2008). This discrepancy in results may be due to diversity in experts and research techniques.

Legal and policy risk's determinant role could be seen from the practice process of Chinese PPP projects. Chinese government departments and scholars have agreed that PPP projects need to be supported by appropriate policies and measures. Since China's first PPP projects launched in 2014, relevant procurement and project contracts have been promulgated. In January 2018, Chinese government departments mentioned that the design of PPP projects' tax system had become a key factor in determining the PPP development. Therefore, it is necessary to make appropriate supplements and amendments to current tax regulations and policies in a timely manner. In project contract law, the distribution of responsibilities among the parties must be clarified to ensure smooth operation of PPP projects. Accordingly, it can be seen that legal risk plays a crucial role in Chinese PPP projects.

2. Interest rate risk was the most essential risk, and organization and coordination risk ranked second in Chinese PPP projects, according to the rankings of risk impact through the F-ANP method. In some PPP project risk evaluation research, the risk impact degree of interest rate has been ranked lower; this may be because some researchers used F-AHP, a process which does not consider interactions among risk factors. In fact, interest rate changes affect project construction cost, financing cost and other factors. However, some studies have assumed that these risk factors were independent. This may lead to a disassociation of the findings from the actual situation. For organization and coordination risk, Chan et al. (2010) proposed that the distribution of responsibilities between public and private sectors and the degree of coordination of project operations is a key in the success of PPP projects.

Finally, these results are validated by the existing literature and by experts in related fields. This study is analyzed using theories and Chinese practice through the assistance of project decisionmakers and experts' feedback. Based on the feedback of the experts, and results from the ISM and F-ANP methods, risk response strategies were outlined for risk management of PPP projects in China.

This study may engender a comprehensive understanding of the risks of PPP projects and of how to manage risks, in priority order, according to the degree of risk influence. Although this study addressed the scientific and societal meaning of PPP projects in China, it had some limitations. There is a certain diversification due to geographical differences among countries. In different areas, the forms and degree of influence of PPP risks were disparate. When applied to specific projects, a statistical analysis of the results was needed for empirical validation. In addition to this, only 35 risk indices were introduced into the risk index system of Chinese PPP projects. There are other risk factors which may be sub-factors of the 35 risk indices. Thus, the risks may not fully reflect all the factors due to the dynamic change of risks. In the future, other sub-factors may be added into the index system and analyzed, by building upon this study's methodology as a pioneering or benchmarking study. This study may help shed some light on the context of risk factors in PPP projects.

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References

Abdelgawad, M., & Fayek, A. R. (2010). Risk management in the construction industry using combined Fuzzy FMEA and Fuzzy AHP. *Journal of Construction Engineering and Management*, *136*(9), 1028-1036. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000210

Chan, A. P. C., Lam, P. T. I., Chan, D. W. M., Cheung, E., & Ke, Y. (2010). Critical success factors for PPPs in infrastructure developments: Chinese perspective. *Journal of Construction Engineering and Management*, *136*(5), 484-494. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000152

Chung, S. H., Lee, A. H., & Pearn, W. L. (2005). Product mix optimization for semiconductor manufacturing based on AHP and ANP analysis. *The International Journal of Advanced Manufacturing Technology*, *25*(11), 1144-1156. https://doi.org/10.1007/s00170-003-1956-8

Dou, Y., & Sarkis, J. (2010). A joint location and outsourcing sustainability analysis for a strategic off shoring decision. *International Journal of Production Research*, *48*(2), 567-592. https://doi.org/10.1080/00207540903175145

Dou, Y., Zhu, Q., & Sarkis, J. (2014). Evaluating green supplier development programs with a grey-analytical network process-based methodology. *European Journal of Operational Research*, *233*(2), 420-431. https://doi.org/10.1016/j.ejor.2013.03.004

Dyer, R. F., & Forman, E. H. (1992). Group decision support with the analytic hierarchy process. *Decision Support Systems*, *8*(2), 99-124. https://doi.org/10.1016/0167-9236(92)90003-8

Ebrahimnejad, S., Mousavi, S. M., & Seyrafianpour, H. (2010). Risk identification and assessment for build-operate transfer projects: a fuzzy multi attribute decision making model. *Expert Systems with Applications*, *37*(1), 575-586. https://doi.org/10.1016/j.eswa.2009.05.037

Elbarkouky, M. M. G., MagdyAbouShady, A., & Marzouk, M. (2014). Fuzzy consensus qualitative risk analysis framework for real estate projects. *International Journal of Architecture, Engineering and Construction*, *3*(3), 195-209. https://doi.org/10.7492/IJAEC.2014.016

European Commission. (2003). *Guidelines for successful public-private partnerships*. Retrieved from http://ec.europa.eu/regional_policy/sources/docgener/guides/ppp_en.pdf

Fayek, A., Young, D. M., & Duffield, C. F. (1998). A survey of tendering practices in the Australian construction industry. *Engineering Management Journal*, *10*(4), 29-34. https://doi.org/10.1080/10429247.1998.11415005

Feizi, F., Karbalaeiramezanali, A., & Mansouri, E. (2017). Calcic iron skarn prospectivity mapping based on fuzzy AHP method, a case study in Varan area, Markazi province, Iran. *Geosciences Journal*, *21*(1), 123-136. https://doi.org/10.1007/s12303-016-0042-9

Govindan, K., Diabat, A., & Shankar, K. M. (2015). Analyzing the drivers of green manufacturing with fuzzy approach. *Journal of Cleaner Production*, *96*(1), 182-193. https://doi.org/10.1016/j.jclepro.2014.02.054

Govindan, K., Palaniappan, M., Zhu, Q., & Kannan, D. (2012). Analysis of third party reverse logistics provider using interpretive structural modeling. *International Journal of Production Economics*, *140*(1), 204-211. https://doi.org/10.1016/j.ijpe.2012.01.043

Govindan, K., Shankar, K. M., & Kannan, D. (2016). Application of fuzzy analytic network process for barrier evaluation in automotive parts re-manufacturing towards cleaner production-a study in an Indian scenario. *Journal of Cleaner Production*, *114*, 199-213. https://doi.org/10.1016/j.jclepro.2015.06.092

Guneri, A. F., Cengiz, M., & Seker, S. (2009). A fuzzy ANP approach to shipyard location selection. *Expert Systems with Applications*, *36*(4), 7992-7999. https://doi.org/10.1016/j.eswa.2008.10.059

He, J. (2008). Financing risk evaluation model for hydropower projects based on multi-level dynamic fuzzy evaluation. *Guangxi Water Conservancy and Hydropower*, *2*, 29-32 (in Chinese).

Horenbeek, A. V., & Pintelon, L. (2014). Development of a maintenance performance measurement framework-using the analytic network process (ANP) for maintenance performance indicator selection. *Omega*, *42*(1), 33-46. https://doi.org/10.1016/j.omega.2013.02.006

Jajarmizadeh, M., & Eslamloo, F. (2017). The effects of TQM practices on innovation using an ISM/Fuzzy-ANP approach. *International Business Management*, *11*(3), 635-648.

Jharkharia, S., & Shankar, R. (2007). Selection of logistics service provider: an analytic network process (ANP) approach. *Omega*, *35*(3), 274-289. https://doi.org/10.1016/j.omega.2005.06.005

Kahraman, C., Cebeci, U., & Ruan, D. (2004). Multi-attribute comparison of catering service companies using fuzzy AHP: The case of Turkey. *International Journal of Production Economics*, *87*(2), 171-184. https://doi.org/10.1016/s0925-5273(03)00099-9

Kannan, D., Diabat, A., & Shankar, K. M. (2014). Analyzing the drivers of end-of-life tire management using interpretive structural modeling (ISM). *International Journal of Advanced Manufacturing Technology*, *72*(9–12), 1603-1614. https://doi.org/10.1007/s00170-014-5754-2

Kannan, G., & Haq, A. N. (2007). Analysis of interactions of criteria and sub-criteria for the selection of supplier in the built-in-order supply chain environment. *International Journal of Production Research*, *45*(17), 3831-3852. https://doi.org/10.1080/00207540600676676

Karsak, E. E., Sozer, S., & Alpteki, S. E. (2003). Product planning in quality function deployment using a combined analytic network process and goal programming approach. *Computers and Industrial Engineering*, *44*(1), 171-190. https://doi.org/10.1016/s0360-8352(02)00191-2

Ke, Y. J., Wang, S. Q., Chan, A. P. C., & Lam, P. T. I. (2010). Preferred risk allocation in China's public-private partnership (PPP) projects. *International Journal of Project Management*, *28*(5), 482–492. https://doi.org/10.1016/j.ijproman.2009.08.007

Kirchsteiger, C. (1999). On the use of probabilistic and deterministic methods in risk analysis. *Journal of Loss Prevention in the Process Industries*, *12*(5), 399-419. https://doi.org/10.1016/S0950-4230(99)00012-1

Kumar, L., Jindal, A., & Velaga, N. R. (2018). Financial risk assessment and modelling of PPP based Indian highway infrastructure projects. *Transport Policy*, *61*(2), 2-11. https://doi.org/10.1016/j.tranpol.2017.03.010

Li, B., Akintoye, A., Edwards, P. J., & Hardcastle, C. (2005). The allocation of risk in PPP/PFI construction projects in UK. *International Journal of Project Management*, *23*(1), 25-35. https://doi.org/10.1016/j.ijproman.2004.04.006

Li, F. W., Phoon, K. K., Du, X. L., & Zhang, M. J. (2013). Improved AHP method and its application in risk identification. *Journal of Construction Engineering and Management*, *139*(3), 312-320. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000605

Li, J., & Zou, P. X. W. (2008). Risk identification and assessment in PPP infrastructure projects using fuzzy analytical hierarchy process and life-cycle methodology. *Australian Journal of Construction Economics and Building*, *8*(1), 32-46. https://doi.org/10.5130/ajceb.v8i1.2996

Li, J., & Zou, P. X. W. (2011). Fuzzy AHP-based risk assessment methodology for PPP projects. *Journal of Construction Engineering and Management*, *137*(12), 1205-1209. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000362

Liu, H., & Sun, H. (2018). PPP project financing risk analysis based on DEMATEL-ANP. *Journal of Systems Science*, *26*(1), 131-135 (in Chinese).

Liu, Q. N., Wang, Y. W., Yao, M. L., & Li, J. (2017). Evolution and simulation of operational risk of PPP project based on system dynamics. *Journal of Engineering Management*, *31*(5), 57-61 (in Chinese).

Liu, R. (2014). *Urbanization rate 70% needs 50 trillion investments*. Retrieved from http://news.cnfol.com/huiyihuodong/20140506/17783242.shtml

Lyons, T., & Skitmore, M. (2004). Project risk management in the Queensland engineering construction industry: a survey. *International Journal of Project Management*, *22*(1), 51-61. https://doi.org/10.1016/S0263-7863(03)00005-X

Mandal, A., & Deshmukh, S. G. (1994). Vendor selection using interpretive structural modelling (ISM). *International Journal of Operations and Production Management*, *14*(6), 52-59. https://doi.org/10.1108/01443579410062086

McKinsey. (2013). *China is expected to spend more than $16 trillion on infrastructure from 2013 to 2030*. Retrieved from http://news.cnfol.com/130326/101,1277,14707166,00.shtml

Ministry of Finance of the People's Republic of China. (2018). *The ministry of finance actively normalizes PPP mode and the number and investment funds of PPP projects continue to grow*. Retrieved from http://www.chinappp.cn/News/NewsDetail/10267.html

Ng, A., & Loosemore, M. (2007). Risk allocation in the private provision of public infrastructure. *International Journal of Project Management*, *25*(1), 66-76. https://doi.org/10.1016/j.ijproman.2006.06.005

Nixon, J. D., Dey, P. K., Ghosh, S. K., & Davies, P. A. (2013). Evaluation of options for energy recovery from municipal solid waste in India using the hierarchical analytical network process. *Energy*, *59*, 215-223. https://doi.org/10.1016/j.energy.2013.06.052

Sadeghi, N., Fayek, A. R., & Pedrycz, W. (2010). Fuzzy Monte Carlo simulation and risk assessment in construction. *Computer-Aided Civil and Infrastructure Engineering*, *25*(4), 238-252. https://doi.org/10.1111/j.1467-8667.2009.00632.x

Salah, A., & Moselhi, O. (2015). Contingency modelling for construction projects using fuzzy set theory. *Engineering Construction and Architectural Management*, *22*(2), 214-241. https://doi.org/10.1108/ecam-03-2014-0039

Shaheen, A. A., Fayek, A. R., & AbouRizk, S. M. (2007). Fuzzy numbers in cost range estimating. *Journal of Construction Engineering and Management*, *133*(4), 325-334. https://doi.org/10.1061/(ASCE)0733-9364(2007)133:4(325)

She, L., & Tang, S. (2017). Research on the performance evaluation of the contract governance in the PPP mode based on AHP. In *International Conference on Construction and Real Estate Management* (pp. 309-317). Guangzhou, China. https://doi.org/10.1061/9780784481059.032

Shen, L. Y., Platten, A., & Deng, X. P. (2006). Role of public-private partnerships to manage risks in public sector projects in Hong Kong. *International Journal of Project Management*, *24*(7), 587-594. https://doi.org/10.1016/j.ijproman.2006.07.006

Sipahi, S., & Timor, M. (2010). The analytic hierarchy process and analytic network process: an overview of applications. *Management Decision*, *48*(5), 775-808. https://doi.org/10.1108/00251741011043920

Song, J., Song, D., Zhang, X., & Sun, Y. (2013). Risk identification for PPP waste-to-energy incineration projects in China. *Energy Policy*, *61*(9), 953-962. https://doi.org/10.1016/j.enpol.2013.06.041

Songer, A. D., Diekmann, J., & Pecsko, R. S. (1997). Risk analysis for revenue dependent infrastructure projects. *Construction Management and Economics*, *15*(4), 377-382. https://doi.org/10.1080/014461997372935

Tazaki, E., & Amagasa, M. (1979). Structural modeling in a class of systems using fuzzy sets theory. *Fuzzy Sets and Systems*, *2*(1), 87-103. https://doi.org/10.1016/0165-0114(79)90018-6

Toosi, S. L. R., & Samani, J. M. V. (2017). Prioritizing watersheds using a novel hybrid decision model based on fuzzy DEMATEL, Fuzzy ANP and Fuzzy VIKOR. *Water Resources Management*, *31*(9), 2853-2867. https://doi.org/10.1007/s11269-017-1667-9

Tyagi, M., Kumar, P., & Kumar, D. (2015). Analysis of interactions among the drivers of green supply chain management. *International Journal of Business Performance and Supply Chain Modelling*, *7*(1), 92-108. https://doi.org/10.1504/IJBPSCM.2015.068137

Valipour, A., Yahaya, N., Md Noor, N., Kildienė, S., Sarvari, H., & Mardani, A. (2015). A fuzzy analytic network process method for risk prioritization in freeway PPP projects: an Iranian case study. *Journal of Civil Engineering and Management*, *21*(7), 933-947. https://doi.org/10.3846/13923730.2015.1051104

Woodward, D. G. (1995). Use of sensitivity analysis in build own-operate-transfer project evaluation. *International Journal of Project Management*, *13*(4), 239-246. https://doi.org/10.1016/0263-7863(95)00016-J

Wu, Y., Li, L., Xu, R., Chen, K., Hu, Y., & Lin, X. (2017). Risk assessment in straw-based power generation public-private partnership projects in China: A Fuzzy Synthetic Evaluation analysis. *Journal of Cleaner Production*, *161*(9), 977-990. https://doi.org/10.1016/j.jclepro.2017.06.008

Ye, S., & Tiong, R. K. L. (2000). Government support and risk-return trade-off in China's BOT power projects. *Engineering, Construction and Architectural Management*, *7*(4), 412-422. https://doi.org/10.1108/eb021163

Yin, S. H., Wang, C. C., Teng, L. Y., & Hsing, Y. M. (2012). Application of DEMATEL, ISM, and ANP for key success factor (KSF) complexity analysis in RD alliance. *Scientific Research and Essays*, *7(19)*, 1872-1890.

Zhang, G., & Zou, P. X. W. (2007). Fuzzy analytical hierarchy process risk assessment approach for joint venture construction projects in China. *Journal of Construction Engineering and Management*, *133*(10), 771–779. https://doi.org/10.1061/(ASCE)0733-9364(2007)133:10(771)

Zhang, P., Wang, L. P., Zhang, P., & Wu, Y.Q. (2017). Sustainability performance evaluation model on PPP projects. *Techno-economics and Management Research*, *2*, 14-17 (in Chinese).

Zhang, W., & Zhang, W. D. (2012). Risk Evaluation study of PPP project based on network hierarchy analysis (ANP). *Project Management Technology*, *10*(10), 84-88 (in Chinese).

Zhao, X., Chen, L., Pan, W., & Lu, Q. (2017). AHP-ANP-Fuzzy Integral integrated network for evaluating performance of innovative business models for sustainable building. *Journal of Construction Engineering and Management*, *143*(8). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001348