Developing a Fuzzy Risk Allocation Model for PPP Projects in China

Yelin Xu[1]; Albert P. C. Chan[2]; and John F. Y. Yeung[3]

Abstract: Equitable allocation of risks between the government and the private sector in concession agreement is essential to the success of public-private partnership (PPP) projects. The decision-making process, based on the established risk allocation principles expressed in linguistic terms, requires qualitative judgment and experiential knowledge of construction experts. However, it is subjective, partial, and implicit in actual application. This paper aims to develop a fuzzy synthetic evaluation model for determining an equitable risk allocation between the government and the private sector. By doing so, it assists the PPP project practitioners to transform the risk allocation principles in linguistic terms into a more usable and systematic quantitative-based analysis using fuzzy set. Twenty-three principles and influencing factors for risk allocation were identified through a comprehensive literature review. Nine critical risk allocation criteria (RACs) that evaluate the risk carrying capability of project participants were further identified, validated, and compiled based on the experts' knowledge via face-to-face interviews. On the other hand, the weighting for each critical risk allocation criterion was determined through a two-round Delphi questionnaire survey. A set of knowledge-based fuzzy inference rules was then established to set up the membership function for the nine RACs. Based on the research findings, a fuzzy synthetic evaluation model was finally established to determine an equitable risk allocation between the government and the private sector.

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Introduction

In recent years, there is a rapid economic expansion in Asia. It results in a sharp increase in the demand for investment in water, power, highway, telecommunications, and other infrastructures (Thomas et al. 2003). A large number of construction projects are undergoing and a lot more are yet to come (Ng and Wong 2006). China is no exception. Public-private partnerships (PPPs) financing modalities, with the ability of attracting foreign and private capital in the development of infrastructure, have been identified by the People's Republic of China Country Strategy and Program Update (2006–2008) as innovative tools for financing major infrastructure projects (Asian Development Bank 2005). PPPs are collaborations in which the public and private sectors both bring their complementary skills to a project, with different levels of involvement and responsibility, for the sake of providing public services more efficiently (Hong Kong Efficiency Unit 2003a). The PPP form of procurement is recognized as an effective way of delivering value-for-money public infrastructure or services (Deng et al. 2006).

PPP seeks to combine the advantages of competitive tendering and flexible negotiation and to allocate risk on an agreed basis between the public and private sectors (Li et al. 2005). It is essential for the public client and the private bidders to evaluate all of the potential risks throughout the whole life cycle of a PPP project. Government and private sector bodies must place close attention on the procurement process while negotiating contracts for PPP to ensure an equitable risk allocation between them (Oudot 2005). Systematic risk management allows early detection of risks and encourages the PPP stakeholders to identify, analyze, quantify, and respond to the risks, as well as to take measures to introduce risk mitigation policies (Akbiyikli and Eaton 2004). A fundamental principle is that risks associated with the implementation and delivery of services should be allocated to the party best able to manage the risk in a cost effective manner (Loosemore and McCarthy 2008). With the fast pace of market-oriented transformation in the planned economy of China, a delicate balance has to be sought among private sector capacity, government regulatory function, and public satisfaction (Deng et al. 2006).

However, few, if any, research studies focus on exploring a comprehensive, objective, reliable, and quantitative risk allocation model for PPP projects. The aims of this research study are to identify the critical criteria for equitable risk allocation associated with PPP projects in China and to establish a quantitative model for equitable risk allocation. The model can assist the PPP project participants to transform the linguistic risk allocation principles into a more usable and systematic quantitative-based decision-making process. The research findings presented in this paper are believed to contribute to the development and application of PPP

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at large and enable those interested investors to better understand the risk allocation of PPP projects in particular.

Literature Review

Although a number of building and construction projects have adopted PPP approach in western countries for decades, they are not equally successful and some of these PPP projects have been exposed to extremely high risks (Thomas et al. 2003). A strong need to manage the risks for PPP projects is becoming a critical issue. A number of researchers have carried out extensive studies on risk allocation (Li et al. 2005; Ng and Loosemore 2007; Medda 2007). Akbiyikli and Eaton (2004) adopted a holistic approach to conduct a research study on systematic risk management in PPP procurement. They took a view that risks need to be identified and managed in all phases of the PPP procurement process. Li et al. (2004a,b, 2005) conducted a questionnaire survey to solicit the opinions of U.K. practitioners on their preferences for risk allocation of PPP construction projects. Wang (2002) opined that only very few PPP projects in China could perform successfully due to a lack of an equitable risk sharing mechanism. There is a strong need for more systematic and in-depth research to examine the risk sharing mechanism and risk management of the PPP procurement approach to enhance the understanding of the whole processes and related issues.

The most widely accepted principle of risk allocation of PPP projects is to distribute the risk to a party who has the greatest capacity, such as expertise and authority, to manage the risk effectively and thus charge the lowest risk premium (Li et al. 2005). However, in practice, the greatest risk management capability is difficult to be clearly determined (Lam et al. 2007). Therefore, the determination is often based on subjective intuition. Some literatures state that risk can be better allocated if the management capability of the parties is pairwise determined (Gao and Jiang 2008). In addition, the public sector tends to allocate more risks to the private sector either for inability or unwillingness to manage these risks. However, too many risks taken by the private sector are not efficient transfer of responsibility; many risks may inevitably be transferred back to the public sector in the form of higher risks (Loosemore and McCarthy 2008). Communities benefit most from the private provision of public infrastructure when project risks are distributed appropriately between the private and public sectors (Liu and Wang 2006). This is not an easy task, given the technical, legal, political, and economic complexity of infrastructure projects and the range of constituencies involved. Recent research reveals that for most PPP projects, risk management practices are highly variable, intuitive, and subjective (Lam et al. 2007). Risk allocation is a complex and flexible process, which depends on many factors, such as participants' risk attitude and the capability of managing risk and risk premium (Zhang et al. 2002; Lam et al. 2007). Therefore, it is necessary to comprehensively consider the critical risk allocation principles and influencing factors so as to allocate the risk equitably. After conducting the comprehensive literature review on various risk allocation principles and influencing factors, a total of 23 principles and influencing factors for risk allocation of PPP projects is identified (as shown in Table 1).

Research Methodology

Overall Research Framework

The methodology employed in this research study is adapted from the research work of Chan et al. (2004). It is based on a comprehensive literature review, face-to-face interviews, and Delphi questionnaire survey for data collection, fuzzy set theory, and fuzzy synthetic evaluation as quantitative tools for data analysis. Fig. 1 shows the flow of overall research framework.

Face-to-Face Interviews

The identified risk allocation principles and influencing factors were further filtered, scrutinized, and verified through a total of 13 face-to-face interviews with field experts. All of them possess eminent practical experience in construction projects. They included project managers, contract managers, consultants, and academics with research track record in PPP (Table 2). During the process of face-to-face interviews, experts were asked to select the most vital criteria for equitable risk allocation from the 23 risk allocation principles and influencing factors identified through the comprehensive literature review. They were also encouraged to add additional risk allocation criteria (RACs) if deemed appropriate. After summarizing the opinions of experts from face-to-face interviews, a total of nine RACs was identified, which form the base for developing the subsequent Delphi questionnaire survey form. The interviews deepened the understanding of the effectiveness and efficiency for each of the risk allocation principles and influencing factors.

Delphi Questionnaire Survey

The Delphi questionnaire survey was then used to obtain the consolidated views of a group of experts via several rounds of intensive questionnaires interspersed with controlled opinion feedback and with results of each round being fed into the next round (Ludwig 1997). It is best suited in fields where there are no adequate historical data for the use of other methods. The features are designed to minimize the biasing effects of dominant individuals, of irrelevant communications, and of group pressure toward conformity. Manoliadis et al. (2006) stated that the key issues in preparing a Delphi survey included (1) the definition of experts and their selection; (2) the number of rounds adopted; and (3) the questionnaire structure in each study round.

Selection of Expert Panel

One of the most important considerations when carrying out a Delphi study is the identification and selection of potential members to constitute the panel of experts (Ludwig 1997; Stone and Busby 1996; Yeung et al. 2007). The selection of members is important because the validity of the study is directly related to this selection process. The following criteria were devised to identify eligible participants for this study:

1. Experts have been involved in the management of PPP projects or have a detailed knowledge of the PPP procurement model.
2. Practitioners have extensive working experience in the construction industry.

Thirty-four experts participated in the two rounds of Delphi questionnaire survey. The background information of these experts is shown in Table 3. The experts represent a wide spectrum of construction professionals and they can provide a balanced view for the Delphi study. The 47% respondents came from the private sector, 20.5% from the public sector, and the remaining were researchers and academics. Furthermore, over 90% of the experts had more than five years of industrial experience. All experts held positions in either high or middle level. Many of the experts had been involved with more than one practical PPP

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Table 1. Principles and Influencing Factors for Equitable Risk Allocation of PPP Projects

	Principles and influencing factors for equitable risk allocation of PPP projects	Arndt and Maguire 1999	Wang et al. 2007	Hong Kong Efficiency Unit 2003b	Thomas et al. 2003	Zhang et al. 2002	Zhu et al. 2007	Deng et al. 2006	Liu and Wang 2006	Lam et al. 2007	Gao and Jiang 2008	Jin and Doloi 2008	Loosemore and McCarthy 2008	Total
1	Criterion of liability (the fault rule)							√	√					2
2	Be able to foresee the probability of occurrence				√					√	√		√	4
3	Be able to evaluate the possible severity of the risk consequence				√					√			√	3
4	Be able to avoid, minimize, monitor, and control the chance of risk occurrence			√	√					√	√		√	5
5	Be able to minimize the loss when risk occurs			√	√					√	√		√	5
6	Be able to sustain the consequences of the risk				√					√			√	3
7	Risk exposure must have the upper limit					√			√					2
8	Be able to bear the risk at the lowest price			√										1
9	Lowest transaction cost											√		1
10	Has the ability (expertise, capability, and resources) to manage the risk effectively and efficiently						√					√	√	3
11	Fair principle (right and obligation balance)							√						1
12	Premium charged by the risk undertaker is considered to be reasonable and acceptable				√					√	√		√	4
13	Enhance the credibility, reputation, and efficiency in risk management									√				1
14	Risk should be allocated to the party who assume the direct loss					√								1
15	Risk attitude of a project participant (risk neutral, risk prone, or risk averse)		√								√		√	3
16	Economics, commercial requirements, and debt financier's requirements	√												1
17	Bargaining power and negotiation tactics	√			√									2
18	Company and national culture and policies	√												1
19	Cooperation history											√		1
20	Partner's risk commitment											√		1
21	Social and environmental issues (risk management environmental uncertainty)				√							√		2
22	Level of governmental support				√									1
23	Need for work, market compulsion caused by competition				√									1

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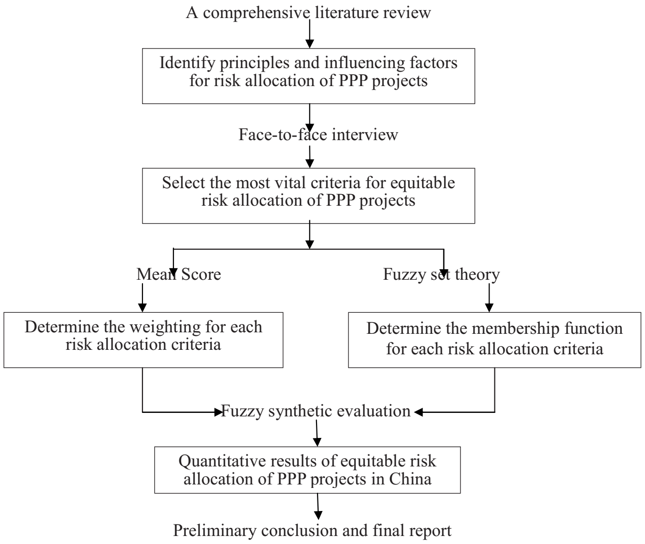

Fig. 1. Flow of the overall research framework

project. The rich hands-on industrial working experience, senior job positions, and relevant organizations of the selected experts ensure the validity of this Delphi survey.

Format of Delphi Questionnaires

The Delphi method adopted in this research consists of two rounds. In the first round of Delphi questionnaire, experts were asked to provide ratings for the nine RACs based on a five-point Likert scale (1=least important and 5=most important). They were also encouraged to propose additional criteria if deemed appropriate. In Round 2 of the Delphi survey, the 34 Delphi experts were provided with the consolidated results from Round 1. The average ratings of the 34 experts for each RAC and the respondent's own ratings in Round 1 were provided. The respondents were asked to reassess their ratings in the light of the mean scored by the 34 experts.

Table 2. Background Information of the 13 Interviewees

(1) Role of interviewees (%)				
Category	Public sector	Private sector	Academic	In total
Percentage	23	54	23	100
(2) Industrial experience of interviewees (%)				
Category	5 years or below	6–10 years	11–15 years	16 years or above
Percentage	8	8	15	69
(3) PPP experiences of interviewees (%)				
Category	None	1–2 years	3–5 years	6 years or above
Percentage	8	15	31	46

Table 3. Background Information of Delphi Experts

(1) Role of survey respondents (%)				
Category	Public sector	Private sector	Academic	In total
Percentage	20.5	47.0	32.5	100
(2) Industrial experience of survey respondents (%)				
Category	5 years or below	6–10 years	11–15 years	16 years or above
Percentage	9.0	23.5	47.0	20.5
(3) PPP experience of survey respondents (%)				
Category	None	1–2 years	3–5 years	6 years or above
Percentage	14.7	52.9	20.5	11.9

Data Analysis Method

Two mathematical tools, including mean score (MS) and fuzzy synthetic evaluation, were used to analyze data collected from the two rounds of Delphi survey. MS is a statistical technique used to establish the relative importance of each RAC. Fuzzy synthetic evaluation was used to assess the overall risk carrying capability (RCC) index (RCCI) of the government and the private sector for each risk factor. Fig. 2 shows the flow of analytical procedures.

MS Ranking Technique

Chan and Kumaraswamy (1996) adopted the "MS" method to establish the relative importance of causes of delay in building construction projects in Hong Kong as suggested by the clients, consultants, and contractors. The data collected from the current questionnaire survey were also analyzed using the same technique. The five-point Likert scale (1=least important and 5 =most important) as described previously was used to calculate the MS for each RAC, which was then used to determine its relative ranking in descending order of importance. These rankings made it possible to triangulate the relative importance of the RACs. The MS for each RAC was computed by the following formula:

$$\mathrm{MS} = \frac{\sum (f \times s)}{N} \qquad (1 \le \mathrm{MS} \le 5)$$

where s=score given to each RAC by the respondents, ranging from 1 to 5 (1=least important and 5=most important); f =frequency of each rating (1–5) for each RAC; and N=total number of responses concerning a particular RAC.

Fuzzy Synthetic Evaluation

Fuzzy synthetic evaluation is a method to assess multiple criteria decision making. Its purpose is to provide a synthetic evaluation of an object relative to an objective in a fuzzy decision environment with a number of factors (Hsu and Yang 1997). In this study, it is used to calculate the RCCI of PPP project stakeholders.

A multicriteria evaluation model requires three basic elements:

1. a family of basic criteria/factors $\pi=\{f_1,f_2,\ldots,f_m\}$;
2. a set of alternatives $E=\{e_1,e_2,\ldots,e_n\}$; and
3. for every object $u \notin U$, there is an evaluation matrix $R=(r_{ij})_{m\times n}$. In the fuzzy environment, r_{ij} is the degree to which alternative e_j satisfies the criterion f_j. It is presented by the fuzzy membership function of alternative e_j with respect to the criterion f_j. With the preceding three elements, for a given $u \notin U$, its evaluation result can be derived (Fig. 3).

Research Findings and Discussions

Identification of 23 Principles and Influencing Factors for Equitable Risk Allocation of PPP Projects

After conducting the comprehensive literature review, a total of 23 principles and influencing factors for equitable risk allocation

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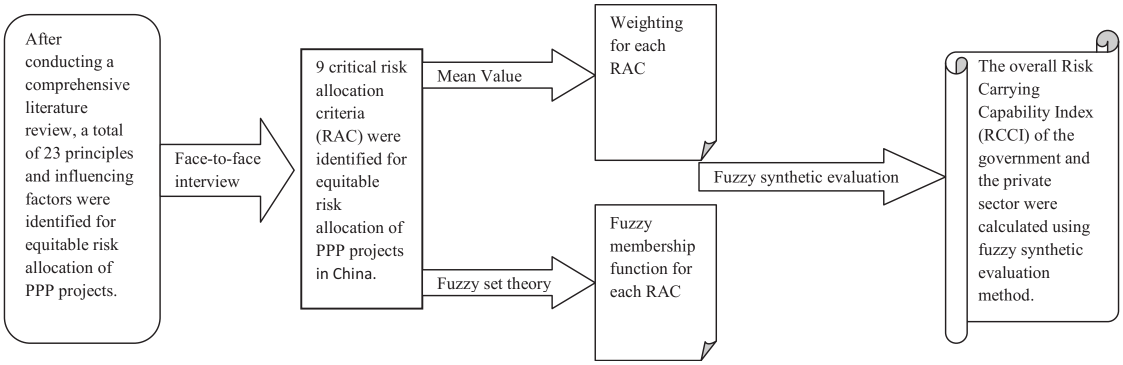

Fig. 2. Flow of analytical procedures

was identified. Table 1 shows all the 23 principles and influencing factors of which "Be able to avoid, minimize, monitor, and control the chance of risk occurrence" and "Be able to minimize the loss when risk occurs" are the two most frequently cited principles and influencing factors; with "Be able to foresee the probability of occurrence," "premium charged by the risk undertaker is considered to be reasonable and acceptable" being the third. It is useful to adopt these principles to allocate risks to reach an equitable risk sharing decision (Loosemore and McCarthy 2008). However, like most of the management doctrines, all these risk allocation principles commonly use natural language in the expressions, which are ambiguous in actual application (Li et al. 2005).

Identification of Nine Most Critical RACs for Equitable Risk Allocation of PPP Projects

Through face-to-face interviews with field experts, principles and influencing factors which have been selected by 50% of experts or above were selected as RAC. This method for criteria selection

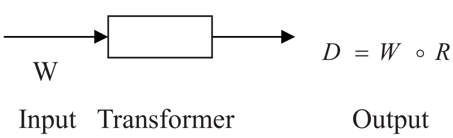

Fig. 3. Process of fuzzy synthetic evaluation

was confirmed by Yeung et al. (2007) and Chan et al. (2001). A total of nine RACs was identified as shown in Table 4 and they could be categorized into three groups, namely, (1) capability of risk management; (2) incentive mechanism; and (3) risk preference. It is obvious that a rational criteria system is beneficial to project participants to deal with risk management and control, encourage them to communicate, and exchange risk information with each other. Thus, the optimum risk management can be guaranteed. Based on the critical RACs identified, the process of risk allocation is to evaluate the RCC of the government and the private sector based on their abilities, incentive obtained, and risk preference. These can be further turned into the process of determining the weighting and membership function on each RAC.

Development of Appropriate Weightings for the Nine RACs

A statistical analysis was performed on the 34 questionnaires received in which the mean ratings for the nine RACs were computed. The weighting for each of the nine RACs was computed by using the following equation (Chow 2005; Yeung et al. 2007):

$$W_i = \frac{M_i}{\sum_{i=1}^{9} M_i}$$

where W_i represents the weighting of a particular RAC; M_i represents the mean ratings of a particular RAC; and ΣM_i represents the summation of mean ratings of all the RACs.

Table 4. Criteria for Equitable Risk Allocation

Criteria for equitable risk allocation			
Capability of risk management	F1	Foresee the risk	The ability to foresee the probability of risk occurrence and evaluate possible severity of the risk consequence
	F2	Control the chance of risk occurrence	The ability to avoid, minimize, monitor, and control the chance of risk occurrence
	F3	Minimize the loss if risk occurs	The ability to minimize the loss if risk occurs (minimize the severity, extra cost, and delay)
	F4	Sustain the consequence	The ability to sustain the consequences of the risk
	F5	Bear the risk at the lowest price	The ability to bear the risk at the lowest price
Incentive mechanism	F6	Obtain reasonable premium	Be able to get reasonable and acceptable premium
	F7	Obtain intangible asset	Be able to enhance risk undertaker's credibility, reputation, and efficiency in risk management
	F8	Assume the direct loss	Be able to assume the direct loss
Risk preference	F9	Risk attitude	Risk should be allocated to the party who prefer to assume the risk (risk neutral, risk prone, or risk averse)

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Table 5. Weightings of the Two Rounds of Delphi Questionnaire Survey

	Round 1			Round 2		
Criteria for risk allocation of PPP projects in China	Mean	Rank	Weighting	Mean	Rank	Weighting
F1—control the chance of risk occurrence	3.97	1	0.15	4.09	1	0.15
F2—minimize the loss if risk occurs	3.59	2	0.135	3.58	2	0.13
F3—bear the risk at the lowest price	3.23	3	0.12	3.41	3	0.125
F4—obtain reasonable premium	3.00	4	0.115	3.03	5	0.11
F5—sustain the consequence	2.94	5	0.11	3.11	4	0.115
F6—assume the direct loss	2.76	6	0.105	2.68	6	0.10
F7—foresee the risk	2.52	7	0.095	2.65	7	0.10
F8—obtain intangible asset	2.35	8	0.09	2.56	8	0.09
F9—risk attitude	2.20	9	0.08	2.24	9	0.08
Number (n)			34		34	
Kendall's coefficient of concordance			0.338		0.457	
Level of significance			0.000		0.000	

Table 5 shows the nine RACs together with their corresponding weightings of Rounds 1 and 2. The RCCI is developed to evaluate the acceptable risk level of each project participant. The index can be represented by the following formula:

$$\begin{aligned}\mathrm{RCCI} = {} & 0.15 \times \mathrm{RAC1} + 0.13 \times \mathrm{RAC2} + 0.125 \times \mathrm{RAC3} + 0.11 \\ & \times \mathrm{RAC4} + 0.115 \times \mathrm{RAC5} + 0.10 \times \mathrm{RAC6} + 0.10 \\ & \times \mathrm{RAC7} + 0.09 \times \mathrm{RAC8} + 0.08 \times \mathrm{RAC9}\end{aligned}$$

The RCCI is composed of nine weighted RACs and the index is derived based on the assumption that this is a linear and additive model. It is logical and valid to derive this linear and additive model because the correlation matrix as shown in Table 6 reveals that the nine weighted RACs are not highly correlated with each other at 5% significance level (most of them are insignificantly correlated with each other). In addition, the units of measurement for the nine weighted RACs are different so it is not likely to have any multiplier effect between them. Though it seems more sophisticated to use a nonlinear model to fit the data obtained, overfitting is a common problem with nonlinear models especially when the sample size is not sufficiently large (Neter et al. 2005; Weisberg 2005). That is why a linear, but not nonlinear model, is recommended if the relationship among variables is not proved to be nonlinear. Practically speaking, it is simpler and easier to use this model to calculate the RCCI for the government and the private sector. The same research methodologies were applied to develop a performance index for measuring the performance of partnering projects in Hong Kong (Yeung et al. 2007) and relationship-based construction projects in Australia.

In order to obtain a measure of consistency, a statistical test was applied involving the calculation of the Kendall coefficient of concordance (W) for the RACs provided by the 34 experts (Chan et al. 2001) with the aid of the Statistical Packages for Social Sciences (SPSS) computer software. If the concordance coefficient is equal to 1, it means that all the experts rank the RACs identically. In contrast, if the concordance coefficient is equal to 0, it means that all the experts rank the RACs totally differently. Table 5 also shows that Kendall's coefficient of concordance (W) for the rankings of the nine weighted RACs in Round 1 was 0.338, which was statistically significant at 1% level. The null hypothesis that

Table 6. Correlation Matrix among the Nine Weighted RACs (for Round 2 of the Delphi Survey)

	F1	F2	F3	F4	F5	F6	F7	F8	F9
F1	1	0.149[a]	−0.024	−0.032	−0.273	−0.091	0.006	−0.061	0.248
		0.0401	0.893	0.855	0.118	0.607	0.974	0.733	0.157
F2		1	0.063	0.123	0.317	−0.153	−0.153	−0.086	0.263
			0.722	0.488	0.068	0.388	0.388	0.630	0.133
F3			1	0.276	−0.147	0.137	0.130	0.135	−0.119
				0.115	0.408	0.438	0.465	0.448	0.503
F4				1	0.103	0.265	0.096	0.210	−0.236
					0.561	0.129	0.591	0.234	0.178
F5					1	0.310	−0.095	−0.030	0.169
						0.075	0.592	0.867	0.376
F6						1	0.239	0.276	−0.058
							0.174	0.114	0.745
F7							1	0.453[b]	−0.304
								0.007	0.080
F8								1	−0.113
									0.525
F9									1

[a]Correlation is significant at the 0.05 level (two-tailed).
[b]Correlation is significant at the 0.01 level (two-tailed).

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Table 7. Input Variables and Linguistic Term I

F1, F2, F3, F4, F5 (capability of risk management)		Range of percentage of likelihood (%)
1	Very low	0–25
2	Low	0–50
3	Moderate	25–75
4	High	50–100
5	Very high	75–100

Table 8. Input Variables and Linguistic Term II

F6, F7, F8 (incentive mechanism)		Range of percentage of likelihood (%)
1	Very unlikely	0–25
2	Unlikely	0–50
3	Moderate	25–75
4	Likely	50–100
5	Very likely	75–100

the respondent's ratings within the group are unrelated to each other would have to be rejected. Therefore, it can be concluded that a significant amount of agreement among the respondents within the group of panel experts is found.

In Round 2, the consistency of the experts' weightings was again computed using the SPSS software by calculating the Kendall coefficient of concordance (W). Table 5 showed that there are some changes for the rank order of the nine weighted RACs. "Obtain reasonable premium" changed from the fourth rank to the fifth rank and "sustain the consequence" changed from the fifth rank to the fourth rank. Although there are some changes for the rank order of the nine RACs, their weightings are similar to those of Round 1. The consistency of the experts' rankings for the RACs was improved by 35.2% to 0.457, which was also statistically significant at 1% level.

Determination of the Membership Function for Each RAC

The fuzzy synthetic evaluation model is developed for the risk allocation between the government and the private sector in a concession agreement. Three linguistic input variables, denoted by I–III, are defined based on the nine RACs. To assess a risk event, the ranges of percentage are used to indicate (1) the ranges of likelihood of the risk being foreseeable, controllable, avoidable, manageable, and sustainable by the concessionaire; (2) the ranges of likelihood to obtain benefits from bearing the risk; and (3) the ranges of degree of willingness to undertake the risk, which forms the three types of input variables. Based on the fuzzy set theory, the linguistic terms are defined to describe the input variables to facilitate the building of fuzzy inference rules. For the linguistic Term I, the set is {very low, low, moderate, high, very high} (Table 7 and Fig. 4). For the linguistic Term II, the set is {very unlikely, unlikely, moderate, likely, very likely} (Table 8 and Fig. 5). For the linguistic Term III, the set is {strongly averse, averse, neutral, preferable, strongly preferable} (Table 9 and Fig. 6).

The procedure for transforming input data such that they belong to a particular fuzzy subset is known as fuzzification. Two widely used fuzzification functions are the S function and π function. They are defined in Fig. 7. S and π functions are used to represent the fuzzy membership functions of input variables in the model. The ranges of each term of input variable are defined in Tables 6–8. Figs. 4–6 illustrate the fuzzification functions for input variables (input variable is a percent). The output variable of the model is the risk factor's membership function for each corresponding risk allocation criterion.

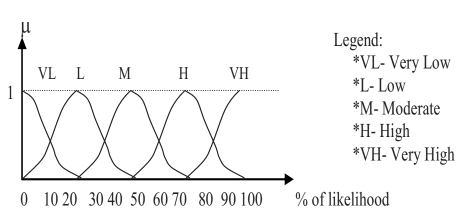

Fig. 4. Fuzzification functions for "capability of risk management"

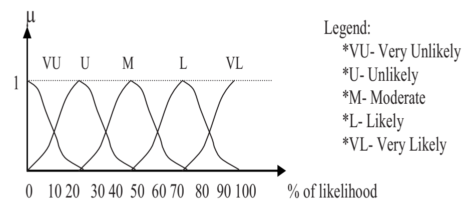

Fig. 5. Fuzzification functions for "incentive mechanism"

Table 9. Input Variables and Linguistic Term III

F9 (risk preference)		Range of percentage of likelihood (%)
1	Strongly averse	0–25
2	Averse	0–50
3	Neutral	25–75
4	Preferable	50–100
5	Very preferable	75–100

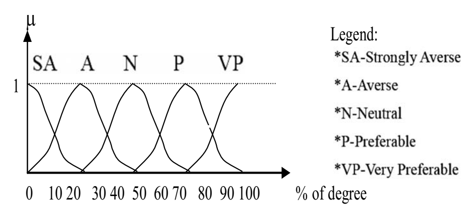

Fig. 6. Fuzzification functions for "risk preference"

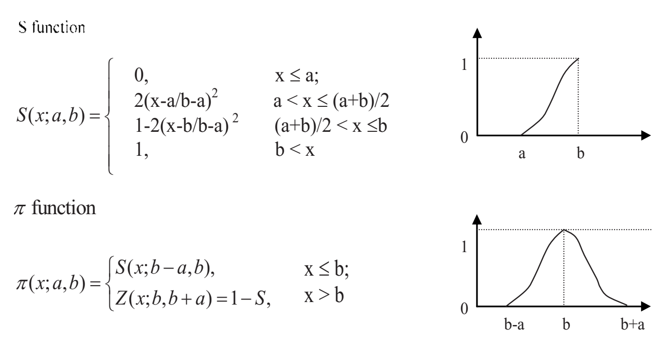

Fig. 7. Function S and Π used for fuzzification of input variables

Table 10. RCCI of the Government (Inflation Rate Volatility)

RCCI of the government			
RACs	Weighting	Membership function of RAC	Membership function of risk carry capability index ($B1$)
1. The ability to avoid, minimize, monitor, and control the chance of risk occurrence	0.15	(0.46, 0.22, 0.17, 0.12, 0.03)	
2. The ability to minimize the loss if risk occurs	0.13	(0.17, 0.42, 0.29, 0.12, 0.00)	
3. The ability to bear the risk at the lowest price	0.125	(0.00, 0.02, 0.27, 0.44, 0.27)	
4. Be able to get reasonable and acceptable premium	0.11	(0.68, 0.32, 0, 0, 0)	(0.18, 0.16, 0.30, 0.25, 0.10)
5. The ability to sustain the consequences of the risk	0.115	(0.02, 0.02, 0.22, 0.49, 0.25)	
6. Be able to assume the direct loss	0.10	(0.07, 0.10, 0.51, 0.25, 0.07)	
7. The ability to foresee the risk	0.10	(0.00, 0.15, 0.37, 0.34, 0.14)	
8. Be able to enhance risk undertaker's credibility, reputation, and efficiency in risk management	0.09	(0.00, 0.02, 0.61, 0.30, 0.07)	
9. Risk attitude	0.08	(0.07, 0.12, 0.49, 0.25, 0.07)	

Quantitative Calculations of Risk Allocation

After developing appropriate weightings for the nine RACs and establishing fuzzy membership functions for each RAC, the quantitative calculations of risk allocation between the government and the private sector can be derived by the following three steps:
Step 1. calculate the RCCI of the government and the private sector through fuzzy synthetic evaluation;
Step 2. normalize the index value; and
Step 3. determine the proportion of risk allocation between the government and the private sector.

Step 1: Calculate the RCCI

Let B denote the membership function of RCCI of PPP participants (the government or the private sector) and W and R denote the weighting and membership function of each RAC. Based on the weighting and membership function of each RAC obtained from the aforementioned process, the RCCI for each party can be obtained through fuzzy synthetic evaluation model. There are four models commonly used to determine the results of the evaluation (Lo 1999)

$$\text{Model 1:} M(\wedge,\vee),\quad b_j = \bigvee_{i=1}^{m} (w_i \wedge r_{ij}) \quad \forall \quad b_j \in B$$

$$\text{Model 2:} M(\bullet,\vee),\quad b_j = \bigvee_{i=1}^{m} (w_i \times r_{ij}) \quad \forall \quad b_j \in B$$

Models 1 and 2 are suitable for single-item problems because only the major criteria are considered; other minor criteria are ignored. For RCCI of the government or the concessionaire, however, each RAC should have its influence on the overall index level

$$\text{Model 3:} M(\bullet,\oplus),\quad b_j = \min\left(1, \sum_{i=1}^{m} w_i \times r_{ij}\right) \quad \forall \quad b_j \in B$$

$$\text{Model 4:} M(\wedge,+),\quad b_j = \sum_{i=1}^{m} (w_i \wedge r_{ij}) \quad \forall \quad b_j \in B$$

The symbol $\oplus$ in Model 3 represents the summation of product of weighting and membership function. Model 3 is suitable when many criteria are considered and the difference in the weighting of each criterion is not great. Model 4 will miss some information with smaller weighting. Therefore, it yields similar results to those derived from Models 1 and 2. Accordingly, Model 3 is suitable for calculating the overall RCCI.

Step 2: Normalize the Index Value

Employing equation $A=\Sigma_{k=1}^{5} B_k \times M$, where A is the score of overall RCCI; B is the membership function of RCCI; M is a constant from the weighting vectors of 0.125, 0.25, 0.5, 0.75, and 0.875. (The mean value of the range of percentage is shown in Tables 6–8.) The result of normalization of the index value is also a definite constant.

Step 3: Determine the Proportion of Risk Allocation between the Government and the Private Sector

Let $A1$ and $A2$ denote the RCCI of the government and the private sector, respectively

$$\text{Risk should be borne by the government} = \frac{A1}{A1+A2} \times 100\%$$

$$\text{Risk should be borne by the private sector} = \frac{A2}{A1+A2} \times 100\%$$

Illustrative Example

A risk factor, inflation rate fluctuation, is chosen to illustrate how to use the model to quantitatively determine the risk allocation of PPP projects in China. The Delphi experts (part of them) were invited to set up the membership function for each RAC as shown in Tables 10 and 11.

According to the process of fuzzy synthetic evaluation introduced above, the procedures for the illustration are as follows:

1. set up the membership function of each RAC according to the participants' actual condition (capability of risk management, incentive mechanism, and risk preference);
2. calculate the membership function of RCCI using fuzzy synthetic evaluation; and

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3. calculate the proportion of risk allocation between the government and the private sector.

From the nine critical RACs, it can be seen that the setup of member function for each RAC depends on three items: (1) project participants' ability to foresee, avoid, sustain, and minimize the loss; (2) benefits obtained from bearing the risk; and (3) project participants' risk preference. The membership functions of inflation rate fluctuation are shown in Tables 10 and 11.

The results are obtained using Model 3

$$B1 = |0.15 \quad 0.13 \quad 0.125 \quad 0.11 \quad 0.115 \quad 0.10 \quad 0.10 \quad 0.09 \quad 0.08| \cdot \begin{vmatrix} 0.46 & 0.22 & 0.17 & 0.12 & 0.03 \\ 0.17 & 0.42 & 0.29 & 0.12 & 0.00 \\ 0.00 & 0.02 & 0.27 & 0.44 & 0.27 \\ 0.68 & 0.32 & 0.00 & 0.00 & 0.00 \\ 0.02 & 0.02 & 0.22 & 0.49 & 0.25 \\ 0.07 & 0.10 & 0.51 & 0.25 & 0.07 \\ 0.00 & 0.15 & 0.37 & 0.34 & 0.14 \\ 0.00 & 0.02 & 0.61 & 0.30 & 0.07 \\ 0.07 & 0.12 & 0.49 & 0.25 & 0.07 \end{vmatrix} = (0.18,\ 0.16,\ 0.30,\ 0.25,\ 0.10)$$

Likewise

$$B2 = (0.07,\ 0.13,\ 0.43,\ 0.26,\ 0.11)$$

$$A1 = (0.18,\ 0.16,\ 0.30,\ 0.25,\ 0.10) \cdot (0.125,\ 0.25,\ 0.5,\ 0.75,\ 0.875)^T = 0.49$$

and

$$A2 = (0.07,\ 0.13,\ 0.43,\ 0.26,\ 0.11) \cdot (0.125,\ 0.25,\ 0.5,\ 0.75,\ 0.875)^T = 0.5475$$

Therefore, risk should be borne by the government $=[A1/(A1+A2)]\times 100\% = 47.2\%$ and risk should be borne by the private sector $=[A2/(A1+A2)]\times 100\% = 52.8\%$.

This illustrative example indicates that the risk of inflation rate fluctuation should be shared by the government and the private sector with proportions of 47.2 and 52.8%, respectively. These proportions are tally with the practical risk allocation of PPP projects in China. Take the water supply project in Chengdu as an example. The project located in Chengdu City is a build operate transfer type of PPP between Chengdu Government and Chengdu Generale de Eauv–Marubeni with a 30-year concession period after completion of construction. It has been opened officially. The water price of this project is decided by the bidder (the private sector) in the bid. The bidder needs to make an assumption on the inflation rate and shall assume risks arising from inconsistency between the actual inflation rate and the estimated one. This means inflation risks were shared by the government and the private sector jointly.

Conclusions

It is widely accepted that equitable risk allocation is essential to the successful implementation of PPP projects. In this paper, a fuzzy risk allocation model has been proposed. It transforms imprecise linguistic risk allocation principles and experiential expert knowledge into a more usable quantitative-based analysis using a fuzzy set theory approach. Through a comprehensive literature review and face-to-face interviews for data collection, nine critical RACs for PPP projects were identified, validated, and compiled. The weighting and membership function for these criteria were also obtained by two rounds of Delphi questionnaires survey and fuzzy set theory. Then, the fuzzy risk allocation model for PPP projects in China was therefore established through a fuzzy synthetic evaluation approach.

The fuzzy risk allocation model provides an explicit, comprehensive, and systematic framework in risk allocation practice rather than a subjective and untraceable approach based on individual's intuitive judgment. Risk allocation of different PPP projects in China can then be evaluated and compared objectively based on the RCCI. As a decision support tool, it enriches the current body of knowledge and understanding of both academics and practitioners in the PPP procurement approach to achieve equitable risk sharing. It can also be modified to suit a specific

Table 11. RCCI of the Private Sector (Inflation Rate Volatility)

RCCI of the private sector			
RACs	Weighting	Membership function of risk allocation indicators ($R2$)	Membership function of RCCI ($B2$)
1. The ability to avoid, minimize, monitor, and control the chance of risk occurrence	0.15	(0.29, 0.34, 0.25, 0.12, 0.00)	
2. The ability to minimize the loss if risk occurs	0.13	(0.02, 0.10, 0.37, 0.34, 0.17)	
3. The ability to bear the risk at the lowest price	0.125	(0.00, 0.05, 0.44, 0.34, 0.17)	
4. Be able to get reasonable and acceptable premium	0.11	(0.05, 0.20, 0.27, 0.24, 0.24)	(0.07, 0.13, 0.43, 0.26, 0.11)
5. The ability to sustain the consequences of the risk	0.115	(0.07, 0.12, 0.49, 0.25, 0.07)	
6. Be able to assume the direct loss	0.10	(0.00, 0.05, 0.49, 0.32, 0.14)	
7. The ability to foresee the risk	0.10	(0.07, 0.10, 0.51, 0.25, 0.07)	
8. Be able to enhance risk undertaker's credibility, reputation, and efficiency in risk management	0.09	(0.00, 0.07, 0.59, 0.24, 0.10)	
9. Risk attitude	0.08	(0.00, 0.05, 0.66, 0.22, 0.07)	

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context or project strategy by adjusting the RAC, the membership functions of the input variables, and the fuzzy inference rules.

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