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Risk identification and assessment in PPP infrastructure projects using fuzzy analytical hierarchy process and life-cycle methodology

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ABSTRACT

To fulfil the increasing demands of the public, Public Private Partnership (PPP) has been increasingly used to procure infrastructure projects, such as motor ways, bridges, tunnels and railways. However, the risks involved in PPP projects are unique and dynamic due to large amount of investment and long concession period. This paper aims to develop a risk identification framework from the perspectives of project life cycle, and an assessment framework for risks associated with PPP project using fuzzy analytical hierarchy process (AHP). First the paper reviews the current literature to identify common risks in PPP infrastructure projects and classification methods used. The risks identified from the literature were classified using project life cycle perspectives. Following that, the paper presents the advantages of fuzzy AHP. Furthermore, the paper provides a framework for assessment of risks in PPP projects followed by an illustrative example where the data was obtained from survey questionnaires. The paper concludes that risks associated in PPP infrastructure projects are unique and therefore it is beneficial to classify them from project life cycle perspectives, and the proposed fuzzy AHP method is suitable for the assessment of these risks.

Keywords: PPP infrastructure project, risk identification, risk assessment, fuzzy, analytical hierarchy process

INTRODUCTION AND RESEARCH AIMS

A PPP can be defined as a long term relationship between the public and private sectors that has the purpose of producing public services or infrastructure (Cartlidge, 2006). The partnerships between the government and private sectors have been seen as useful to overcome the resource deficit experienced by governments coping with increased mandates as the result of administrative decentralisation (Batley, 1996; Kim, 1997; Morgan, 1998). Private participation can either undertake some of this mandate, thereby releasing funds for other purposes, or can assist in funding public projects through private "finance initiatives (directly) or lease/concession arrangements and Build-Operate-Transfer schemes (indirectly) (Batley, 1996; Gidman et al., 1995; Kim, 1997). Under a PPP arrangement, the combination of skills and experience from a range of social and economic sectors promises to provide a synergy to project operation (Morgan, 1998; Payne, 1999; UNCHS, 1993, p. 23). PPP arrangements have been used in many countries, such as in USA (Fischer et al, 2006; Smith, 2003), UK (Li, 2005; Akintoye,1998), German (Fischer et al, 2006), China (Wang, 2000), Australia (Darvish et al 2006; Grimsey and Levis, 2002) , India (Singh,2006), Mexico (Jones,2000), Portugal (Lemos et al, 2004), and in different sectors such as transport, technology, water, prisons, health, welfare, and urban regeneration (Singe, 2006; Li, 2005; Lemos et al, 2004;Wang, 2000; Jones, 2000). PPP projects may take different forms such as Build Operate Transfer (BOT), Build Own Operate Transfer (BOOT), Leasing, Joint Ventures or Operation and Management contracts, etc (Davish et al, 2006).

However, due to the long concession period and large amount of investment, the risks associated with PPP projects should not be underestimated. Generally, risk management includes: risk identification, risk assessment and risk response (AS4360, 2004; PMBOK, 2004; Al-Bahar, 1989). It is clear that risks should be assessed before being responded. Usually, there are two ways to assess risks, qualitative, and quantitative (Ezekiel and Alasdair, 2003). To execute a pro-active risk assessment, statistical analysis is ideally employed to do the quantitative assessment. But most risks are difficult to quantify because the underpinning information is usually unavailable or insufficient. Though the idea of PPP can be traced back to 1782, the first formal BOT project was not used until early 1980s by Turkey's Prime Minister Targut Ozal (Grimsey and Levis, 2002). Therefore, there was no project virtually run its full course. In this case, risk assessment methods used to date are mainly qualitative (Singh et al, 2006; Li et al, 2005; Lemos et al, 2004).

Quantitative methods currently used in risk assessment include ranking method which uses scales of 1 to 5 to measure its likelihood of occurrence (probability) and its consequences (impact) (Asenova and Beck, 2003; Wang, 1999; Akintoye et al,1998), sensitivity analysis and Monte Carlo simulation (Grimsey & Lewis, 2002; Dey & Ogunlana, 2004), fuzzy set, analytic hierarchy process (AHP) (Dey & Ogunlana, 2004). The analytic hierarchy process (AHP), is a technique used to solve a problem in a complex, un-anticipated and multi-criteria situation (Nigim et al. 2003). A PPP project is a multi-stage project, with each stage having its unique risk factors and successful criterion. To make a holistic and synthesized assessment of risks from project lifecycle perspective, we contend AHP as the assessment technique in this paper.

The aims of this paper include (1) developing a risk identification framework from project life cycle perspectives and (2) presenting a fuzzy AHP method for assessment of risks in PPP projects.

RESEARCH METHODOLOGY

The paper first reviewed the literature on PPP risk management and summarized a risk list in PPP projects from lifecycle perspective. The second step is the development of a model for assessment of these risks objectively using fuzzy AHP to give them a rank. At last, based on the data collected from survey questionnaires, an illustrative example is given to demonstrate how the proposed framework may be applied to assess risks in PPP infrastructures projects.

RISK IDENTIFICATION & CLASSIFICATION

Risk management begins with risk identification and classification (Al-Bahar, 1989; PMBOK, 2004). Thus before assessing risks in PPP projects, it is important to identify and classify the risks.

The most often used method of risk identification is to use a risk checklist. We produce the risk checklist based on a literature review. To generalize the checklist, we choose the papers which include the risk list of PPP projects in different countries including the UK, China, India, and Portugal. The UK, where have had a lot of PPP projects experience, represent the developed countries, while China and India represent the developing countries, and Portugal represents the countries in between. To reflect the recent practice of PPP project, we have chosen the papers published after 1998. Below is the brief introduction of the 6 papers we have chosen.

1. Sight & Kalidindi (2006, India) introduced an Annuity Model, a traffic risk–neutral model by which the granting authority pays the traffic revenue annually to private sector over the concession period in India. According to the risk allocation framework of this model, the risk factors were classified into technical, environmental, social, economic and financial factors. No specific risk assessment methods were introduced in this paper.
2. Li et al (2005, UK) proposed a meta-classification approach on the basis of three levels of risk factors for PPP/PFI projects in the UK, macro level, meso level and micro level risks. The macro level risks comprise risks external to the project itself. The meso level risks include risks occurring within the system boundaries of the project. The micro level risks represent the risks found in the stakeholder relationships formed in the procurement process. Under each level, the risks are further classified according to the sources of risks, such as risks associated with market, natural, construction, etc. Li et al (2005) then conducted an opinion survey by using a postal questionnaire, to explore risk allocation preferences in PPP/PFI projects in the UK.
3. Lemos et al (2004, Portugal) studied 2 bridges cases in Lusoponte Portugal, which includes an overview of the project's background and an analysis of the main risk categories stating both the actual risks encountered and the mitigation measures. The risk factors were classified into 6 categories: Social, Legal, Economic, Environmental, Political and Regulatory and Technological, which included not only the technical factors but also a realistic assessment of environmental and social risks.
4. Grimsey and Lewis (2002, UK) analysed the principles of risk

evaluation of PPP projects, using a case study of a waste water treatment facility in Scotland. Based on the literature review, 9 categories risks were summarized, technical risk, construction risk, operating risk, revenue risk, financial risks, force majeure risk, regulatory/political risks, environmental risks, project default. Then, key risk factors in the water plant were assessed. The authors assessed the nature and quantum of risk from different perspectives of the major project parties, using different risk analysis techniques. Procurer used sensitivity analysis, sponsors preferred Monte-Carlo simulation and lender choosing downside sensitivity analysis.

5. Wang et al (2000, China) identified about 50 risks in 6 categories, Political risks, Construction risks, Operating risks, Market and revenue risks, Financial risks and Legal risks, and mitigating measures associated with BOT/PPP power projects based on literature review and case studies on several BOT projects in China in 1990s, then filtered the risks and measures through an unstructured interviews and discussions. After that, an international survey on risk management of BOT projects in developing countries were made to evaluate the criticality of these risks, using a 6 points rating systems. The ranks were based on the average of the respondents' scores.
6. Akintoye et al (1998, UK) provided the perceptions of clients, contractors and financial institutions on risk associated with PFI (Private Financing Initiate) and how these determine their approach to PFI schemes based on a questionnaire. They summarized a list of risks associated with PFI projects (without classification) compiled from a variety of sources firstly, then asked the respondents to rate the level of importance on Likert Scale of 1~5. An index of relative importance was calculated and the levels of importance divided into strong, moderate and weak importance.

When identifying the risks associated with PPP projects, risk classification is very important because it reflects the purpose of risk management. Zou et al. (2007) noted that the aim of risk classification is to structure the various risks influencing projects objectives. From the 6 papers, we can see the most commonly used way to classify risks is based on the sources of risks. Though it is a good classification method, it can not reflect the perspective of lifecycle risk management. Raftery (1994) stated that the maximum benefits of risk management can be derived only if the process is applied continuously throughout the project life cycle. Flanagan and Norman (1993) also said risk management is a system which aims to identify and quantify all risks to which business or project is exposed so that a conscious decision can be taken on how to manage the risks. The Australian Government Guidelines on PPPs also stressed the importance of conducting risk identification and assessment over the whole life of the project procurement (Australian Government 2005). To conduct a lifecycle risk management, it is important to identify and classify the risks from lifecycle perspective. We propose to classify the risks of PPP projects from project's lifecycle perspective.

We classify the risk factors into 6 stages, which include feasibility study, financing, design, construction, operation and transfer. This covers the whole life cycle of a PPP project. With this classification some risk factors may appear in more than one stage. Table 1 shows the stage-specific risks summarized from the 6 papers reviewed.

PROPOSED FUZZY AHP METHOD FOR ASSESSMENT OF RISKS PPP INFRASTRUCTURE PROJECTS

The analytical hierarchy process (AHP) was developed by Saaty in 1970s. As per Saaty (1980), the first step of AHP is to formulate the decision problem in a hierarchy structure. The fundamental hierarchy structure was developed by Saaty including three levels, as demonstrated in Figure 1. The second step is to carry out pair-wise comparison Where elements in each level are pair-wise compared with respect to their importance to the entire decision problem. After checking the consistency of the pair-wise comparison, the ranking of each element and the priority of alternatives can be computed. AHP has been used in various disciplines, such as public policy, strategic planning, viability determination, forecasting, and project management due to its simplicity, easy to use and great flexibility (Brent et al. 2007, Ho 2007). Some researchers have also introduced it into construction area. Zhang and Zou (2007) sets up a hierarchy structure of the risks and then develops a fuzzy AHP model for the appraisal of the risk environment pertaining to

Table 1: Risk identification and classification based on project lifecycle

Risk category	*Risk factors*	*Singh et al, 2006,India*	*Li et al 2005, UK*	*Lemos, et al, 2004, Portugal*	*Grimsey, et al, 2002, UK*	*WANG, et al, 2000, China*	*Akintoye, et al, 1998, UK*	*Total*
Feasibility study	Environmental pollution	√	√	√	√	√	√	6
	Risk of not-permit/ approval	√	√	√		√	√	5
	Land acquisition and compensation problems	√	√	√		√	√	5
	Public opposition	√	√			√	√	4
	Pre-investment risk	√		√			√	3
	Exclusivity, (i.e. not providing second facility		√	√		√		3
	Level of demand for project		√	√			√	3
	Political opposition/hostility		√			√		2
	Poor public decision-making process		√		√			2
Financing	Interest rate volatility	√	√	√	√	√	√	6
	Inflation rate volatility	√	√	√	√	√	√	6
	Legislation change	√	√	√	√	√	√	6
	Low financial attraction of project to investors	√	√	√	√		√	5
	High finance costs		√	√	√	√	√	5
	Poor financial market	√	√	√			√	4
Design	Design deficiency	√	√	√	√		√	5
	Too many design changes	√	√	√	√		√	4
	Unproven engineering techniques		√		√			1
Construction	Construction cost overrun	√	√	√	√	√	√	6
	Delay completion	√	√	√	√	√	√	6

Risk category	*Risk factors*	*Singh et al, 2006,India*	*Li et al 2005, UK*	*Lemos, et al, 2004, Portugal*	*Grimsey, et al, 2002, UK*	*WANG, et al, 2000, China*	*Akintoye, et al, 1998, UK*	*Total*
	Environmental pollution	√	√	√	√	√	√	6
	interest rate volatility	√	√	√	√	√	√	6
	Inflation rate volatility	√	√	√	√	√	√	6
	Difficulties in land acquisition and compensation	√	√	√		√	√	5
	Too many late design variation	√	√	√		√	√	5
	Non-reliability and creditworthiness of local parties	√	√		√	√	√	5
	public opposition	√	√			√	√	4
	Construction force majeure events	√	√		√	√		4
	Poor quality workmanship		√			√	√	3
	Excessive contract variation		√			√	√	3
	non-availability of material / Labour		√	√		√		3
	Insolvency / default of subcontractor or suppliers		√			√	√	3
	Bad weather	√	√			√		3
	Poor Geotechnical conditions		√			√		2
	Operation revenues below expectation	√	√	√	√	√	√	6
	Fluctuating market demand	√	√	√	√	√	√	6
	Operation / maintenance cost overrun	√	√	√	√	√	√	6
Operation	Environmental pollution	√	√	√	√	√	√	6
	interest rate volatility	√	√	√	√	√	√	6
	Inflation rate volatility	√	√	√	√	√	√	6
	Legislation change	√	√	√	√	√	√	6

Risk category	*Risk factors*	*Singh et al, 2006,India*	*Li et al 2005, UK*	*Lemos, et al, 2004, Portugal*	*Grimsey, et al, 2002, UK*	*WANG, et al, 2000, China*	*Akintoye, et al, 1998, UK*	*Total*
	Lack of reliability and creditworthiness of local parties	√	√	√	√	√	√	6
	Low productivity during operation	√	√	√	√		√	5
	Technology risk	√	√		√	√	√	5
	public opposition because of high product/service price/fees	√	√			√	√	4
	Operator's inability	√	√			√	√	4
	Exclusivity, (i.e. not second facility)		√	√		√		3
	Political force majeure events	√	√			√		3
	Debt risk	√					√	2
	Expropriation, revoke, sequestration of assets		√			√		2
	Prolonged downtime during operation			√		√		2
Transfer	low residual value		√	√			√	3
	Transmission failure			√		√		2

the joint venture projects to support the rational decision making of project stakeholders. Salman et al (2007) introduced a model which evaluates the relationships between decision factors related to project feasibility determination based on the analytical hierarchy process (AHP) technique. Deng (1999) presented a fuzzy approach (using AHP) for tacking qualitative Multicriterion Analysis problems in a simple and straightforward manner, a tender selection problem being empirically studied with the approach.

Wang et al. (2007) revealed that the traditional AHP requires crisp judgment, while, in risk management, it is not an easy task to assess the level of risks in a crisp judgment because of the imprecise information and the uncertainty nature of risks. The fuzzy set theory is designed to deal with the problems, which are the source of imprecision. In recent years, research addressing the combination

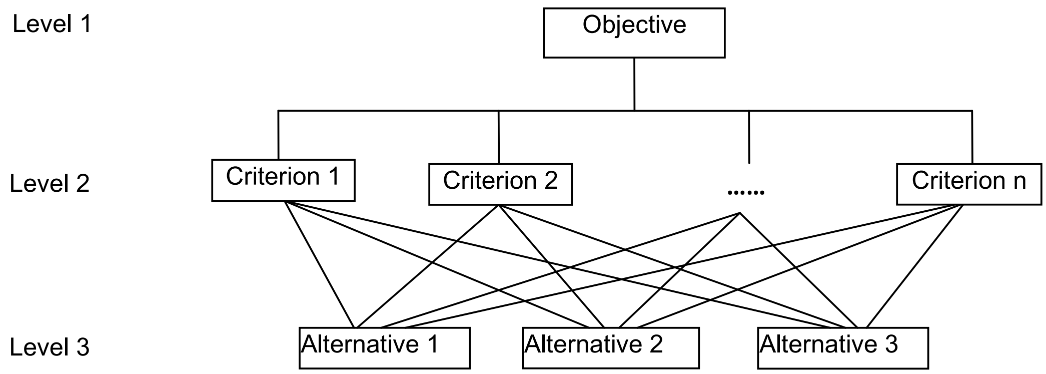

Figure 3: Heirarchy Structure (Saaty 1980)

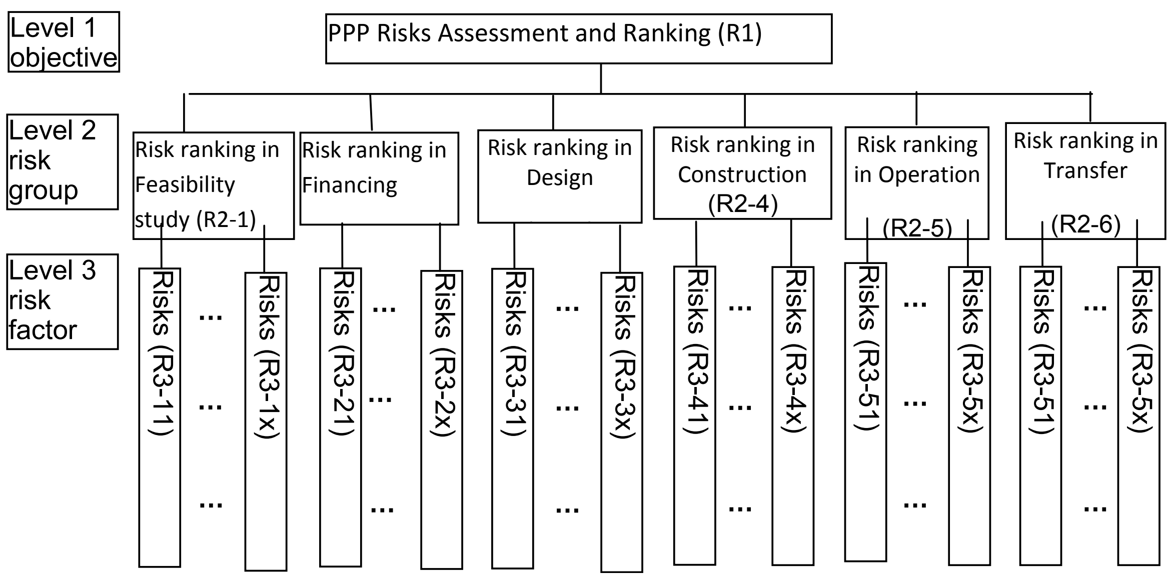

Figure 2: PPP Risks hierarchy structure

Fuzzy scale	*Definition of the fuzzy set*	*Intensity of importance*
1	1	Two activities contribute equally to the objective
$\tilde{1} \sim \tilde{3}$	(1,1,3) ~(1,3,5)	Experience and judgment slightly favour one activity over another
$\tilde{3} \sim \tilde{5}$	(1,3,5)~(3,5,7)	Experience and judgment strongly favour one activity over another
$\tilde{5} \sim \tilde{7}$	(3,5,7)~(5,7,9)	An activity is favoured very strongly over another; its dominance demonstrated in practice

Table 4: The definition of fuzzy number and their scale

between the fuzzy set theory and AHP has gained prominence. It has been accepted that the fuzzy set theory in AHP is more appropriate and effective than the traditional AHP in consideration of an uncertain pair-wise comparison environment (Cheng et al. 1999, and Kang and Lee 2007).

The assessment of risks in PPP infrastructure projects using fuzzy AHP comprises the following four steps:

Step 1: construction of the PPP risks hierarchy structure

A hierarchy is a particular type of system, which is based on the assumption that the entities, which we have identified, can be grouped into disjoint sets, with the entities of one group influencing the entities of only one other group, and being influenced by the entities of only one other group (Saaty, 1980). It is the basis do further analysis. Saaty believed that a hierarchy structure "gives the great detail of information on the structure and function of the system in the lower levels and provide an overview of the actors and their purposes in the upper levels" (Saaty 1980 p14). In this model, the hierarchy structure of PPP project risks can be constructed based the classification method developed above (Figure 2).

Step 2: formation of a reciprocal matrix

The process of AHP is able to reduce the subjectivity or vagueness of the expression of the risk likelihood and consequence by weighting the vaguely expressed risk magnitude on a scale from 1 to 9 (Saaty, 1980). In this paper, we use

e fuzzy number from $\tilde{1}$ to $\tilde{7}$ to set the scale, as following table 2. Fuzzy number is not a real number, but is characterized by a given interval of real numbers (a_1, a_2, a_3), the up and lower limit of which is a_1 and a_3, centring with a_2, for example, $\tilde{3}$ is characterized by (1,3,5) meaning the up and lower limit is 1 and 5, the centre being 3. In that way, the vagueness and uncertainty can be simulated. Table 2 shows the fuzzy numbers and their scale we will use to do pair-wise comparison.

The concept of AHP is then applied to set priority of each element at each level. In the prioritization procedure the determination of the relative importance of each element is achieved using a pair-wise comparison. The pair-wise comparison matrix can be formulated by denoting the relative importance of *i*th element with respect to *j*th element with a_{ij}, then $1/a_{ij}$ represents the relative importance of *j*th element with respect to *i*th element, as shown in Equation (1).

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \vdots & \vdots & \cdots & \vdots \\ & & \cdots & \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix}$$

(1)

where $i=j$, $a_{ij}=1$; where $i \neq j$, $a_{ij}=\tilde{1} \sim \tilde{7}$ & $1/\tilde{7} \sim 1$

Step 3: Ranking of risk factors by calculating the reciprocal matrix.

The ranking of the risk factors is achieved by calculating the above pair-wise comparison matrix. Firstly, the fuzzy weighing of the pair-wise comparison matrix (ϖ_i) can be computed by equation (2) and the fuzzy arithmetic operation (3) and (6) （Deng,1999）. In order to avoid the contradiction of subjective judgments, the consistency should be checked by equation (7) and (8) (Satty, 1980; Byckley, 1985).

$$\tilde{w} = \frac{\sum_{i=1}^{n} \tilde{a}_{ij}}{\sum_{j=1}^{n} \sum_{i=1}^{n} \tilde{a}_{ij}} \qquad (2)$$

$$\tilde{A}^{-1} = \left(\frac{1}{a_3}, \frac{1}{a_2}, \frac{1}{a_1} \right) \qquad (3)$$

$$\tilde{A} \oplus \tilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \qquad (4)$$

$$\tilde{A} \otimes \tilde{B} = (a_1 b_1, a_2 b_2, a_3 b_3) \qquad (5)$$

$$\frac{\tilde{A}}{\tilde{B}} = \left(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1} \right) \qquad (6)$$

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad (7)$$

$$CR = \frac{CI}{RI} \qquad (8)$$

where, *CR* denotes the consistency ratio; *CI* denotes the consistency index; *RI* denotes the average random consistency index, as shown in Table 3. N is the order of the pair-wise comparison matrix.

When CR < 0.1, the pair-wise comparison matrix achieves satisfactory consistency and it is considered acceptable; otherwise, either subjective judgments or the pair-wise comparison should be improved.

Step 4: Defuzzification of the fuzzy weighing

To prioritize the risk factors, their fuzzy weighing need to be compared and ranked. To facilitate the pair-wise comparison process and to avoid the complex and unreliable process of comparing fuzzy weighing, this paper use α -cut technique (5) (Zhang, 1999) and risk index λ (6) (Cheng, 2005) to defuzzificate the fuzzy weighing and get a crisp weighing of each risk factor.

$$\begin{cases} w_1^{\alpha} = w_1 + \alpha(w_2 - w_1) \\ w_3^{\alpha} = w_3 - \alpha(w_3 - w_2) \end{cases} \qquad (9)$$

$$w = \lambda w_3^{\alpha} + (1-\lambda) w_1^{\alpha} \qquad (10)$$

AN ILLUSTRATIVE EXAMPLE – APPLICATION OF THE PROPOSED METHOD/FRAMEWORK

To demonstrate the application of the proposed assessment framework, survey questionnaires were used to collect data. To allow more objective responses from the respondents, a hypothetical example as described in the following section is attached to the survey questionnaires. The respondents are required to reflect to this example while completing the survey questionnaires.

[The hypothetical example] A new express highway is to be built between X City and Y City to increase the traffic efficiency. The highway will be delivered using a PPP scheme in the form of Build / Operate / Transfer (BOT). The main technical features are: proposed length 80km, 6 traffic lanes; design speed 120km/h (on the plane); 15 major bridges, total length 11km; 4 interchanged grade intersections ; 6 non-interchanged grade intersections; 5 underpasses; 1 service area; 1 administration centre. The estimated total investment is RMB 4.2 billion Chinese Yuan (equivalent to 560 million US dollar), which will be raised by the project company and recovered by the traffic toll fees. The project company will borrow RMB 2.8 billion Yuan (equivalent to 373 million US dollar) from banks and invest RMB 1.4 billion Yuan (equivalent to 187 million US dollar) with its own capital.

The main conditions in the PPP/BOT contract include:

- the project company will be authorized the exclusive rights of investment, exploration, design, construction, operation (including getting income from traffic fees) and maintain, etc.
- 30 years concession period (including 42 months construction period), the concession period can be extended upon approval
- Tolls will be decided according to the type, tonnage and seats of vehicles and the National Development and Reform Committee. If any adjustment on rates and way are needed, the company project should apply to the governmental department in charge.
- The government will not authorize or construct another competitive expressway which may decrease the income of the expressway within 30 km on its both sides, except the ones which have been approved. If it does so, the agreement will be got between the government and the project company.
- If there is any plan change the capital structure or transfer the concession contract to other party, the project company should ask the permission of the government.
- the government is responsible helping the project company to apply for the authorities of purchasing using right of land, coordinating the relationship with the project company and other governmental administration departments, acquiring the land.

In total 23 people were invited to fill in the survey questionnaires which was developed based on the risk factors listed in Table 1. Among them, there are Project Managers, Departmental Managers and Engineers. Most of them have worked in transportation construction area for 10~20 years. Table 4 shows the respondents' profiles.

Table 3: Average Random Consistency Index (Saaty 1980)

N	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.48	1.49

Work experience(years)			*Position*		
>20	10~20	<10	Engineers	Project Managers	Departmental Managers
3	16	4	5	9	9

Table 4: Survey respondents' profile

The 23 respondents were asked to tick the risk factors that could occur in a PPP infrastructure (expressway) project and the results are shown in Table 5

The risk factors that had more than 50% positive responses from the respondents are treated as important risk factors and therefore were used to form the hierarchy structure of the expressway projects, see Figure 3.

The 23 respondents were then asked to conduct pair-wise comparisons between different project stages (e.g. compare design stage with construction stage, and construction to operation stage, etc.) and the risk factors within each stage. The results of the pair-wise comparisons between different stages are shown in Table 4. Limited to the length of the paper, the other pair-wise comparison results will not appear in the paper. As per equation (2) ~ (8), the fuzzy weighing of each stage can be computed, as well as the fuzzy weighing of risk factors under each stage. The stages' fuzzy weighing and their corresponding risk factors' fuzzy weighing can be multiplied to get the synthesized fuzzy weighing of each risk factor. The fuzzy weighing of each risk factor is then defuzzied as per equation (9) and (10). The final ranking results of the risk factors and their synthesized weighing are show in Table 5.

Stage	*Risk factor*	*Total counts (out of 23)*
Feasibility study	Land acquisition and compensation problems	19
	Planning deficiency	17
	Poor public decision-making process	17
	permit/ approval risk	13
Financing	Interest rate volatility	18
	Financial Legislation change	17
	Poor financial market	17
	Inflation rate volatility	16
	Little financial attraction of project to investors	13
	Ill capital structure	12
Design	Lack design flexibility	20
	Too many design changes	18
	Design deficiency	13
Construction	Capital materialized problem	21
	Completion delay	19
	Too many late design variation	18
	Construction cost overrun	17
	Poor quality workmanship	17
	Safety risk	16
	Inflation rate volatility	16
	Construction force majeure events	11

Stage	*Risk factor*	*Total counts (out of 23)*
Operation	Legislation change	21
	Operation / maintenance cost overrun	20
	Fluctuating market demand	19
	Environment pollution	18
	Operator inability	15
	public opposition because of high product/service price	14
	Operation safety problems	13
	interest rate volatility	11
	Inflation rate volatility	11
Transfer	Little residual value	21
	Transmission failure	12

Table 5; Survey results on possible risk factors in PPP infrastructure projects

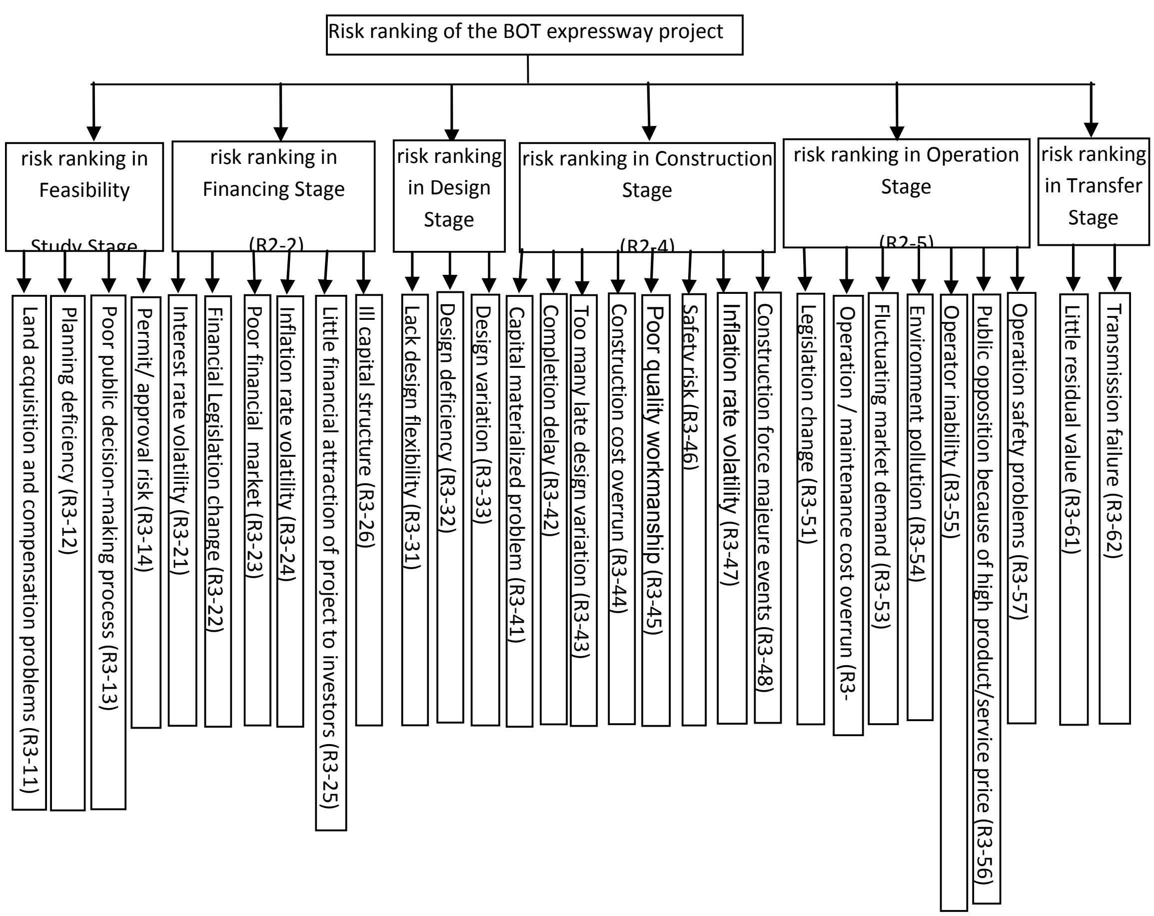

Figure 3: The risk hierarchy structure of PPP/BOT expressway project

Project stages	Feasibility Stage (R2-1)	Financing Stage (R2-2)	Design Stage (R2-3)	Construction Stage (R2-4)	Operation Stage (R2-5)	Transfer Stage (R2-6)
Feasibility Stage (R2-1)	1	$\tilde{3}$	$\tilde{5}$	$1/\tilde{3}$	$1/\tilde{3}$	$1/\tilde{3}$
Financing Stage (R2-2)	$1/\tilde{3}$	1	$\tilde{3}$	$\tilde{3}$	$1/\tilde{3}$	$1/\tilde{3}$
Design Stage (R2-3)	$1/\tilde{5}$	$1/\tilde{3}$	1	$\tilde{3}$	$\tilde{1}$	$\tilde{1}$
Construction Stage (R2-4)	$\tilde{3}$	$1/\tilde{3}$	$1/\tilde{3}$	1	$\tilde{1}$	$\tilde{1}$
Operation Stage (R2-5)	$\tilde{3}$	$\tilde{3}$	$\tilde{1}$	$\tilde{1}$	1	$\tilde{3}$
Transfer Stage (R2-6)	$\tilde{3}$	$\tilde{3}$	$\tilde{1}$	$\tilde{1}$	$1/\tilde{3}$	1

Table 6: A sample pair-wise comparison matrix

No.	*Risk factors*	*Weighting*	*No.*	*Risk factors*	*Weighting*
1	Low residual value (R3-61)	0.3199	16	Operation safety problems (R3-57)	0.0715
2	Design deficiency (R3-32)	0.2257	17	Poor financial market (R3-23)	0.0671
3	Legislation change (R3-51)	0.2136	18	Completion delay (R3-42)	0.0645
4	Planning deficiency (R3-12)	0.2053	19	Lack design flexibility (R3-31)	0.0607
5	Risk on not-Permit/ approval (R3-14)	0.1534	20	Transmission failure (R3-62)	0.0565
6	Financial Legislation change (R3-22)	0.1494	21	Little financial attraction of project to investors (R3-25)	0.053
7	Design variation (R3-33)	0.1432	22	Interest rate volatility (R3-21)	0.0503
8	Difficulties in land acquisition and compensation problems (R3-11)	0.1305	23	Safety risk (R3-46)	0.049
9	Fluctuating market demand (R3-53)	0.1264	24	Operation / maintenance cost overrun (R3-52)	0.0463
10	Capital materialized problem (R3-41)	0.107	25	Public opposition because of high product/service price (R3-56)	0.0424
11	Environmental pollution (R3-54)	0.105	26	Poor public decision-making process (R3-13)	0.0422
12	Construction cost overrun (R3-44)	0.0931	27	Inflation rate volatility (R3-24)	0.0419
13	Ill capital structure (R3-26)	0.09	28	Too many late design variation (R3-43)	0.0378
14	Construction force majeure events (R3-48)	0.0887	29	Poor quality workmanship (R3-45)	0.0361
15	Operator’s inability (R3-55)	0.0715	30	Inflation rate volatility (R3-47)	0.0196

Table 7: Defuzzied weights of each risk

CONCLUSIONS

As a procurement method for large scale infrastructure projects, PPP has been used in many countries. To achieve a successful PPP project, the lifecycle risks are identified based on the literature review and classified according to project stages. The advantages of fuzzy AHP in terms of its objective measurement make it suitable for systematically assess the risks in PPP infrastructures projects. The conceptual model of fuzzy AHP proposed in this paper was verified by an illustrative example to be effective and efficient for assessment of risks in PPP infrastructure projects. It is concluded that using lifecycle perspective to identify, classify and rank the risks associated in PPP infrastructure project is feasible and using fuzzy AHP to assess the risks are effective and objective.

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