Fuzzy Analytical Hierarchy Process Risk Assessment Approach for Joint Venture Construction Projects in China

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Abstract: Research and practice show that construction joint venture (JV) activities in China are opportunities that can bring potential benefits but at the same time may generate many risks. While research has studied these risks and presented useful advice for managing individual risks, the methodologies used to analyze the risks were mainly qualitatively based, and there is a gap in using the quantitative method that can integrate a risk expert's knowledge to assess the risks associated with JV projects. This paper sets up a hierarchy structure of the risks and then develops a fuzzy analytical hierarchy process (AHP) model for the appraisal of the risk environment pertaining to the JVs to support the rational decision making of project stakeholders. An empirical case study is used to demonstrate the application of the proposed fuzzy AHP model. It is concluded that the fuzzy AHP model is effective in tackling the risks involved in JV projects. The information presented in this paper should be shown to all parties considering JV business opportunities in China, and the proposed approach should be applicable to the research and analysis of risks associated with any type of construction projects.

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Introduction

Since the early 1980s, China's "open door" policy has continuously attracted overseas investment and today makes her the second largest recipient of foreign direct investment in the world (Chadee and Qiu 2001). The construction industry is one of the major areas absorbing overseas investment, and the proportion of investment is still rapidly increasing (Wang et al. 1999; Luo et al. 2001). The most common form of cooperation has been through joint ventures (JVs) between the Chinese and overseas parties (Luo 2001; Shen et al. 2001). Sino-foreign construction JVs can provide opportunities for the foreign parties to expand their business to the Chinese market, which may indicate large and continuous benefits and also reduce potential risks in an unfamiliar market (Norwood and Mansfield 1999). From the Chinese perspective, JVs can not only attract foreign investment but also bring advanced technologies and management expertise.

While studies have examined many risks and presented constructive advice for managing individual risks, few attempts have been made in pursuit of a quantitative method to assess the impacts of risks on a particular JV project and to further evaluate the project viability holistically. This paper first sets up a hierarchy structure of risks associated with Sino-foreign construction JVs and then develops a fuzzy analytical hierarchy process (AHP) model for the appraisal of the risk environment pertaining to the JV implementation in procuring construction projects. An empirical case study is used to demonstrate the application of the model.

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Research Aims and Significance

Based on a critical literature review of risks and risk management practice for Sino-foreign JVs in the Chinese construction industry (which will be discussed in the following sections), it is found that many efforts have been made to use surveys and case studies to explore key risks associated with construction JVs and to identify strategies to manage these risks in the operation of JVs. The outcomes of these works can help industry practitioners to recognize and take action to manage the possible key risks at an early stage. However, the characteristics of different JVs mean that different risks may occur in the JV practices and result in different levels of consequences. Many risks cannot be avoided and need to be managed by the project team collaboratively. Although the project partners are eager to identify these risks, finding a quantitative approach to evaluate the comprehensive level of all risks associated with the proposed JV to support rational and objective decision making seems to be more significant at the formative stage of the JV.

This paper aims to provide a generic quantitative model to comprehensively assess the levels of risks that come with individual Sino-foreign construction JV projects and to evaluate whether a JV is really viable for project delivery. The fuzzy AHP approach is chosen for developing the model, a method that is often used to tackle complex project decision making that calls for subjective judgment based on well-established logical reasoning, rather than on simple feeling and intuition. In doing so, the complex and unstructured problem is broken down into components/elements, and then a hierarchy structure is set

J. Constr. Eng. Manage., 2007, 133(10): 771-779

Table 1. Potential Benefits of Sino-Foreign Joint Ventures

Parties	Potential benefits to the joint venture parties
Chinese partners	Company's capability improved in terms of size and scope of work undertaken
	Company's expertise broadens
	Sharing risks
	Bridging knowledge and expertise gaps
Overseas partners	Access to new areas of the world without having to carry all the risks
	Greater access of overseas company to local partner's market and local consulting engineers
	Exploring opportunities
Chinese construction industry	Cross-fertilization of ideas from different companies
	Attracting capital investment and making up the shortage of funds in capital construction
	Transfer of advanced building technology and project management skills
	Stimulating the development of export-oriented contracting
	Improving the existing imperfect mechanism of the construction market
	Strengthening domestic construction firm's competitiveness

up to project the relationship between different hierarchy levels and among these elements. Each element may have a different level of importance for a given type of project, and meanwhile have a different level of performance in the proposed project. Synthesizing the generic relative importance and the forecast performance can determine the general performance of the examined project.

In Sino-foreign construction JVs, many common risks exist due to the different backgrounds of the project partners and also the technical and financial issues pertaining to the projects. These risks may have different levels of importance for the success of the JV projects. A specific JV project tends to be exposed to different risks compared with other JV projects, and hence the fuzzy AHP method is one of the optimal technique for evaluating the risks associated with JVs and provides comprehensive decision making. In detail, expert judgment is used to take account of the different importance of each element for the construction JV projects, and experts' further appraisal is used to estimate the potential performance of each element in the examined project.

This research is significant because the information presented in this paper provides a comprehensive risk assessment tool to all parties concerned, including the Chinese companies and the overseas companies who consider seizing the JV business opportunities in China. Furthermore, the proposed model/methodology will be applicable and useful to the analysis of other types of project risks. Finally, the proposed model may form a base for further studies in the field.

Policies, Forms, and Benefits of Sino-Foreign Joint Ventures

A joint venture (JV) may be defined as "the commercial agreement between two or more companies in order to allow greater ease of work and cooperation towards achieving a common aim, through the manipulation of the appropriate resources" (Norwood and Mansfield 1999). The enormous demands for housing and infrastructure in China ensure opportunities for both domestic and foreign construction companies. Since the 1980s, the Chinese construction market has gradually been open to overseas companies. However, establishing wholly foreign-owned construction firms used to be prohibited in China (Gale and Luo 2004), so foreign contractors had to set up construction JV companies to acquire the business.

After China's entry into the World Trade Organization (WTO) on December 11, 2001, the Chinese government promised to extend the privileges of overseas contractors in the construction field through three steps: (1) at first, foreign enterprises are not permitted to establish their branch organization in China to contract for projects directly; (2) within the three years immediately after China's accession to the WTO, foreign enterprises will be allowed step by step to establish solely foreign-owned enterprises but can only contract for limited types of projects; and (3) with five years of China's entry, solely foreign-owned businesses will be allowed gradually to contract all types of projects (Fang et al. 2004).

Foreign-invested construction enterprises and engineering institutes have been regulated through decrees 113 and 114 and their supporting regulations (MOC 2002a,b). The Interim Measures on Construction Project Management, Decree 200, requires a foreign enterprise engaged in project management to possess a skill qualification certificate. The newly released draft Provisions on the Administration of Foreign Invested Construction Engineering Service Enterprises also gives a good indication of how the position of foreign engineering consulting firms will be formalized in China (Cox 2006). Although these policies potentially expand the market for foreign enterprises, Sino-foreign JVs are still the preferred form of cooperation used in practice (Chan and Suen 2005), which might be due to unique benefits, as mentioned previously.

In relation to construction project procurement, JVs can be divided into equity JVs (also called integrated JVs) and nonequity JVs (also called nonintegrated or contractual JVs) (Mansfield et al. 1993; Glaister and Buckley 1996; Luo et al. 2001). In a typical Sino-foreign JV, the overseas parties are usually responsible for providing the majority of financing, advanced technologies, imported equipment (which is not available in China), and management and marketing expertise. The local parties can provide land, labor, and facilities and also make substantial contributions to local business knowledge and good working relationships with governments (Fan 1988; Shen et al. 2001; Xu et al. 2005). Norwood and Mansfield (1999) and Luo et al. (2001) summarized the potential benefits of construction JVs, as shown in Table 1. In brief, Sino-foreign JVs can maximize the strengths of Chinese and overseas partners and contribute to the success of the collaborative projects and the improvement of mechanism in the Chinese construction industry.

J. Constr. Eng. Manage., 2007, 133(10): 771-779

Literature Review in Relation to Risk Management in Sino-Foreign JVs

Foreign construction companies are encouraged to enter the local market in the form of JVs in China and the Southeast Asia region (Li et al. 1999). Due to historical and geographical issues, China and the Southeast Asia region countries have similar economic, environmental, and cultural backgrounds, which may result in similar risks in the JV practices. The following sections present a review of literature in relation to risk management in JVs with a focus on the Chinese construction market.

Li et al. (1999) conducted research from the angle of risk management and control in international construction JV businesses in East Asia. They classified the risks into three main groups: internal, project-specific, and external. The internal risks refer to those that are unique in a JV and are developed from the nature of the operation that causes conflicts within the JV organization. The project-specific risks refer to unexpected developments during the construction period that lead to time and cost overruns or to shortfalls in the performance parameters of the completed project. The external risks represent the risks that derive from the competitive macro environment that the JV operates. Li et al. (1999) examined 25 potential risks with the aid of questionnaire surveys and identified the top five risks: client's cash flow problems, financial problems in the partner's parent company, inconsistency in government policies, laws and regulations, economy fluctuation, and poor relationship. They also proposed that a foreign construction firm in an overseas JV practice could reduce its risks if it would carefully select its local partner, ensure that a good JV agreement is drafted, choose the right staff and subcontractors, establish good project relationships, and secure a fair construction contract with its client. Li and Tiong (1999) also proposed a risk management model for JVs in the construction industry, in which eight risk-mitigating measures—partner selection, agreement, employment, control, subcontracting, engineering contract, good relationship, and renegotiation—were proposed and incorporated to help construction firms improve their decision-making process for JVs.

Shen et al. (2001) extracted a list of 58 risk factors associated with Sino-foreign construction JVs from literature and categorized them into six groups: financial, legal, management, market, policy, and technical related. They then conducted surveys to examine these risks in the Chinese construction market and established a risk significance index to identify the most important risks. The top 3 ranked risks include "cost increase due to changes of policies," "improper project feasibility study," and "project delay," and the top 10 risks consist of 5 related to management, 2 related to market, 2 related to policy, and 1 related to technical issue. Shen et al. (2001) also analyzed the highly ranked and typical risks and proposed practical risk management strategies such as improving cooperation with government agencies, employing contracts to manage risks properly, and controlling technical risks.

From the perspectives of the Chinese contractors, Fang et al. (2004) investigated risks encountered by local contractors while contracting for projects in the Chinese construction market. In comparison to Li et al.'s (1999) research, Fang et al. (2004) divided risks into two categories: external risks and internal risks. They referred to external risks as those that are beyond the direct control of project managerial personnel, such as factors related to government policies and weather. However, they combined the project-specific risks with internal risks and referred to them as those that may produce a direct influence on specific projects and can be subdivided into preproject phrase-related risks, design related, subcontractors and suppliers related risks, and so on. Similar to Shen et al.'s (2001) research, Fang et al. (2004) used a risk importance index to evaluate the risk importance based on surveys and found that the main risks currently encountered by Chinese contractors in domestic markets include owner's irregular behavior, government departments' interference in construction markets, certain external environmental factors, subcontractors' incompetence, and the poor quality of suppliers' goods. The research results provided valuable information for foreign contractors to gain a better understanding of the potential risks in the Chinese construction market.

Gale and Luo (2004) carried out a full population survey of 160 Sino-foreign JV-based construction companies in four of China's provinces to investigate key factors for the success of JVs at the formation stage. By comparing perceptions of the Chinese and foreign executives from these JVs, they identified a consensus agreement on five factors leading to JV success at the formation stage, including "selection of suitable partners," "obtaining enough information about potential partners before negotiation," "clear statement of JV agreement," "clear identification of partners' objectives," and "control of the majority ownership of the capital." They also found that foreign respondents appear to show more concern about cultural compatibility, while the Chinese partners expect a long-term attitude in cooperation through forming JVs to achieve their objectives, rather than short-term benefits. They concluded that the different perceptions associated with JV success held by Chinese and foreign partners may not exist at the JV formation stage, although essentially there are different perceptions between local partners in developing countries and Western partners about criteria associated with the JV success.

Walker and Johannes (2003) interviewed nine senior executives from JV organizations operating in the segment of the Hong Kong construction market and found that a JV's *raison d'etre* is a market-driven response to change, globalization, business process alignment, and aims to achieve customer focus. However, significant problems may arise with political and cultural differences stemming form one JV partner not understanding the political and historical pressures influencing their partners. JV partners also risk being implicated in their partner's corruption and/or illegal activity, perhaps due to poor definition or interpretation of laws and regulations applying to the project. They also found that complexity arises out of the potentially diverse motivations of various partners.

By means of empirical surveys with senior personnel from five construction companies with JV experience, Norwood and Mansfield (1999) discussed how JVs may best be conducted and identified the advantages and disadvantages of construction JVs, motives for forming construction JVs, and lessons learned from construction JV activities, as well as project goals achieved through joint venturing. They stated that the main disadvantages for Western contractors entering the Chinese construction market were that they were facing fierce competition from both Japanese and Korean contractors and would have to work more with manpower and less with mechanization. In addition, problems arose within the management structures of JVs as a result of differences within Asian and Western cultures. Likewise, Swierczek (1994) found that many conflicts take their source at the development of the culture of JVs and also proposed that "understanding the main dimensions of culture and how they affect conflict assists in creating a common culture for JVs and provides (for a collaborative approach) for managing conflicts as they emerge."

J. Constr. Eng. Manage., 2007, 133(10): 771-779

Table 2. Risks Associated with Sino-Foreign Joint Ventures

Internal risks	Project-specific risks	External risks
(1) Partner's financial ability	(1) Cash flow problems of client	(1) Cost rise due to changes of policies
(1) Distrust among partners	(2) Project delay	(2) Bureaucracy for late approvals
(3) Local partners' incompetence	(3) Subcontractor/supplier's incompetence	(3) Economy fluctuation
(4) Interference by parent companies	(4) Excessive design variations by client	(4) Exchange rate and convertibility
(5) Disagreement on staff allocation	(5) Incomplete contract terms	(5) Force majeure and social disorder
(6) Disagreement on work allocation	(6) Disagreement on some conditions of contract	(6) Inflation
(7) Dispute on technology transfer	(7) Improper project planning and budgeting	(7) Import restriction/local protectionism
(8) Internal conflicts between parties	(8) Client's improper intervention in construction phase	(8) Security problems
(9) Inadequate project organization structure	(9) Unpredicted technical problems in construction	(9) Safety issues during construction
(10) Bankruptcy of project partner	(10) Incompetence of project management team	(10) Language barrier
(11) Poor relations within project partners		(11) Capital return difficulty
(12) Change of organization within local partner		(12) Different social, cultural, and religious background
		(13) Pollution
		(14) Loss incurred due to corruption
		(15) Expropriation
		(16) Poor relations with government bodies
		(17) Shortage in supply of water, gas, and electricity

Risks Associated with Sino-Foreign JVs

The aforementioned literature explored the risks associated with Sino-foreign JVs in the Chinese construction market. These risks were classified according either to their nature (e.g., financial risks, technical risks, etc.) or their relationship with the JV organizations (e.g., internal risks, external risks, etc.) To serve for articulating the risks originating from the feature of multiparties within JVs, the risk classification method proposed by Li et al. (1999) is adopted in the case study in this paper to summarize the risks identified by the past research (Li et al. 1999; Shen et al. 2001; Walker and Johannes 2003; Fang et al. 2004; Gale and Luo 2004), as shown in Table 2. It should be noted that the risks presented in Table 2 only encompass the major ones, and different projects may expose some different risks.

Although past efforts examined risk management issues in Sino-foreign JVs and key risks were highlighted together with some strategies proposed to tackle them, it appears that little attempt has been undertaken to give a quantitative assessment of the comprehensive level of all risks associated with Sino-foreign JVs, which might be of more concern to most foreign contractors expecting to enter the Chinese construction market with a reasonable and acceptable level of risks. This research aims to provide a generic quantitative method to assess the comprehensive level of risks coming along with any JV projects to evaluate whether a JV is really viable. As different projects tend to expose one to different risks and different risks have different levels of impact on the success of JVs, the fuzzy AHP method is one of the most optimal techniques to evaluate the risks associated with JVs and to provide comprehensive information to project partners to make rational decisions.

Proposed Fuzzy AHP Risk Assessment Approach

Resembling human reasoning in its use of approximate information and uncertainty to generate decisions, fuzzy set theory is specifically designed to mathematically represent uncertainty and to vagueness and to provide formalized tools for dealing with the imprecision intrinsic to many problems. The AHP is one of the most extensively used multicriteria decision-making methods for dealing with complex decision problems (Kablan 2004) in which factors are categorized into different groups and levels and then prioritized or weighted accurately and consistently.

At the formation stage, most risks associated with a JV are unclear to the project partners. These risks, as described by the literature, are multifaceted and strongly project-related. Judgment of these risks is normally vague and imprecise at this stage. The Chinese and overseas partners need to make a comprehensive assessment with respect to the risky condition pertaining to the proposed Sino-foreign JV. The fuzzy AHP approach will be employed to tackle the multifaceted risk assessment involved in the decision making of the JV. The fuzzy AHP approach includes three steps: setting up the hierarchy structure of risks, determining the weight vector by the AHP, and fuzzy assessment of risks, as presented below.

Hierarchy Structure of Risks

A list of risks associated with Sino-foreign JVs can be identified and then classified where Li et al.'s (1999), Shen et al.'s (2001), and Fang et al.'s (2004) methods can be referred to. To produce a generic hierarchy structure, the risks can be sorted into l groups at the criteria level, with a few risks at the attribute level under each group, as shown in Fig. 1. Please note that more levels can be incorporated into the hierarchy structure in which the principle of the AHP approach is the same.

It should be noted that the AHP requires that a problem be decomposed into levels, each of which is comprised of elements. The elements of a given level are mutually independent, but comparable to the elements of the same level. This assumption is the fundamental to the proposed Fuzzy AHP method. Hence, the way to categorize the risks and the relationship/nature of the risk factors at the same level will determine the effectiveness and validity of the method. For example, in Wang et al.'s (2004) paper, the risks related to construction projects were divided into "country level," "market level" and "project level." Under such categori-

J. Constr. Eng. Manage., 2007, 133(10): 771-779

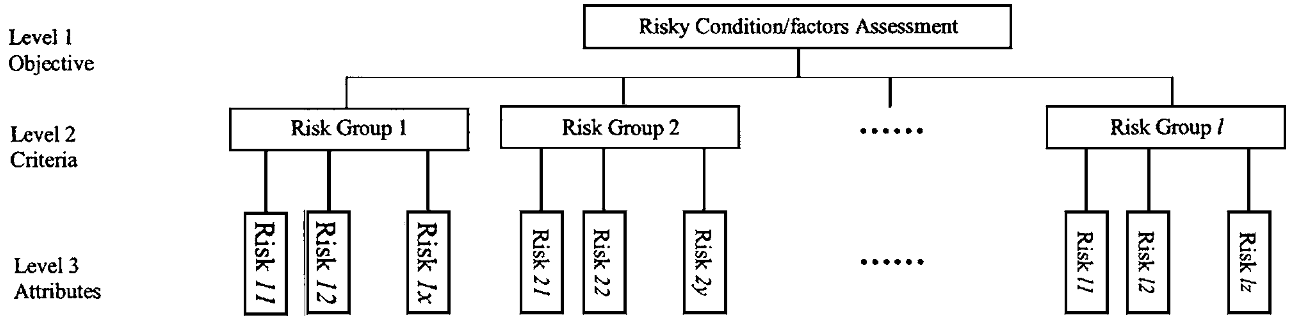

Fig. 1. Hierarchy structure of risk factors

zation, the risk factors are strongly correlated. For instance, the country level risks may influence both the market and project levels risks, while the market level risks may influence the project risks. As a result, a factor at one particular level may influence other factors at another level. For example, "the foreign exchange and convertibility" and "inflation and interest rates" at market level can cause "cost overrun" at project level. Hence, the independency among elements cannot be guaranteed. As a reference, when setting up the hierarchy structure for the proposed fuzzy AHP model, the categorization methods of risk factors need to ensure the maximum independency among elements at the same level.

Determination of Weight Vector ω by AHP

AHP is used for scaling the weights of the elements (risks) in each level of the hierarchy with respect to the elements (risks) of the next higher level. This is done by means of pairwise comparisons of the activities to indicate the strength with which one activity dominates another vis-à-vis the criterion under which they are compared. The reason lies in that the performance of a system is a result of the interaction of various factors but every factor plays its own role and makes contribution to the system as a whole.

As per Saaty (1980), the pairwise comparison is established using a nine-point scale that converts the human preferences between available alternatives as equal importance, weak importance, strong importance, very strong importance and absolute importance, as shown in Table 3. The comparison is based on expert judgment. Suppose m experts are invited. Each expert's opinion is obtained and analyzed individually to determine the weight vector ω_i pertaining to Risk Group i $(i=1-l)$. The following procedures provide a method to obtain the relative weight of risk factors at Level 3 under Risk Group 1.

As shown in Fig. 1, Risk Group 1 includes x number of risk factors, which is defined by

$$\mu=\{\mu_1\ \mu_2\ \cdots\ \mu_x\} \tag{1}$$

According to AHP, the pairwise judgment matrix for the relative weight of risk factors based on the k^{th} expert's opinion $(k=1-m)$ is an x-by-x nonzero reciprocal matrix, as presented below

$$P=\begin{bmatrix} 1 & p_{12} & \cdots & p_{1x} \\ 1/p_{12} & 1 & \cdots & p_{2x} \\ \vdots & \vdots & \ddots & \vdots \\ 1/p_{1x} & 1/p_{2x} & \cdots & 1 \end{bmatrix} \tag{2}$$

where x=number of risk factors under Risk Group 1 and p_{ij}=scale value of the pair of factors μ_i and μ_j $(i,j=1-x)$, which is normally assigned to a 1–9 scale as per Table 3. As per the method proposed by Saaty (1980), the eigenvector is given by

$$\omega'_{1k}=(\omega'_{1k1}\ \omega'_{1k2}\ \cdots\ \omega'_{1kx}) \tag{3}$$

$$\omega'_{1ki}=\sqrt[x]{\prod_{j=1}^{x} p_{ij}} \tag{4}$$

Then the eigenvector needs to be normalized by

$$\omega_{1ki}=\frac{\omega'_{1ki}}{\sum_{j=1}^{x}\omega'_{1kj}} \tag{5}$$

Based on the opinion of Expert k, the weight vector ω_{1k} of the risk factors under Risk Group 1 is determined

$$\omega_{1k}=(\omega_{1k1}\ \omega_{1k2}\ \cdots\ \omega_{1kx}) \tag{6}$$

Finally, in order to avoid artificial errors and the contradiction of different factors, a consistence check needs to be conducted until a satisfactory condition is obtained. A consistency check is a unique advantage of AHP compared to other methods. The maxi-

Table 3. Linguistic Measures of Importance (Adapted from Saaty 1980)

Scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance	There is evidence favoring one activity over another but it is not conclusive
5	Strong importance	Good evidence and logical criteria exist to show one is more important
7	Very strong importance	Conclusive evidence as to the importance of one activity over another
9	Absolute importance	Evidence in favor of one activity over another is of the highest possible form of affirmation
2,4,6,8	Intermediate values between adjacent scale values	When compromise is needed

J. Constr. Eng. Manage., 2007, 133(10): 771-779

Table 4. Average Random Consistency Index

x	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

mum eigenvalue λ_{max} is a measure of consistency of judgment. This can be conducted by the following equation:

$$\dot{\lambda}_{max} = \frac{1}{x}\sum_{i=1}^{x}\frac{(P\omega_{1k})}{\omega_{1ki}} \tag{7}$$

$$CR = \frac{CI}{RI} = \frac{1}{RI}\left(\frac{\lambda_{max} - x}{x-1}\right) \tag{8}$$

where CR denotes the consistency ratio; CI denotes the consistency index; RI denotes the average random consistency index, as shown in Table 4; x=order of the judgement matrix. When $CR < 0.1$, the matrix has satisfactory consistency; otherwise, it should be adjusted.

After all m experts' opinions are analyzed and the weight vector ω_{1k} ($k=1-m$) based on each expert's judgment are worked out, the weight vector ω_1 for Risk Group 1 is determined by

$$\omega_1 = \frac{1}{m}\sum_{k=1}^{m}\omega_{1k} = \left(\frac{\sum_{k=1}^{m}\omega_{1k1}}{m}\ \frac{\sum_{k=1}^{m}\omega_{1k2}}{m}\ \cdots\ \frac{\sum_{k=1}^{m}\omega_{1kx}}{m}\right) \tag{9}$$

It should be noted that the invited experts may have different levels of knowledge of the risks associated with JVs, and hence their opinions may have different levels of impact on the pairwise comparison. A weight coefficient reflecting the expert difference can be incorporated in the above equation. However, this issue is not considered in this paper to simplify the research.

Likewise, the weight vectors ($\omega_2-\omega_l$) for risk factors at Level 3 under Risk Group $2-l$ can be obtained by means of the above-described method. And the weight vectors ω_G for the risk groups at Level 2 under the general objective can also be determined with this method.

Fuzzy Evaluation Matrix

Grounded on a thorough understanding of the characteristics of the proposed Sino-foreign JV project, the same or another group of experts may be invited to comment on the performance of each risk factor within the project. Again, assume that the objective being evaluated is the risk factors at Level 3 under Risk Group 1 and the set is defined as $\mu=\{\mu_1\ \mu_2\ \cdots\ \mu_x\}$. The appraisal set is the possible evaluation grading result, as defined by

$$V = \{\nu_1\ \nu_2\ \cdots\ \nu_n\} \tag{10}$$

Herein, the grades are linguistic measures of the performance of each risk factor, such as *good, poor, high* and *low*; n is the number of the grades. The appraisal of risk factor i under Risk Group 1 as per the appraisal set is defined as an appraisal vector:

$$R_{1i} = (r_{1i1}\ r_{1i2}\ \cdots\ r_{1in}) \tag{11}$$

$$r_{1ih} = \frac{N_{1ih}}{m} \tag{12}$$

where r_{1ih} ($h=1-n$) is the fuzzy membership degree of appraisal of the factor i under Risk Group 1 to the grade h; N_{1ih}=frequency of appraisal grading result ν_h for factor i; m=number of experts. The above description can be regarded as a fuzzy subset of V

$$f:\mu \to f(V);\ \mu_i| \to (r_{1i1}\ r_{1i2}\ \cdots\ r_{1in}) \tag{13}$$

The fuzzy appraisal matrix R_1 of all x factors is

$$R_1 = \begin{bmatrix} R_{11} \\ R_{12} \\ \vdots \\ R_{1x} \end{bmatrix} = \begin{bmatrix} r_{111} & r_{112} & \cdots & r_{11n} \\ r_{121} & r_{122} & \cdots & r_{12n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{1x1} & r_{1x2} & \cdots & r_{1xn} \end{bmatrix} \tag{14}$$

The fuzzy appraisal matrixes (R_2-R_l) of risk factors under Risk Group $2-l$ can be obtained using the same method, which will not be further explained here.

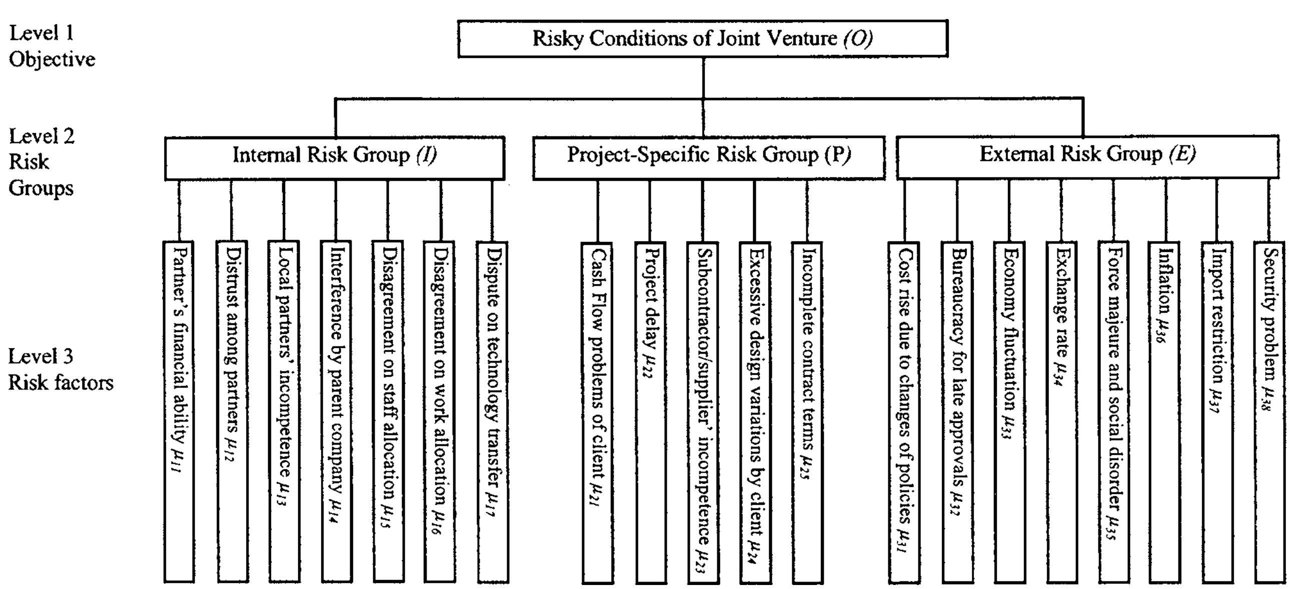

Fig. 2. Hierarchy of risks associated with a Sino-foreign JV freeway project

J. Constr. Eng. Manage., 2007, 133(10): 771-779

Table 5. Weight Vectors of Risk Factors and Risk Groups

Risks/risk groups	Experts	Weight vector (weight coefficient of risks/risk groups)	Maximum eigenvalue (λ_{max})	CI	CR
Internal risks	1	$\omega_{11}=(0.296,0.177,0.146,0.117,0.106,0.096,0.061)$	7.33	0.054	0.041
	2	$\omega_{12}=(0.313,0.174,0.143,0.115,0.105,0.091,0.058)$	7.31	0.051	0.039
	3	$\omega_{13}=(0.124,0.219,0.187,0.137,0.145,0.119,0.068)$	7.56	0.094	0.071
	4	$\omega_{14}=(0.392,0.105,0.098,0.133,0.121,0.095,0.056)$	7.44	0.074	0.056
	5	$\omega_{15}=(0.314,0.254,0.078,0.118,0.107,0.079,0.049)$	7.50	0.083	0.063
	Average	$\omega_{1}=(0.288,0.186,0.130,0.124,0.117,0.096,0.059)$			
Project-specific risks	1	$\omega_{21}=(0.375,0.210,0.159,0.128,0.128)$	5.06	0.015	0.013
	2	$\omega_{22}=(0.419,0.215,0.150,0.121,0.094)$	5.18	0.045	0.040
	3	$\omega_{23}=(0.188,0.463,0.108,0.077,0.164)$	5.11	0.029	0.026
	4	$\omega_{24}=(0.236,0.287,0.165,0.205,0.106)$	5.29	0.073	0.065
	5	$\omega_{25}=(0.134,0.449,0.106,0.267,0.044)$	5.21	0.053	0.048
	Average	$\omega_{2}=(0.270,0.325,0.138,0.160,0.107)$			
External risks	1	$\omega_{31}=(0.290,0.167,0.140,0.111,0.101,0.093,0.053,0.045)$	8.13	0.018	0.013
	2	$\omega_{32}=(0.282,0.213,0.124,0.103,0.091,0.103,0.043,0.041)$	8.24	0.034	0.024
	3	$\omega_{33}=(0.204,0.343,0.148,0.073,0.082,0.072,0.041,0.038)$	8.30	0.042	0.030
	4	$\omega_{34}=(0.181,0.386,0.086,0.088,0.083,0.074,0.043,0.058)$	8.48	0.069	0.049
	5	$\omega_{35}=(0.180,0.096,0.088,0.084,0.062,0.096,0.356,0.037)$	8.60	0.086	0.061
	Average	$\omega_{3}=(0.228,0.241,0.117,0.092,0.084,0.088,0.107,0.044)$			
Risk groups	1	$\omega_{G1}=(0.540,0.297,0.163)$	3.01	0.005	0.008
	2	$\omega_{G2}=(0.297,0.240,0.163)$	3.01	0.005	0.008
	3	$\omega_{G3}=(0.320,0.558,0.122)$	3.02	0.009	0.016
	4	$\omega_{G4}=(0.286,0.143,0.571)$	3.00	0	0
	5	$\omega_{G5}=(0.136,0.625,0.238)$	3.02	0.009	0.016
	Average	$\omega_{G}=(0.316,0.433,0.252)$			

Note: CI=consistency index; CR=consistency ratio.

Fuzzy AHP Evaluation

To explore the level of risky condition in a JV, a comprehensive evaluation can be made by multiplying Eq. (9) and (14) using an appropriate fuzzy arithmetic operator σ. To consider the collaborative impacts of all risks and at the same time keep the information of individual risk, a fuzzy arithmetic operator $\sigma=(\bullet,\oplus)$ is chosen, as per Zhang (1991). At Level 3, the appraisal of risk factors under Risk Group 1 can be calculated in the following appraisal vector B_1:

$$B_1=\omega_1\sigma R_1=(b_{11}\ b_{12}\ \cdots\ b_{1n}) \tag{15}$$

where $b_{1j}=1\wedge\sum_{i=1}^{x}\omega_{1i}r_{1ij}$ as per Eqs. (9) and (14). The appraisal vectors of risk factors under all risk groups comprise the appraisal matrix R_G at Level 2, as presented by

$$R_G=\begin{bmatrix}B_1\\B_2\\\vdots\\B_l\end{bmatrix}=\begin{bmatrix}\omega_1\sigma R_1\\\omega_2\sigma R_2\\\vdots\\\omega_l\sigma R_l\end{bmatrix} \tag{16}$$

where B_i=appraisal vector of risk factors under Risk Group i.

The final fuzzy evaluation vector B of the risk performance in the JV practice is made by multiplying the weight vector ω_G and the appraisal vector R_G of risk groups, as shown by

$$B=\omega_G\sigma R_G=(b_1\ b_2\ \cdots\ b_l) \tag{17}$$

According to the maximum subordination law, the comprehensive level of risky condition associated with the project can be decided by

$$b_{max}=b_1\vee b_2\vee\cdots\vee b_l=\max\{b_1\ b_2\ \cdots\ b_l\} \tag{18}$$

Case Study—Application of Fuzzy AHP Approach to a Sino-Foreign JV Construction Project

A freeway JV construction project in Hebei, Peoples Republic of China is presented as an empirical case study to illustrate the applicability of the fuzzy AHP approach developed. The People's Government of Hebei Province was the project client, and one Chinese contractor and one overseas contractor comprised the Sino-foreign JV parties. Based on experience and preliminary research with respect to the risks associated with JVs in Chinese construction market, the foreign contractor identified a list of 20 risks and categorized them into three groups: internal, project specific, and external risks, as shown in Fig. 2. As per the definitions (Li et al. 1999), these risk groups are in parallel rather than one governing another. The risks under these categories are less likely to be influenced by other factors at the same level. Hence, this kind of classification method can minimize the correlations between risk factors at the same level, which satisfies the fundamental prerequisite of the proposed fuzzy AHP approach.

In the structure, the risky condition assessment (O) at Level 1 is the objective; internal (I), project-specific (P), and external (E) risk groups at Level 2 are three criteria for the risky condition assessment; risk factors ($\mu_{11}-\mu_{38}$) at Level 3 are attributes under the three risk groups. The two levels of risk membership sets are defined, namely with the objective level $O=\{I,P,E\}$ and the risk group level $I=\{\mu_{11},\mu_{12},\cdots,\mu_{17}\}$, $P=\{\mu_{21},\mu_{22},\cdots,\mu_{25}\}$, and $E=\{\mu_{31},\mu_{32},\cdots,\mu_{38}\}$.

Five domestic and overseas experts with robust knowledge and experience of Sino-foreign JVs and freeway construction are invited to carry out the pairwise comparison of the importance of

J. Constr. Eng. Manage., 2007, 133(10): 771-779

Table 6. Fuzzy Evaluation of Risky Condition of the Freeway Joint Venture

Risks/risk groups	Attributes	Weight coefficient	Appraisal matrix/vector					
				(very severe,	severe,	medium,	light,	very light)
Internal risks	μ_{11}	0.288	$R_{11}=$	(0.3,	0.3,	0.1,	0.1,	0.2)
	μ_{12}	0.186	$R_{12}=$	(0.2,	0.2,	0.3,	0.2,	0.1)
	μ_{13}	0.130	$R_{13}=$	(0.3,	0.2,	0.3,	0.1,	0.1)
	μ_{14}	0.124	$R_{14}=$	(0.3,	0.1,	0.4,	0.1,	0.1)
	μ_{15}	0.117	$R_{15}=$	(0.1,	0.1,	0.4,	0.3,	0.1)
	μ_{16}	0.096	$R_{16}=$	(0.3,	0.3,	0.2,	0.1,	0.1)
	μ_{17}	0.059	$R_{17}=$	(0.2,	0.1,	0.3,	0.2,	0.2)
Appraisal vector of internal risk group (I)			$\mathbf{B}_1=$	(0.252,	0.208,	0.257,	0.248,	0.135)
Project-specific risks	μ_{21}	0.270	$R_{21}=$	(0.1,	0.6,	0.2,	0.1,	0.0)
	μ_{22}	0.325	$R_{22}=$	(0.2,	0.4,	0.2,	0.1,	0.1)
	μ_{23}	0.138	$R_{23}=$	(0.1,	0.2,	0.1,	0.4,	0.2)
	μ_{24}	0.160	$R_{24}=$	(0.2,	0.2,	0.1,	0.2,	0.3)
	μ_{25}	0.107	$R_{25}=$	(0.2,	0.1,	0.3,	0.1,	0.3)
Appraisal vector of project-specific risk group (P)			$\mathbf{B}_2=$	(0.159,	0.362,	0.181,	0.157,	0.140)
External risks	μ_{31}	0.228	$R_{31}=$	(0.1,	0.2,	0.2,	0.1,	0.4)
	μ_{32}	0.241	$R_{32}=$	(0.3,	0.2,	0.4,	0.1,	0.0)
	μ_{33}	0.117	$R_{33}=$	(0.1,	0.2,	0.2,	0.3,	0.2)
	μ_{34}	0.092	$R_{34}=$	(0.1,	0.3,	0.3,	0.2,	0.1)
	μ_{35}	0.084	$R_{35}=$	(0.2,	0.2,	0.2,	0.1,	0.3)
	μ_{36}	0.088	$R_{36}=$	(0.1,	0.4,	0.2,	0.2,	0.1)
	μ_{37}	0.107	$R_{37}=$	(0.1,	0.1,	0.3,	0.3,	0.2)
	μ_{38}	0.044	$R_{38}=$	(0.2,	0.2,	0.1,	0.3,	0.2)
Appraisal vector of external risk group (E)			$\mathbf{B}_3=$	(0.161,	0.216,	0.264,	0.172,	0.188)
Risk groups	I	0.316	$B_1=$	(0.122,	0.180,	0.285,	0.267,	0.148)
	P	0.433	$B_2=$	(0.198,	0.213,	0.262,	0.252,	0.076)
	E	0.252	$B_3=$	(0.161,	0.216,	0.264,	0.172,	0.188)
Appraisal vector of risky condition of the freeway JV (O)			$\mathbf{B}=$	(0.189,	0.277,	0.226,	0.158,	0.150)

risk factors at Level 3 and risk groups at Level 2. By means of Eqs. (1)–(6), the feedback is collated and analyzed to obtain the weight vector of each expert's judgment matrix, as shown in Table 5. The maximum eigenvalue λ_{max} and consistency index (CI) and ratio (CR) pertaining to each expert's judgment matrix are calculated as well, using Eqs. (7) and (8). It is evident that all values of CR are less than 0.1. Therefore, it can be concluded that a reasonable level of consistency has been achieved by using expert judgment. Then the average weight vectors of risk factors at Level 3 and risk groups at Level 2 are determined.

Based on a thorough investigation of the JV parties and the proposed freeway construction projects, the above five experts and another five senior personnel from the foreign contractor company are invited to evaluate the performance of each risk factor within this Sino-foreign construction JV. The appraisal set of the performance includes five grades as described by V={extremely severe, severe, medium, light, very light}. The feedbacks are analyzed and the results are presented in Table 6. By means of Eqs. (10)–(14), the expert's judgment with respect to the performance of each risk factor is statistically fractioned to form the appraisal vector, and the vectors of all risk factors under a risk group comprise the appraisal matrix. Then the appraisal vector of each risk group is obtained with the aid of Eq. (15), and the final fuzzy evaluation vector of the risky condition of the freeway JV is determined by Eqs. (16) and (17), as shown by $\mathbf{B}=(0.189, 0.277, 0.226, 0.158, 0.150)$ at the bottom of Table 6.

According to the maximum subordination law, the comprehensive level value (b_{max}) of the risky condition associated with the Sino-foreign freeway construction JV equals 0.277, which indicates that the risky condition is at the ***severe*** level. If planning to proceed with the JV project, the foreign contractor needs to take appropriate risk management strategies to deal with the risks appropriately. The key risks can be preliminarily identified as per the expert's judgment matrix in Table 6. For example, among the project-specific risks, the client's cash flow and project delay are regarded as the major risks influencing the success of the JV. The methods to manage these risks have been proposed by Li et al. (1999) and Shen et al. (2001), including to "carefully select its local partner, ensure that a good JV agreement is drafted, choose the right staff and subcontractors, establish good project relationships, and secure a fair construction contract with its client" (Li et al. 1999) and "improving cooperation with government agencies, employing contracts to manage risks properly and controlling technical risks" (Shen et al. 2001).

Conclusions

Under China's "open door" policies, overseas contractors and developers are encouraged to enter the Chinese construction market in the form of JVs with local firms. While this brings unprecedented opportunities to the overseas entities, enormous risks may arise due to the different cultural, political, economic, and environmental background between the Chinese and foreign parties. In addition, diverse financial and technical risks also apply to

J. Constr. Eng. Manage., 2007, 133(10): 771-779

different construction projects. Previous studies have explored and assessed the risks from qualitative manners, but limited research has been dedicated to the quantitative assessment of the risky conditions/factors of Sino-foreign construction JVs. This paper has first reviewed the related literature and then developed a quantitative risk assessment model for Sino-foreign JV projects using fuzzy set theory and AHP techniques. In this approach, the hierarchical structure of risks associated with a JV construction project is established first. Based on expert judgment, the weight coefficients of risk groups and risk factors are acquired with the aid of the AHP techniques and the fuzzy evaluation matrixes of risk factors are founded through fuzzy set theory. Then the aggregation of weight coefficients and fuzzy evaluation matrices produces the appraisal vector of risky conditions of the JV.

Based on the maximum subordination law, the comprehensive level of risky condition can be determined, which provides judgmental information for a rational decision making. In the later part of the paper, an empirical case study on a Sino-foreign freeway JV construction project is provided to demonstrate the applicability of the fuzzy AHP approach developed. It is concluded that while opportunities are great, the risks associated with the Sino-foreign JV projects should be properly assessed, and the proposed fuzzy AHP method is suitable for such tasks. The outcome of this paper provides an effective method for the Chinese and overseas contractors and investment entities to evaluate the risky conditions of their construction joint venture businesses in China. It should be pointed out that although this paper was written in relation to Sino-foreign JV construction projects, the fuzzy AHP approach presented herewith should be equally useful in analyzing and assessing the risks associated with any types of construction projects or other types of JV businesses in China or elsewhere.

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J. Constr. Eng. Manage., 2007, 133(10): 771-779