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Evaluation and Ranking of Risk Factors in Transnational Public-Private Partnerships Projects: Case Study Based on the Intuitionistic Fuzzy Analytic Hierarchy Process

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Abstract

Due to the growing trend of world economic globalization and "The Belt and Road" initiative launched by the Chinese government, transnational public-private partnership (TPPP) has become a crucial way for construction and investment companies to invest in other countries. However, investing in another country for PPP projects is not free of risks, due mainly to the unfamiliarity with different environments and conditions. This paper aims at identifying and evaluating risk factors in TPPP projects. Drawing on the X hydropower project, the identified 22 critical risk factors affecting the TPPP project were assessed by industry experts who had direct involvement in the project. The intuitionistic fuzzy analytic hierarchy process (IFAHP) technique was used in the assessment of the risk factors. The results indicated that technology risk, natural environment risk, construction risk, administrative risk, and political risk were the top five risk factors. The findings of this study improve the understanding of the risk factors in TPPP projects and could be useful for risk management professionals and researchers. Future research is needed to develop risk assessment and management models for TPPP projects, based on current risk factors in TPPP projects.

Author keywords: Transnational public-private partnerships; Risk factors; Intuitionistic fuzzy analytic hierarchy process; Case study.

Introduction

Over the last several decades, public-private partnership (PPP) has become popular in many countries, including the UK, the USA, Australia, South Africa, China, and other developing countries. It has increasingly been embraced as an effective way to deliver infrastructure projects (Cabaniss 2002; Hodge and Greve 2007). PPP combines the advantages of competitive tendering and flexible negotiation to achieve higher efficiency and better monitoring of projects (Aliu et al. 2014), and it is a strategy to share risks and benefits between public and private sectors (Bing et al. 2005). Due to the long period and complex stakeholder relationships involved in PPP contracts, risk management in PPPs has attracted considerable attention from both scholars and practitioners. However, the lack of systematic risk assessment and management frameworks has been one of the critical reasons for the failures of PPP projects (Li and Zou 2011).

Along with the development of the world economy's globalization and intergradation, companies are trying to seek different opportunities and new markets to expand their business (Hall 2002). Similarly, in the PPP area, international or transnational PPP projects create larger markets for global investors. The Chinese government published "The Belt and Road Initiative" in 2015, which has led to an increasing cross-country investment trend. Infrastructure is one of the most important objectives of this strategy because many countries along "The Belt and Road" are developing countries with huge infrastructure gap of investment, construction and procurement. Some consider Transnational PPP (TPPP) as one of the most efficient methods to procure infrastructure projects from across different countries (Yu et al. 2017). TPPP has been defined as a "continuous and relatively institutionalized transboundary interactions between public and private actors that formally strive for the provision of collective goods, whereas private actors can be for-profit and/or civil society organizations" (Schäferhoff et al. 2009).

TPPP has been adopted in various industries, such as transportation, water plant, and power plant. For example, a foreign-owned company from France invested in the Laibin B Power Plant which is the first Build–Operate–Transfer (BOT) project in China. Another project in the Caribbean Island of Aruba named “The Green Corridor” has its main goals to include creating interests and promoting networks and consortiums for both local and international parties (Aruba 2011). In such kind of projects, host governments play important roles to select suitable private sectors, accepting the responsibility to create an attractive investment climate and properly preparing projects to stimulate interests from private companies (Wibowo and Alfen 2015). However, given the complexity of TPPP projects, uncertainties, challenges and conflicts are virtually inevitable during implementation (Buurman et al. 2009). Adaptation to different cultures and environments in a short period, establishment a long-term relationship between foreign investors and the local government, and a short duration to familiarize oneself with the local legislations are a few examples of well-recognized risks of TPPP (Parola et al. 2013; Ritter 2010; Wibowo and Alfen 2015).

Over the years, studies have been done to understand and highlight the risk factors in domestic PPP projects. However, only limited scholarly attention has been directed toward the need to analyse the risk factors in TPPP projects (Schäferhoff 2009). In order to successfully manage TPPP projects, it is necessary to identify and evaluate their potential risks. The objective of this study is to propose an intuitionistic fuzzy analytical hierarchy process (IFAHP) as a risk assessment framework to handle the vagueness of expert judgments and improve the assessment accuracy. By using this method, participated experts used intuitionistic fuzzy sets to evaluate the occurrence possibility and severity of each risk factor in AHP matrix. The findings of this study help in better understanding the key risks in TPPP projects. With a better understanding of the key risks, practitioners, stakeholders, and policy makers could adequately prepare for the possible risks to be encountered in their TPPP projects.

Literature Review

Risk Assessment in PPP

The number of publications relating to risk management in PPP projects is increasing, because risks have been considered crucial and are of interest to both scholars and practitioners (Ke et al. 2009). There are four main stages in risk management in PPP projects, including risk identification, risk assessment, risk allocation and risk response (Ameyaw and Chan 2015a). Risk identification is the initial stage, which has been considered the most important stage in risk management during the whole lifecycle of PPP. Hence, the subsequent risk management tasks are all inherently dependent on the input of risk inventory from the first stage (Dey and Ogunlana 2004).

The primary purposes of performing an evaluation of risk factors in PPP projects are to identify the critical risk factors, and analyse the extent to which risks may negatively impact the success of the projects or the objectives of the stakeholders. Probability and severity are the two most important attributes to measure risk factors and have been widely used. Thomas et al. (2006) presented a probability-impact assessment framework, involving evaluation of occurrence probability of each risk factor and their impact on stakeholders' objectives like cost, time, quality and safety. After risk evaluation, the impact of each risk factors can be calculated and ranked. Ameyaw and Chan (2015b) adopted fuzzy synthetic evaluation approach to measure the probability and severity of risk factors to calculate the risk impact for water supply PPP projects in developing countries. Ke et al. (2011) used a two-round Delphi survey to identify the key risks in China's PPP projects. The probability of occurrence and severity of the consequence were derived from surveys to calculate each risk factor's significance index score.

For TPPP projects, foreign investors need to identify the relevant risks in host countries before making investment decisions in order to avoid high uncertainties. They should understand the applications of antifragility for projects and outline the potential risks through the use of local governance, data collection and a bimodal strategy for infrastructure development (Babovic et al. 2017). Wang et al. (2000) focused on the critical risk factors in TPPP projects, analysing foreign exchange risk and revenue risk in China's BOT projects. Chou and Pramudawardhani (2015) presented a cross-country study that compared drivers, critical success factors and risk allocation strategies in Taiwan, Singapore, China, the United Kingdom and Indonesia, showing differences in these regions to help foreign investors make informed investment decisions.

The literature review above identifies that while many studies exist on the identification, evaluation, and ranking of risk factors in PPP projects, studies that are specifically focusing on risk analysis in TPPP projects are limited. Therefore, carrying out a study that is specifically focused on the analysis of risk factors in TPPP projects is relevant. (Xu and Liao 2014)

IFAHP Method

IFAHP is an extended version of the analytic hierarchy process (AHP) and the fuzzy analytic hierarchy process (FAHP) methods. It is useful for solving complex multi-criteria decision-making problem (Xu and Liao 2014). AHP is a useful theory of relative measurement in the form of pairwise comparisons by decomposing a complex problem into simple and multilevel hierarchical structures. It can incorporate both tangible and intangible judgement criteria in a decision problem and analyse/model them based on the formalisation of experts' knowledge and experience (Saaty 1988). It is known that the traditional AHP is not able to handle the inherent uncertainty and vagueness in human judgements(Xu and Liao 2014). To overcome this limitation of the traditional AHP, the fuzzy set theory (FST) has been proposed as a viable method that could allow decision makers to use unquantifiable and non-obtainable information and partially ignorant facts to make sound decisions (Kulak et al. 2005). The approach of combining the FST and AHP is known as the FAHP. The first study on FAHP was by Van Laarhoven and Pedrycz (1983), which used triangular membership to describe fuzzy weights and fuzzy performance scores for ranking alternatives. Buckley (1985) complemented the traditional AHP with fuzzy utilities by using fuzzy numbers in the comparison process. Chang (1996) introduced a new method to derive priorities for comparison ratios by triangular fuzzy numbers, which was adopted in many areas, such transportation management (Kulak and Kahraman 2005) and safety management (Dağdeviren and Yüksel 2008).

Intuitionistic fuzzy set (IFS) is extended by fuzzy set which is characterized by a membership function, a non-membership function, and a hesitancy function (Atanassov and Gargov 1989; Atnassov 1999). When decision makers make decisions, they may not clearly indicate the extent to which one alternative is better than others (Herrera-Viedma et al. 2007), or they are unable to express their preferences accurately because of the lack of sufficient knowledge of the alternatives (Mitchell 2004). It is possible that decision makers are not sure to provide preferences between the alternatives and providing an accurate certain preference degree (Deschrijver and Kerre 2003). IFS is a useful method to solve this problem, which has become popular in a broad range of areas, such as decision making (Atanassov et al. 2005; Bing et al. 2005; Herrera-Viedma et al. 2007; Xu 2007), medical diagnosis (De et al. 2001), fuzzy cognitive maps (Papageorgiou and Iakovidis 2013), and fuzzy hardware (Zavala and Nieto 2012).

IFAHP is an extended form of FAHP that combines the advantages of both AHP method and IFS. It can be used to solve more complex problems, where decision makers might have uncertainty in providing preference values of the alternatives (Xu and Liao 2014). Some applications of the IFAHP method in different fields are summarized in Table 1. Table 1 shows the extensive application of the IFAHP method and its versatility in modelling and decision-making processes in practical and complex multicriteria problems. Sadiq and Tesfamariam (2009) adopted the IFAHP method in environmental decision-making under uncertainty. Kaur (2014) applied the IFAHP in solving the vendor selection problem.

Especially in the PPP industry, risk estimation is confronted with challenges such as shortage of data. In such cases, subjective estimations were made by experts with practical knowledge in the field of interest. In some situations, the decision makers might be reluctant or unable to assign the crisp evaluation values to the comparative judgements due to their limited knowledge. IFAHP is a useful way to handle the subjective preferences of experts in assigning the evaluation values to the risk evaluation. (Nguyen 2016). Therefore, in this study, IFAHP was applied to handle both the vagueness and ambiguity related to uncertainties in the risk factors evaluation and ranking in TPPP projects.

Please insert Table 1 here

Research Method

The Framework of IFAHP Used in Risk Assessment

This research was carried out step by step, with the process shown in Fig. 1. In stage 1, literature review was used to identify the risk factors, then the risk factor list was revised and categorized in stage 2. In stage 3, questionnaire was applied to collect data from experts who have experience and knowledge in the TPPP project. The experts were asked to assess each factor based upon two dimensions – probability and severity, using intuitionistic fuzzy set to provide their preferences for the alternatives. After that, evaluation index system was set up for the risk factor probability and severity, respectively, in stage 4. In stage 5, the consistency index was checked and adjusted. In stage 6, the weighting functions were calculated and integrated. The risk factor impact could be calculated using the multiplication formula based on the grade of possibility and severity.

Please insert Fig. 1 here

Identification of Risk Factors

Identification of risk factors in TPPP projects is the initial stage to achieve the project success. One important method of risk identification is to develop a risk checklist (or catalogue) (Bing et al. 2005). In the current study, a two-step method was applied to establish the risk factor list of TPPP projects. The first stage is to identify risk factors through literature review (e.g., Beisheim and Campe (2012), Schäferhoff et al. (2009), Chou and Pramudawardhani (2015), Meng et al. (2011), Rebeiz (2012)). Thirty-seven papers related to risk factors of TPPP projects were identified from the Scopus database, which were comprehensively reviewed to identify 42 risk factors (Yu et.al., 2017).

Establishing a IFAHP Tool for Evaluating TPPP Projects Risk Level

Step 1: Set Up the Evaluation Index System

To develop the IFAHP method, the risk factor evaluation is provided. Four first grade indexes $(A_j, j = 1,2,3,4)$, namely financial/commercial risk category (A_1), legal and socio-political risk category (A_2), technical and natural risk category (A_3), partnership risk category (A_4). Two performance criterias, including possibility (C_1) and severity (C_2), are used to evaluate all alternatives and rank these risk factors.

Step 2: Build the Intuitionistic Fuzzy Judgment Matrix

Intuitionistic fuzzy judge matrix is generated using pairwise comparisons. All the pairwise comparison judgments are represented by IFVs (intuitionistic fuzzy value), so the intuitionistic preference relation can be obtained naturally. Xu (2007) defined the intuitionistic preference relation R on the set $X = \{x_1, x_2, \dots, x_n\}$, which is presented by a matrix $R = (r_{ij})_{n\times n}$, where $r_{ij} = (\mu_{ij}, v_{ij})$. In this definition, μ_{ij} means the degree that the alternative x_i is preferred to the alternative

x_j, and the υ_{ij} denotes the degree to which the object x_i is not preferred to x_j. $\pi_{ij} = 1 - \mu_{ij} - \upsilon_{ij}$, which is interpreted as a hesitancy degree, with the condition

$$\mu_{ij}, \upsilon_{ij} \in [0,1],\ \mu_{ij} + \upsilon_{ij} \leq 1, \mu_{ij} = \upsilon_{ji}, \mu_{ji} = \upsilon_{ij}$$

$$\mu_{ii} = \upsilon_{jj} = 0.5, \pi_{ij} = 1 - \mu_{ij} - \upsilon_{ij}$$

for all $i, j = 1,2,\cdots,n$

In this study, two dimensions were used to evaluate the risk impact, including occurrence possibility and severity. The comparison matrix was adopted two times to measure the possibility and severity respectively.

In this round of the occurrence possibility survey, each expert has to provide the evaluation of possibility in five comparative matrixes, respectively for the first level of risk categories, financial/commercial risk category (A_1), legal and socio-political risk category (A_2), technical and natural risk category (A_3), partnership risk category (A_4). It is similar to measure the severity.

After all experts provide their evaluation matrixes, each matrix will be adopted into the consistency checking, and then the arithmetic average of each participants' score is the final matrix.

Step 3: Consistency Checking

In the pairwise comparisons, consistency checking cannot be ignored due to that inconsistency of preference relations might result in misleading solutions. Each original matrix provided by the participants in the questionnaire survey has to be checked for consistency. Saaty (1988) provided a methodology to check the consistency for conventional AHP. However, if the preference relation is lacking consistency, evaluation makers have to re-evaluate the preferences, due to the fact that the method cannot repair or improve the inconsistent preferences by calculation of the original data. Following this research, Kwong and Bai (2003), Chan and Kumar (2007) used the similar way to check the consistency in fuzzy AHP. In this study, another method was used to check the consistency of the preference relations in IFAHP, which was originated from Xu and Liao (2014). This approach has the advantage to check the consistency of an intuitionistic preference relation and then repair and improve it until consistency is achieved. The consistency checking formula is as follows:

$$d(\overline{R},R) = \frac{1}{2(n-1)(n-2)} \sum_{i=1}^{n} \sum_{j=1}^{n} \left(\left|\overline{\mu}_{ij} - u_{ij}\right| + \left|\overline{v}_{ij} - v_{ij}\right| + \left|\overline{\pi}_{ij} - \pi_{ij}\right| \right) \quad (1)$$

where $d(\overline{R},R)$ is the distance between given intuitionistic preference relation R and its corresponding perfect multiplicative consistent intuitionistic preference relation $\overline{R}$.

For $j > i + 1$时， let $\bar{R} = (\bar{\mu}_{ij},\bar{v}_{ij})$, where

$$\overline{\mu}_{ij} = \frac{\sqrt[j-i-1]{\prod_{t=i+1}^{j-1} \mu_{it}\mu_{tj}}}{\sqrt[j-i-1]{\prod_{t=i+1}^{j-1} \mu_{it}\mu_{tj}} + \sqrt[j-i-1]{\prod_{t=i+1}^{j-1} (1-\mu_{it})(1-\mu_{tj})}}, \quad j > i + 1 \quad (2)$$

$$\bar{v}_{ij} = \frac{\sqrt[j-i-1]{\prod_{t=i+1}^{j-1} v_{it}v_{tj}}}{\sqrt[j-i-1]{\prod_{t=i+1}^{j-1} v_{it}v_{tj}} + \sqrt[j-i-1]{\prod_{t=i+1}^{j-1} (1-v_{it})(1-v_{tj})}}, \quad j > i + 1 \quad (3)$$

For $j = i + 1$， let $\bar{r}_{ij} = r_{ij}$ ；

For $j < i + 1$， let $\bar{r}_{ij} = (\bar{v}_{ji}, \bar{\mu}_{ji})$.

R is an acceptable multiplicative consistent intuitionistic preference relation, if

$$d(\overline{R},R) < \tau$$

τ is the consistency threshold and in general $\tau = 0.1$.

If the $d(\overline{R},R)$ is too large, it means that the transformed intuitionistic preference relation $\overline{R}$ cannot represent the initial preferences of the decision maker. There are two requirements of the modified intuitionistic preference relation R, including passing acceptable multiplicative consistency and maintaining original preference information from the survey participants as much as possible.

Formula (2) and (3) were used to transform $R = (r_{ij})_{n\times n}$ into the corresponding perfect multiplicative consistent intuitionistic preference relation $\bar{R} = (\overline{r_{ij}})_{n\times n}$. And then the R and $\bar{R}$ can be used in formula (1) to calculate $d(\overline{R}, R)$. If $d(\overline{R}, R) < 0.1$, it passes the consistency checking. If not, it should go to the next step to repair and improve the consistency.

To those preference relations which cannot pass the consistency checking, the initial intuitionistic preference relation R and its corresponding perfect multiplicative consistent intuitionistic preference relation $\overline{R}$ can be integrated into a new intuitionistic preference relation $\tilde{R} = (\overline{r_{ij}})_{n\times n}$, where each element is defined as:

$$\tilde{\mu}_{ij} = \frac{(\mu_{ij})^{1-\sigma}(\bar{\mu}_{ij})^{\sigma}}{(\mu_{ij})^{1-\sigma}(\bar{\mu}_{ij})^{\sigma}+(1-\mu_{ij})^{1-\sigma}(1-\bar{\mu}_{ij})^{\sigma}}, i,j = 1,2,\cdots,n \quad (4)$$

$$\tilde{\nu}_{ij} = \frac{(\nu_{ij})^{1-\sigma}(\bar{\nu}_{ij})^{\sigma}}{(\nu_{ij})^{1-\sigma}(\bar{\nu}_{ij})^{\sigma}+(1-\nu_{ij})^{1-\sigma}(1-\bar{\nu}_{ij})^{\sigma}}, i,j = 1,2,\cdots,n \quad (5)$$

Where σ is a controlling parameter, which means the relation between $\tilde{R}$ and R and decided by the participants who provided the original preference relation matrixes. The smaller of the σ value means the closer between $\tilde{R}$ to R. Especially When $\sigma = 0$, $\tilde{R} = R$; when $\sigma = 1$, $\bar{R} = R$.

Based on the aforementioned analysis, an automatic algorithm to repair the inconsistent intuitionistic preference relation can be developed.

$$d(\overline{R}, R^{(p)}) = \frac{1}{2(n-1)(n-2)} \sum_{i=1}^{n}\sum_{j=1}^{n}\left(\left|\bar{\mu}_{ij} - u_{ij}{}^{(p)}\right| + \left|\bar{\nu}_{ij} - \nu_{ij}{}^{(p)}\right| + \left|\bar{\pi}_{ij} - \pi_{ij}{}^{(p)}\right|\right) \quad (6)$$

Where p is the number of iterations, let $p = 1$, and construct the perfect multiplicative consistent intuitionistic preference $\overline{R}$ and $R^{(p)}$, then calculate the distance $d\left(\overline{R}, R^{(p)}\right)$ between $\overline{R}$ and $R^{(p)}$ by formula (6).

If $d\left(\overline{R}, R^{(p)}\right) < \tau$, then output $R^{(p)}$; otherwise, go to the next step to construct the fused intuitionistic preference relation $\widetilde{R}^{(p)} = (\tilde{r}_{ij}^{(p)})_{n\times n}$, $(\tilde{r}_{ij}^{(p)} = (\tilde{\mu}_{ij}^{(p)}, \tilde{v}_{ij}^{(p)}))$.

$$\tilde{\mu}_{ij}^{(p)} = \frac{\left(\tilde{\mu}_{ij}^{(p)}\right)^{1-\sigma}(\overline{\mu}_{ij})^{\sigma}}{\left(\tilde{\mu}_{ij}^{(p)}\right)^{1-\sigma}(\overline{\mu}_{ij})^{\sigma}+\left(1-\tilde{\mu}_{ij}^{(p)}\right)^{1-\sigma}(1-\overline{\mu}_{ij})^{\sigma}}, i,j = 1,2,\cdots,n \quad (7)$$

$$\tilde{v}_{ij}^{(p)} = \frac{\left(\tilde{v}_{ij}^{(p)}\right)^{1-\sigma}(\overline{v}_{ij})^{\sigma}}{\left(\tilde{v}_{ij}^{(p)}\right)^{1-\sigma}(\overline{v}_{ij})^{\sigma}+\left(1-\tilde{v}_{ij}^{(p)}\right)^{1-\sigma}(1-\overline{v}_{ij})^{\sigma}}, i,j = 1,2,\cdots,n \quad (8)$$

Let $R^{(p+1)} = \widetilde{R}^{(p)}$, $(\mu_{ij}^{(p+1)} = \tilde{\mu}_{ij}^{(p)}, v_{ij}^{(p+1)} = \tilde{v}_{ij}^{(p)})$. Let $p = p + 1$, and then, go to formula (6).

Through iteration step, the consistency level of intuitionistic preference relation will be improved without losing much original information.

Step 4: Calculate the Weighting Functions

The *n*-dimensional vector $\omega = (\omega_1, \omega_2, \cdots, \omega_n)$ obtained from the multiplicative preference relation, where ω_i is the weight which accurately represents the relative dominance of the alternative A_i among the alternatives in A.

$$\omega_i = \left(\frac{\sum_{j=1}^{n}\mu_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n}(1-v_{ij})}, 1 - \frac{\sum_{j=1}^{n}(1-v_{ij})}{\sum_{i=1}^{n}\sum_{j=1}^{n}\mu_{ij}}\right), i = 1,2,\cdots,n \quad (9)$$

This method is quite different from methods used in AHP and FAHP, and it does not influence the extension of the original AHP method (Xu and Liao 2014).

Step 5: Integrating the Information

The fifth step of the IFAHP is integrating the information calculated from previous steps. All weights from the lowest level needed to be fused to the highest level based on the following operational rules of IFVs (Xu 2007).

$$r_{ij} \oplus r_{tl} = (\mu_{ij} + \mu_{tl} - \mu_{ij}\mu_{tl}, v_{ij}v_{tl}) \quad (10)$$

$$r_{ij} \otimes r_{tl} = (\mu_{ij}\mu_{tl}, v_{ij} + v_{tl} - v_{ij}v_{tl}) \quad (11)$$

Step 6: Rank the Impact Grade of each Risk Factor

Previous steps must be carried out two times for possibility and severity respectively. After compute these two aspects, the impact of each risk factor can be derived by taking the square root of the product of possibility and severity using flowing formula (Chan et al. 2014):

$$impact = (possibility \times severity)^{0.5}$$

Similarly, the IFV operational rules (formula (11) and (12)) should be used to calculate the risk factor impact:

$$r_{ij}{}^{\lambda} = \left(\mu_{ij}^{\lambda}, 1 - \left(1 - v_{ij}\right)^{\lambda}\right), \lambda > 0 \quad (12)$$

Each risk factor can get its evaluation IFV score after this step. Finally, Szmidt and Kacprzyk (2009) proposed a function to calculate the overall weights of IFVs.

$$\rho(\alpha) = 0.5(1 + \pi_{\alpha})(1 - \mu_{\alpha}) \qquad (13)$$

The smaller value of the $\rho(\alpha)$ means the higher value of the IFV. After calculating the $\rho(\alpha)$, all the risk factors can be ranked in this study based on the impact value of each factor.

Application of the IFAHP in a Power Plant Project

After having presented the proposed methodology, in this section, the results of an empirical case study conducted in a TPPP project will be provided. The actual name of this case is not given for confidentiality reasons; thus, it will be called Project X in this study.

Project Background

The practical case applied in the current research is a power plant project in a southeast developing country, which is a BOT (Build-Operate-Transfer) project invested by a Chinese construction company. A background information of the project is provided in Table 2.

Please insert Table 2 here

Identification of Critical Risk Factors in Project X

After a comprehensive literature review on critical risk factors for TPPP projects (Yu et. al., 2017), there are 42 critical risk factors identified in general TPPP projects. Based on project X, through primary documentary review of contract documentation, country and market report, secondary documentary analysis of industry and professional reports, and newspaper articles, 22 risk factors were identified which might be related to this project and they were grouped into four major categories, namely (1) financial/commercial risk category, (2) legal and social-political risk category, (3) technical and natural risk category, (4) partnership risk category. These clusters were derived primarily on the basis of similar categorizations of PPP risk factors in the literature (Ozdoganm and Talat Birgonul 2000; Salman et al. 2007; Xu et al. 2010). Merna and Smith (1993) mentioned that the concession contract can afford a useful source of information because it is the basis of a long-term contract between public and private stakeholders. To make this identification and categorization more reasonable, financing, construction, operation and revenue package of the project X were also referred to (Ameyaw et al. 2017). Table 3 summarizes the risk factors identified and grouped for the questionnaire survey.

Please insert Table 3 here

Participants and Survey for Risk Assessment

Questionnaire survey is an effective technique for soliciting experts' perceptions (Spector 1994). A number of previous studies on PPP risk management have been conducted by questionnaire survey (Ameyaw and Chan 2015a,b; Ebrahimnejad et al. 2010; Ke et al. 2011; Zeng et al. 2008). The established 22 risk factor list was used to design a questionnaire for a survey. With the objective to measure each risk factor based on IFAHP, the questionnaire was designed based on this methodology. An expert refers to someone who has special skills, knowledge, or experiences by his or her leadership and work in professional organizations, or someone holding an office in professional organizations, or a presenter in national conventions, or someone who has published in recognized journals (Cabaniss 2002). Hence, the five experts in this study were selected based on their knowledge, experience and understanding of the Project X, which was evidenced by their job position and experience in the X project. The experts selection process is reasonable and acceptable and adopted in many previous risk management studies (e.g.., (Ameyaw et al. 2017; Ng and Loosemore 2007; Thomas et al. 2006). Although the size of this risk assessment group is small, reliable measurement results is anticipated because those five experts are all high-level management officials with direct involvement and important decision power in the project planning, risk allocation, contract negotiations and life cycle management of project X. In addition, Li and Zou (2011) invited five experts to evaluate the risk factors of an actual PPP expressway project based on the fuzzy AHP methodology. Ebrahimnejad et al. (2010) selected five experts to establish BOT projects risk ranking team to assess the risk factors using a fuzzy multi attribute decision making model. These previous researches support the reliability of the limited sample.

Table 4 summarizes the participants' profiles. Given the participants' years of working experience in TPPP and their participation in and familiarity with the TPPP project under study, their views were representative for this study to analyse the degree of probability and severity of the TPPP risk factors.

Given the public sector's location outside China and time limitations, the questionnaire was delivered online to the expert from the Ministry of Industry and Mineral Resources of C country. However, for other four experts in China, the questionnaire was delivered in person, and respondents were doing the interview and questionnaire face to face with authors.

Please insert Table 4 here

The Process of Risk Assessment Using IFAHP

This study adopted the IFAHP method in questionnaire to collect measurement data for each risk factor from two dimensions (occurrence possibility and severity). Taken the process of evaluation the possibility as an example, each participant in the questionnaire survey has to provide the evaluation in five tables, respectively for the first level of risk categories, the specific risk factors for financial/commercial risk category (A_1), legal and socio/political risk category (A_2), technical and natural risk category (A_3), partnership risk category (A_4). In each comparison matrix, decision makers need to develop an IFV to describe the preferences between alternatives. The 0.1-0.9 scale satisfies the reciprocal condition as can be seen in Table 5.

Please insert Table 5 here

After all these experts provide their evaluation matrix, each matrix will be adopted into the consistency checking, and then the arithmetic average of each participants' grade is the final matrix.

Step 1: Build the Intuitionistic Fuzzy Judgment Matrix

In this study, two dimensions were used to evaluate the risk impact, including occurrence possibility and severity. The questionnaires survey was adopted two times to measure the possibility and severity respectively. Five experts responded these tables respectively to show their intuitionistic measurement of each risk factor of this power plant TPPP project. Taking the expert 1 as an example, the intuitionistic preference matrix can be seen in Table 6 to 10.

Please insert Table 6 to 10 here

Step 2: Consistency Checking

Absolute consistency cannot be achieved because of the subjective judgement of experts. However, it is necessary to ensure reasonable consistency of pairwise comparisons according to the numerical equation of consistency checking. The intuitionistic preference relation constructed by the experts are always with unacceptable multiplicative consistency due to the lack of knowledge or the difficulty of discriminating the degree to which some alternatives are more serious than others.

Here, taking the comparison matrix for possibility in level 1 as an example to check the consistency. Firstly, applying the equation (2) and (3) to get the $\overline{\mathrm{R}}$. Taking $\overline{r}_{14}$ as an example:

$$\overline{\mu}_{14} = \frac{\sqrt[4-1-1]{\mu_{12}\mu_{24} \times \mu_{13}\mu_{34}}}{\sqrt[4-1-1]{\mu_{12}\mu_{24} \times \mu_{13}\mu_{34}} + \sqrt[4-1-1]{(1-\mu_{12})(1-\mu_{24}) \times (1-\mu_{13})(1-\mu_{34})}}$$

$$= \frac{\sqrt{0.4 \times 0.6 \times 0.45 \times 0.7}}{\sqrt{0.4 \times 0.6 \times 0.45 \times 0.7} + \sqrt{0.6 \times 0.4 \times 0.55 \times 0.3}} = 0.7155$$

$$\overline{v}_{14} = \frac{\sqrt[4-1-1]{v_{12}v_{24} \times v_{13}v_{34}}}{\sqrt[4-1-1]{v_{12}v_{24} \times v_{13}v_{34}} + \sqrt[4-1-1]{(1-v_{12})(1-v_{24}) \times (1-v_{13})(1-v_{34})}}$$

$$= \frac{\sqrt{0.5 \times 0.35 \times 0.5 \times 0.1}}{\sqrt{0.5 \times 0.35 \times 0.5 \times 0.1} + \sqrt{0.5 \times 0.35 \times 0.5 \times 0.1}} = 0.1537$$

We can construct the perfect multiplicative consistent intuitionistic preference relation $\overline{\mathrm{R}} = \left(\overline{r}_{ij}\right)_{4\times4}$ of the intuitionistic preference relation R of possibility risk category:

$$\overline{\mathrm{R}} = \begin{bmatrix} (0.5,0.5) & (0.55,0.3) & (0.55,0.2222) & (0.7155,0.1537) \\ (0.3,0.55) & (0.5,0.5) & (0.5,0.4) & (0.65,0.2222) \\ (0.2222,0.55) & (0.4,0.5) & (0.5,0.5) & (0.65,0.3) \\ (0.1537,0.7155) & (0.2222,0.65) & (0.3,0.65) & (0.5,0.5) \end{bmatrix}$$

By calculating the distance between R and $\overline{\mathrm{R}}$ via equation (1), we get $d\left(\overline{R}, R\right) = 0.1006 > 0.1$, which means the intuitionistic preference relation is of unacceptable consistency. Therefore, we need to repair the consistency. Using equation (4) and (5), the fused intuitionistic preference relation $\widetilde{\mathrm{R}}$ is calculated. Here, letting the $\sigma = 0.6$:

$$\widetilde{\mathrm{R}} = \begin{bmatrix} (0.5,0.5) & (0.55,0.3) & (0.591,0.2331) & (0.7093,0.1711) \\ (0.3,0.55) & (0.5,0.5) & (0.5,0.4) & (0.6303,0.2691) \\ (0.2331,0.591) & (0.4,0.5) & (0.5,0.5) & (0.65,0.3) \\ (0.1711,0.7093) & (0.2691,0.6303) & (0.3,0.65) & (0.5,0.5) \end{bmatrix}$$

With equation (6), we can calculate the distance between $\overline{\mathrm{R}}$ and $\widetilde{\mathrm{R}}$, and the $\mathrm{d}(\overline{\mathrm{R}}, \widetilde{\mathrm{R}})$ =0.03689<0.1, which means $\widetilde{\mathrm{R}}$ is with acceptable multiplicative consistency. The consistency checking and repairing process of other matrixes for each expert can be done following the same process. Conducting this process till all comparison matrixes can pass the consistency checking and do not need to be repaired anymore.

Step3：Calculate the Weighted Matrixes

After all the comparison matrixes of each expert passed the consistency checking, theses measurement information was collected together to obtain the weight of each risk factor. We calculated the average intuitionistic fuzzy set of each comparison matrix according to the consistency repairing results of five expert's evaluation tables.

Taking the possibility measurement of level 1 as an example, the equations

$r_{ij} \oplus r_{tl} = (\mu_{ij} + \mu_{tl} - \mu_{ij}\mu_{tl}, v_{ij}v_{tl})$ and,

$\lambda r_{ik} = \left(1 - (1 - \mu_{ik})^{\lambda}, v_{ik}^{\lambda}\right), \lambda > 0$

were used to calculate the weighted average $\bar{\bar{R}}$:

$$\bar{\bar{R}} = 0.2 \times (r_1 + r_2 + r_3 + r_4 + r_5)$$

$$= \begin{bmatrix} (0.5,0.5) & (0.6263,0.2491) & (0.4878,0.3141) & (0.5956,0.222) \\ (0.2646,0.6163) & (0.5,0.5) & (0.3654,0.5055) & (0.4689,0.3261) \\ (0.3231,0.4778) & (0.5356,0.3519) & (0.5,0.5) & (0.5940,0.2862) \\ (0.239,0.5723) & (0.3475,0.4501) & (0.3058,0.5870) & (0.5,0.5) \end{bmatrix}$$

All the weighted matrixes followed the same process to get the outcome.

Step 4: Integrating the Information

In the following step, the deriving priority vector of each acceptable consistent intuitionistic preference relation can be counted.

By using equation (9), the weights of each risk factor group and each risk factor alternative can be shown in table11.

Please insert Table 11 here

Then based on the $impact = (possibility \times severity)^{0.5}$, applying the IFS calculation rules, the final IFS of the impact of each risk factor in this project were counted, and the ρ was calculated by equation (13) (Shown in Table 12). The smaller the value of $\rho(\alpha)$, the greater the IFV α in the sense of the amount of the information. The Table 12 shows the ranking with detailed scores of each risk factor for this TPPP project using the IFAHP methodology.

Please insert Table 12 here

Discussion

The results in Table 12 shows that the top five risk factors in TPPP projects were technology risk, natural environment risk, construction risk, administrative risk, and political risk. These five risk factors are discussed below.

Technology Risks

Technology was assessed as the top-ranked risk among the risk factors in X project (Table 12). This suggests that TPPP projects involve complex technologies that could pose serious risk to the project. This is critical because potential technology difficulty is necessarily existing in the X project and might related to every TPPP project. For example, lack of innovation in design (Babatunde et al. 2015), lack of reliability and quality of the technical proposal (Wang et al. 1998), technological obsolescence (Ramakrishnan 2014) are all technological challenges of working in a foreign market. Technology risk adversely affected X project because in this project the geological prospecting data and the feasibility study report provided by the local government were not accurate and specific. After winning the contract, the private sector hired a professional team to undertake the geological survey again, and provided reasonable suggestions for engineering technology and design. Therefore, the technology risk seriously impacted the TPPP project in terms of cost and time.

Natural Environment Risk

The risk regarding environment of the host country reminds the investors of TPPP projects to comprehensively investigate the natural conditions of the project location before implementing or even before considering the project. The result indicates that the risk assessment team is highly concerned with the natural environment of the X project. In this project, the seasonal shortage of river water resources is one of the serious environment problems, which might lead to the lack of energy supply. Moreover, this hydropower station is in the tropic area, with changeable climate, horrible snakes, and mosquitoes, and it is possible to occur landslide or other adverse events. Another primary reason is that because C country was under war with neighbouring country for many years, the host country's jungle is full of landmines. According to local media reports, these mines cause about 200 casualties every year. This situation caused problems for the reconnaissance and construction. To insure the safety for workers, host government sent some soldiers to check the exploration area, the construction area, and the reservoir area, finally dug more the 500 landmines. Therefore, serious natural environment affected the construction safety and convenience of X project, and at the same time increased the cost and time of the project. The effect of the natural environment, including geotechnical conditions, weather, environment, population density, etc., on TPPP project is also supported by past research (Jacobs and Franceys 2008; Muller 2003). Governments are responsible for developing policies and making investment decisions for climate change adaptation in an environment that comprises complex, interlinked systems with a number of uncertainties (Buurman and Babovic, 2016).

Construction Risk

The project hints that the risk assessment team is more concerned with the construction stage than the operation stage. X project is in the southwest of C country, and it is 15 kilometres away from a big city. The dam in this project is a roller compacted concrete gravity dam with a total installed capacity of 193,200 kilowatts and annual average generating capacity of 498 million degrees. The main function of this Hydropower Station is to generate electricity, and have auxiliary functions such as urban water supply and irrigation. Because of the huge scale and construction complexity of this project, the potential construction risks and challenges are serious. Potential implications of construction risks in X project may include low project quality, high project cost and long construction period, which may affect the long-term sustainability of the project itself. Based on the contract, construction contractor takes the whole construction risk without government's support, and it makes the potential construction risk impact more serious. If the construction risk is reasonably mitigated so the project quality can be improved and the potential risks in the operation stage can be decreased. In addition, the high rank of construction risk in this study corroborates the findings of previous research (Chou and Pramudawardhani, 2015; Meduri and Annamalai, 2013).

Administrative Risk

Ranked fourth, the risk regarding administration reflects the complexity of conducting PPP project in another country. This finding suggests that different countries have various administrative systems, which might easily cause conflicts during the cooperation among different stakeholders. Policies such as import equipment or materials, restriction on land acquisition have serious impact on the project.

In this case, X Project Company did not consider the strict policy of import materials, so some materials were seized by customs, which led to project delays. To solve administrative problems, supports from governments are important. For X project, on the one hand, during the whole development and implementation period, the relevant Chinese government departments, the Chinese Embassy in C country all helped to handle the relationship between Chinese-funded enterprises, project companies and local governments, and China Export-Import Bank, China Development Bank, China Export & Credit Insurance Corporation all support the project in terms of project financing and guarantee. On the other hand, the C country government has given high attention and strong support. To encourage the enthusiasm of Chinese enterprises, the host government launched some project preferential policies, such as tax exemption period, import tax exemption and so on. The Chinese Prime Minister and the C Country Prime Minister attended the ground-breaking ceremony, which demonstrates it as the largest and most dazzling “Star Project” in C country, and shown the significance.

Political Risk

Political risk reminds the private investors of the difficulties in investing in foreign countries for TPPP projects. In TPPP, private investors do business in politically sensitive sectors with local powerful governments; thus, they need sound and legal political support to ensure fairness, transparency, and long-term sustainability (Wibowo and Alfen 2015). However, in most developing countries, political instability affects infrastructure projects, leading to insufficient payment even expropriation sometimes(Babatunde et al. 2015).

For the project X, the political system of this host country is fragile, and there are contradictions and disputes among different parties. The national risk of this host country in the China International Trust and Investment Corporation (CITIC) insurance risk rating is in the eighth category, which means that the political risk is high. That is, the political system affected by the strength of military strength of the parties, result in the potential threat to the project. However, the current government has been working on domestic political stability. Government implemented opening and free market economic strategy, and attached importance to infrastructure projects.

Other potential political risk factors in the TPPP projects include political interference in the procurement process, political reneging during such long period, the withdrawal of government support network, the termination of concession by government, revocation, expropriation, sequestration, or political force majeure events (Chou and Pramudawardhani 2015; Wang and Tiong 2000). Based on the fair risk allocation principle, governments will benefit from retaining most of the political risks (Lobina 2005) considering their ability to take on this responsibility.

Conclusions

This research identified and assessed the risk factors in a TPPP project using the IFAHP technique. The methodology was explained step by step, and a hydropower case project X in country C showed that the IFAHP method can be used to evaluate and prioritize risk factors in terms of their occurrence possibility and severity. The risk assessment results showed that the top five risk factors in the TPPP project were technology risk, natural environment risk, construction risk, administrative risk, and political risk. This study provided a risk evaluation process, which would help industry practitioners and stakeholders of TPPP projects, including the public and private sectors, to identify and measure the risks in TPPP projects, to identify the most critical risk factors in a specific project, and to make appropriate strategies to allocate and mitigate potential risks.

Although the research objective was achieved, some limitations of this study are worth mentioning. The primary limitations of this research lie in the perception-based assessment of a set of risk factors in a single case study and the small sample size of the risk assessment. The risk assessment may not be representative of all TPPP projects. However, multiple methods, including literature review and project documentary analysis, expert risk rating exercise, and IFAHP were used for the risk assessment, which could be adopted in other TPPP projects for assessment of risk factors. Another limitation is that this study does not explore the allocation and mitigation of the identified risk factors. Moreover, while the present study relied on the literature for the identification of the TPPP risk factors that were assessed in the present study, future research could ask industry experts to also provide their ideas on what the risk factors are, following the literature review, in order to improve the comprehensibility of the risk factor list identified from the literature review. Such an effort may help to identify factors that are in practice but missing from the literature and hence enrich the limited literature on TPPP risk factors. The above-mentioned limitations warrant future research and should also be considered in interpreting and generalizing the study results.

Risk evaluation is a complicated task, in which the vagueness and uncertainty of experts are almost unavoidable. The IFAHP method adopted in this study is suitable for dealing with the uncertainties in expert judgements. To extend and validate the wider applicability of the IFAHP technique and the identified risk factors, further research is required to test the applicability of the risks across infrastructure sectors where TPPP is applied or increasingly considered by the government or private sector. After evaluating risks in TPPP projects, allocating and mitigating the risks are also important tasks for stakeholders in the risk management process (Ameyaw and Chan 2015a). The present study has evaluated and ranked the risk factors in a TPPP project using the IFAHP technique. In the future study, strategies such as agent theory and real option analysis (Liu and Cheah 2009; Luehrman 1998a; Luehrman 1998b) could be used to address the risks in TPPP projects. Moreover, although this study aims to propose a generic process to evaluate the risk factors in TPPP projects, it is equally important to note that the impacts of these risk factors could vary depending on several factors, such as project type (e.g., highway, subway, port terminal, and water treatment facility), and project size (e.g., small or mega projects). The present study focused on the risk factors in a hydropower project. Future studies focusing on other types of projects might be useful for understanding how contextual issues can affect the results.

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Table 1. Selected Previous Studies on Application of the IFAHP Method.

Study	Specific area of application	Summary of application
Sadiq and Tesfamariam (2009)	Environmental decision making	The IFAHP method was applied to an illustrative example to select best drilling fluid (mud) for drilling operations under multiple environmental criteria.
Kaur (2014)	Selection of Vendor	A triangular intuitionistic fuzzy number based approach was proposed for the vendor selection problem using analytical hierarchy process.
Rajaprakash and Ponnusamy (2015)	Ranking business scorecard factor	The IFAHP method was used with Fuzzy Delphi to analyze the uncertainty factors in business scorecard and explore the importance ranking of various factors.
Rajaprakash and Ponnusamy (2016)	Determining the balance scorecard sheet metal industry	The IFAHP method was applied with Fuzzy Delphi to rank the factors in the balance scorecard and identify which area has to be given higher priority in the Balance Scorecard.
Nguyen (2016)	Ship system risk estimation	The IFAHP was used to estimate the propulsion risk of container carriers operating on the North Atlantic Line.

Table 2. Primary information of Project X.

Project Name	X Hydropower station PPP project in country C
Project Type	New project
Sector	Electrical Power——Hydroelectric
Project Content	The main works include dams, water intakes, diversion tunnels, 230 KV switch stations, 10 KM 230 KV double circuit transmission lines, supporting distribution and diversion projects, tail water control weir, and other temporary works and electromechanical installation works.
Concession period	Construction period: 4 years Operation period: 40 years
Total investment	280.5 million US Dollars
PPP type	BOT (Building—Operation—Transfer)
Public sector	Ministry of Industry and Mineral Resources of C country
Private sector	Sinohydro Corporation Limited (China)
Financing institution	The Export-Import Bank of China: provide loans of 72% fixed asset (202 million US Dollars)
Users	X country National Electricity Company: sign the “take or pay” contract with private sector; take responsibility for purchase and payment

Table 3. The risk factor list in TPPP projects.

No.	Risk factor	Definition
Category1(r_1): Financial/Commercial risk category		
r_{11}	Tariff risk	The price of the services offered by TPPP project infrastructure.
r_{12}	Financing risk	The availability and cost of financing.
r_{13}	Currency risk	Related to interest rate or foreign exchange rate.
r_{14}	Demand and revenue risk	The market demand and operational revenue of services offered by TPPP.
r_{15}	Tax risk	About the tax regulation in host country.
r_{16}	Payment risk	Government pay for the private sector and project company pay for the loan.
Category2(r_2): Legal and Socio-political risk category		
r_{21}	Legal risk	Weak or unstable legal framework.
r_{22}	Corruption risk	Dishonest or illegal behavior by stakeholders.
r_{23}	Political risk	Threatens from the political environment.
r_{24}	Administrative risk	Host country government inefficiency or lengthy bureaucratic procedures in administrative procedures.
r_{25}	Lack of government support	Lack of local government assistance when facing problems.
Categoey3(r_3): Technical and natural risk category		
r_{31}	Technology risk	Risks related to technology capacity and quality.
r_{32}	Construction risk	Construction cost and schedule.
r_{33}	Operation risk	Operation cost and productivity.
r_{34}	Force majeure	Superior or irresistible force cannot be anticipated or controlled.
r_{35}	Natural environment risk	Geotechnical conditions, population density impact, environmental problems.
Category4(r_4): Partnership risk category		
r_{41}	Cooperation risk	Conflicts between public sector and private sector during the cooperation.
r_{42}	Credit risk	Stakeholders' unreliability to perform contract.
r_{43}	Worker risk	Risks about staff and labor problem.
r_{44}	Competitiveness risk	Risks caused by potential competitors.
r_{45}	Cultural impediments	Conflicts between stakeholders caused by different culture.
r_{46}	Language differences	Inconvenience and high cost caused by language differences.

Table 4. Designation of Members of the Risk Assessment Team.

Identifier	Participant position	Participant organization	Years of working experience in TPPP	Familiarity with X project	Participant role
1	Project manager	Sinohydro Corporation Limited	15	Very familiar	Involved in the whole life cycle of this project, in charge of project control.
2	Director	Ministry of Industry and Mineral Resources of C country	3	Very familiar	Involved in tariff review, risk allocation and contract negotiations.
3	Project investment and development	Sinohydro Corporation Limited	10	Very familiar	Project planning, Contract negotiations with other stakeholders.
4	Consultant manager	Consultant	4	Very familiar	Provided professional consultation during the life of project X.
5	Technical worker	Construction Contractor	7	Very familiar	Involved in project survey, design and construction.

Table 5. Intuitionistic preference matrix for the risk categories.

0.1-0.9 scale	Meaning
0.1	Extremely not preferred
0.2	Very strongly not preferred
0.3	Strongly not preferred
0.4	Moderately not preferred
0.5	Equally preferred
0.6	Moderately preferred
0.7	Strongly preferred
0.8	Very strongly preferred
0.9	Extremely preferred
Other values between 0-1	Intermediate values used to present compromise

Table 6. Intuitionistic preference matrix for the risk categories.

level 1	P/S*	A_1	A_2	A_3	A_4
A_1	P	(0.5,0.5)	(0.55,0.3)	(0.65,0.25)	(0.7,0.2)
	S	(0.5,0.5)	(0.4,0.5)	(0.45,0.5)	(0.6,0.3)
A_2	P	(0.3,0.55)	(0.5,0.5)	(0.5,0.4)	(0.6,0.35)
	S	(0.5,0.4)	(0.5,0.5)	(0.35,0.6)	(0.6,0.35)
A_3	P	(0.25,0.65)	(0.4,0.5)	(0.5,0.5)	(0.65,0.3)
	S	(0.5,0.45)	(0.6,0.35)	(0.5,0.5)	(0.7,0.1)
A_4	P	(0.2,0.7)	(0.35,0.6)	(0.3,0.65)	(0.5,0.5)
	S	(0.3,0.6)	(0.35,0.6)	(0.1,0.7)	(0.5,0.5)

*Note: P=possibility; S=severity.

Table 7. Intuitionistic preference matrix for risks in financial/commercial category.

A_1		C_1	C_2	C_3	C_4	C_5	C_6
C_1	P	(0.5,0.5)	(0.2,0.6)	(0.1,0.8)	(0.4,0.3)	(0.45,0.35)	(0.2,0.7)
	S	(0.5,0.5)	(0.2,0.7)	(0.4,0.45)	(0.5,0.4)	(0.4,0.35)	(0.3,0.6)
C_2	P	(0.6,0.2)	(0.5,0.5)	(0.25,0.7)	(0.6,0.25)	(0.5,0.4)	(0.35,0.6)
	S	(0.7,0.2)	(0.5,0.5)	(0.4,0.45)	(0.6,0.35)	(0.7,0.15)	(0.35,0.55)
C_3	P	(0.8,0.1)	(0.7,0.25)	(0.5,0.5)	(0.8,0.1)	(0.75,0.2)	(0.45,0.35)
	S	(0.45,0.4)	(0.45,0.4)	(0.5,0.5)	(0.6,0.35)	(0.7,0.2)	(0.4,0.45)
C_4	P	(0.3,0.4)	(0.25,0.6)	(0.1,0.8)	(0.5,0.5)	(0.3,0.4)	(0.3,0.6)
	S	(0.4,0.5)	(0.35,0.6)	(0.35,0.6)	(0.5,0.5)	(0.5,0.3)	(0.3,0.5)
C_5	P	(0.35,0.45)	(0.4,0.5)	(0.2,0.75)	(0.4,0.3)	(0.5,0.5)	(0.4,0.5)
	S	(0.35,0.4)	(0.15,0.7)	(0.2,0.7)	(0.3,0.5)	(0.5,0.5)	(0.2,0.65)
C_6	P	(0.7,0.2)	(0.6,0.35)	(0.35,0.45)	(0.6,0.3)	(0.5,0.4)	(0.5,0.5)
	S	(0.6,0.3)	(0.55,0.35)	(0.45,0.4)	(0.5,0.3)	(0.65,0.2)	(0.5,0.5)

Table 8. Intuitionistic preference matrix for risks in legal and social/political category.

A_2		C_1	C_2	C_3	C_4	C_5
C_1	P	(0.5,0.5)	(0.6,0.3)	(0.65,0.2)	(0.5,0.4)	(0.8,0.1)
	S	(0.5,0.5)	(0.55,0.4)	(0.5,0.4)	(0.6,0.3)	(0.45,0.4)
C_2	P	(0.3,0.6)	(0.5,0.5)	(0.4,0.5)	(0.35,0.6)	(0.6,0.2)
	S	(0.4,0.55)	(0.5,0.5)	(0.2,0.7)	(0.2,0.6)	(0.4,0.5)
C_3	P	(0.2,0.65)	(0.5,0.4)	(0.5,0.5)	(0.3,0.6)	(0.5,0.4)
	S	(0.4,0.5)	(0.7,0.2)	(0.5,0.5)	(0.6,0.2)	(0.6,0.3)
C_4	P	(0.4,0.5)	(0.6,0.35)	(0.6,0.3)	(0.5,0.5)	(0.6,0.2)
	S	(0.3,0.6)	(0.35,0.6)	(0.2,0.6)	(0.5,0.5)	(0.5,0.4)
C_5	P	(0.1,0.8)	(0.6,0.2)	(0.4,0.5)	(0.2,0.6)	(0.5,0.5)
	S	(0.4,0.45)	(0.5,0.4)	(0.3,0.6)	(0.4,0.5)	(0.5,0.5)

Table 9. Intuitionistic preference matrix for risks in technical and natural risk category.

A_3		C_1	C_2	C_3	C_4	C_5
C_1	P	(0.5,0.5)	(0.6,0.2)	(0.65,0.3)	(0.75,0.1)	(0.7,0.2)
	S	(0.5,0.5)	(0.5,0.4)	(0.6,0.3)	(0.1,0.85)	(0.25,0.7)
C_2	P	(0.2,0.6)	(0.5,0.5)	(0.5,0.3)	(0.8,0.15)	(0.7,0.25)
	S	(0.4,0.5)	(0.5,0.5)	(0.55,0.4)	(0.25,0.7)	(0.4,0.5)
C_3	P	(0.3,0.65)	(0.3,0.5)	(0.5,0.5)	(0.7,0.1)	(0.6,0.3)
	S	(0.3,0.6)	(0.4,0.55)	(0.5,0.5)	(0.1,0.85)	(0.2,0.6)
C_4	P	(0.1,0.75)	(0.15,0.8)	(0.1,0.7)	(0.5,0.5)	(0.2,0.7)
	S	(0.8,0.1)	(0.7,0.25)	(0.85,0.1)	(0.5,0.5)	(0.6,0.35)
C_5	P	(0.2,0.7)	(0.25,0.7)	(0.3,0.6)	(0.7,0.2)	(0.5,0.5)
	S	(0.7,0.25)	(0.5,0.4)	(0.6,0.2)	(0.35,0.6)	(0.5,0.5)

Table 10. Intuitionistic preference matrix for risks in partnership risk category.

A_4		C_1	C_2	C_3	C_4	C_5	C_6
C_1	P	(0.5,0.5)	(0.3,0.6)	(0.25,0.7)	(0.5,0.3)	(0.4,0.5)	(0.35,0.6)
	S	(0.5,0.5)	(0.55,0.4)	(0.55,0.3)	(0.6,0.25)	(0.55,0.4)	(0.5,0.4)
C_2	P	(0.6,0.3)	(0.5,0.5)	(0.3,0.6)	(0.6,0.2)	(0.4,0.45)	(0.25,0.7)
	S	(0.4,0.55)	(0.5,0.5)	(0.5,0.35)	(0.6,0.35)	(0.6,0.3)	(0.55,0.35)
C_3	P	(0.7,0.25)	(0.6,0.3)	(0.5,0.5)	(0.5,0.35)	(0.45,0.5)	(0.35,0.6)
	S	(0.3,0.55)	(0.35,0.5)	(0.5,0.5)	(0.6,0.35)	(0.5,0.4)	(0.6,0.3)
C_4	P	(0.3,0.6)	(0.2,0.6)	(0.2,0.7)	(0.5,0.5)	(0.2,0.7)	(0.25,0.7)
	S	(0.3,0.5)	(0.25,0.6)	(0.35,0.3)	(0.5,0.5)	(0.3,0.5)	(0.35,0.5)
C_5	P	(0.5,0.4)	(0.45,0.4)	(0.5,0.45)	(0.7,0.2)	(0.5,0.5)	(0.55,0.4)
	S	(0.4,0.55)	(0.3,0.6)	(0.4,0.5)	(0.5,0.3)	(0.5,0.5)	(0.5,0.4)
C_6	P	(0.6,0.35)	(0.7,0.25)	(0.6,0.35)	(0.7,0.25)	(0.4,0.55)	(0.5,0.5)
	S	(0.4,0.5)	(0.35,0.55)	(0.3,0.6)	(0.5,0.35)	(0.4,0.5)	(0.5,0.5)

Table 11. The weights of each risk factor.

Level 1 P	Level 2 P	Overall P	Level 1 S	Level 2 S	Overall S
(0.2444,0.6205)	(0.0893,0.7859)	(0.0218,0.9188)	(0.1792,0.7239)	(0.0815,0.8144)	(0.0146,0.9488)
	(0.1342,0.7504)	(0.0328,0.9053)		(0.1388,0.7574)	(0.0249,0.9330)
	(0.1724,0.7141)	(0.0421,0.8915)		(0.1410,0.7553)	(0.0253,0.9324)
	(0.0776,0.8127)	(0.0190,0.9290)		(0.1101,0.7846)	(0.0197,0.9405)
	(0.0992,0.7845)	(0.0242,0.9182)		(0.1013,0.7881)	(0.0181,0.9415)
	(0.1369,0.7431)	(0.0335,0.9025)		(0.1540,0.7242)	(0.0276,0.9238)
(0.1768,0.7131)	(0.1895,0.7856)	(0.0335,0.9385)	(0.2301,0.6747)	(0.1939,0.7864)	(0.0446,0.9305)
	(0.1962,0.7829)	(0.0347,0.9377)		(0.1743,0.7955)	(0.0401,0.9335)
	(0.1841,0.7878)	(0.0326,0.9391)		(0.2014,0.7849)	(0.0463,0.9300)
	(0.2008,0.7820)	(0.0355,0.9375)		(0.1837,0.7930)	(0.0423,0.9327)
	(0.1632,0.7908)	(0.0289,0.9400)		(0.1960,0.7866)	(0.0451,0.9306)
(0.216,0.6667)	(0.2068,0.7738)	(0.0447,0.9246)	(0.2488,0.6496)	(0.1860,0.7842)	(0.0463,0.9244)
	(0.1996,0.7763)	(0.0431,0.9254)		(0.1839,0.7842)	(0.0457,0.9252)
	(0.1808,0.7785)	(0.0390,0.9262)		(0.1591,0.8026)	(0.0396,0.9308)
	(0.1422,0.8039)	(0.0307,0.9346)		(0.2068,0.7780)	(0.0514,0.9222)
	(0.1890,0.7784)	(0.0408,0.9261)		(0.2001,0.7801)	(0.0498,0.9230)
(0.154,0.736)	(0.0942,0.7624)	(0.0145,0.9372)	(0.1608,0.7307)	(0.1267,0.6997)	(0.0204,0.9191)
	(0.1007,0.7682)	(0.0155,0.9388)		(0.1259,0.7100)	(0.0202,0.9219)
	(0.1438,0.7291)	(0.0222,0.9284)		(0.1085,0.7290)	(0.0175,0.9270)
	(0.0787,0.7978)	(0.0121,0.9466)		(0.0822,0.7606)	(0.0132,0.9355)
	(0.1306,0.7330)	(0.0201,0.9294)		(0.0985,0.7388)	(0.0158,0.9296)
	(0.1297,0.7338)	(0.0200,0.9297)		(0.0819,0.7583)	(0.0132,0.9349)

Table 12. Ranking of risk factors impact in TPPP projects.

Rank	Risk factor	IFV	$\rho(\alpha)$
1	Technology risk	(0.045467,0.924494)	0.491603
2	Natural environment risk	(0.045069,0.924559)	0.491967
3	Construction risk	(0.044405,0.925316)	0.492265
4	Administrative risk	(0.038747,0.93511)	0.493192
5	Political risk	(0.038847,0.934743)	0.493268
6	Legal risk	(0.038667,0.934641)	0.493497
7	Corruption risk	(0.037299,0.935641)	0.494376
8	Force majeure	(0.039747,0.928693)	0.495279
9	Lack of government support	(0.036069,0.935447)	0.495694
10	Operation risk	(0.039309,0.92855)	0.495784
11	Currency risk	(0.032619,0.914385)	0.509324
12	Financing risk	(0.028561,0.920339)	0.51054
13	Payment risk	(0.030384,0.913827)	0.511855
14	Demand and revenue risk	(0.019341,0.934984)	0.512725
15	Tax risk	(0.020977,0.930827)	0.513104
16	Tariff risk	(0.017853,0.935479)	0.513991
17	Worker risk	(0.019665,0.927728)	0.515954
18	Competitiveness risk	(0.012655,0.941302)	0.516403
19	Credit risk	(0.017714,0.930844)	0.516409
20	Cultural impediments	(0.017845,0.929544)	0.516914
21	Language differences	(0.016219,0.932335)	0.517196
22	Cooperation risk	(0.017196,0.928748)	0.517966

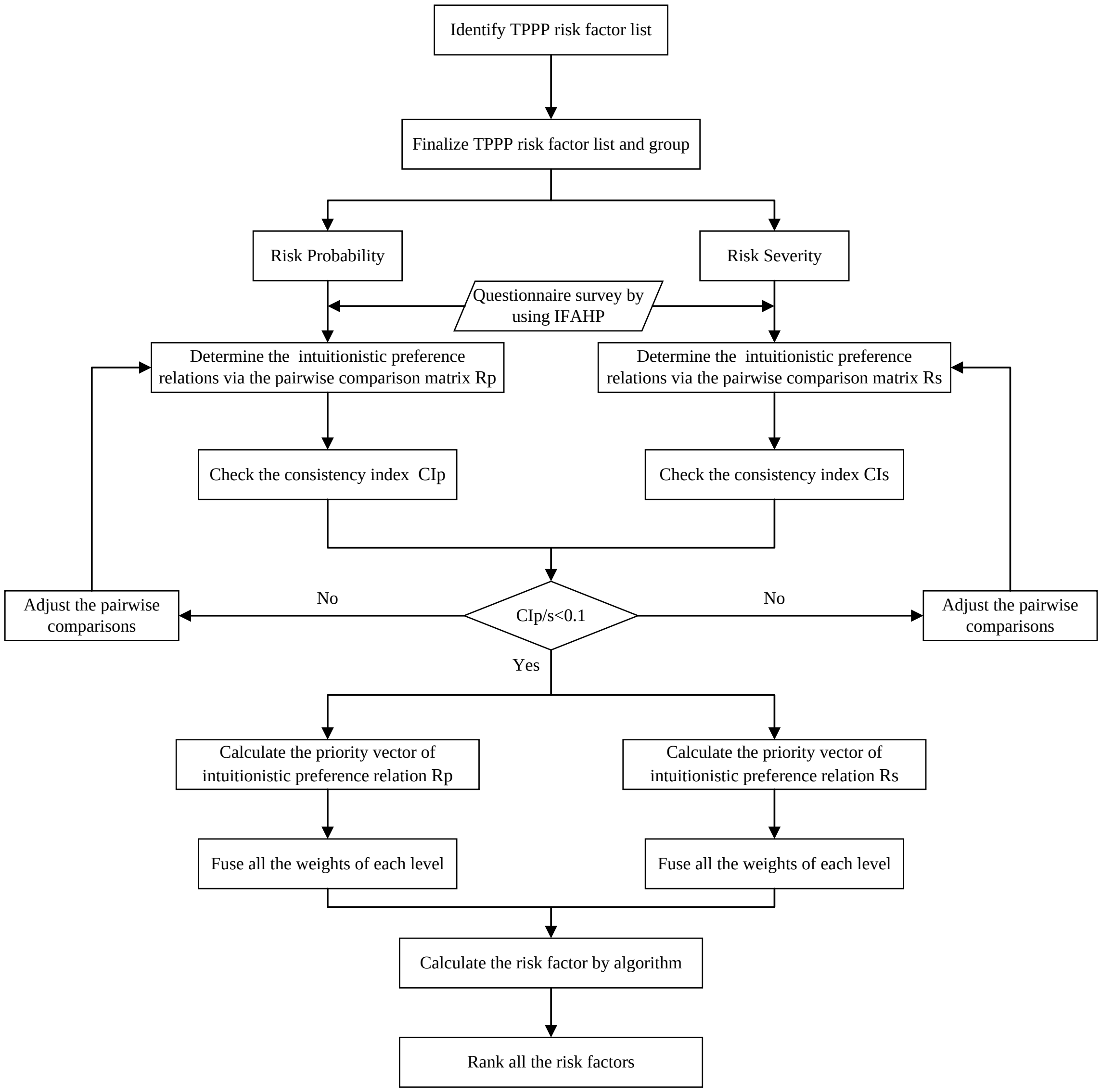

Fig. 1. The process of adopting IFAHP in ranking risk factors in TPPP projects.