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Using fuzzy risk assessment to rate cost overrun risk in international construction projects

Irem Dikmen *, M. Talat Birgonul [1], Sedat Han

Middle East Technical University, Civil Engineering Department, 06531 Ankara, Turkey

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Abstract

Determination of an appropriate mark-up while bidding for international construction projects is a critical decision. Level of mark-up is a function of risks associated with a project. Construction companies may benefit from a tool that helps them to assess the level of risk so that they can determine an appropriate mark-up. The aim of this paper is to propose a fuzzy risk assessment methodology for international construction projects and develop a tool to implement the proposed methodology. The proposed methodology uses the influence diagramming method for construction of a risk model and a fuzzy risk assessment approach for estimating a cost overrun risk rating. A computerized system has been developed for an international construction company and applicability of this system during risk assessment at the bidding stage has been tested by using real company and project information. Although the developed tool is company-specific, similar tools may be developed for other companies using the same methodology and expert judgments that reflect different company objectives and risk policies.

Keywords: International construction; Risk management; Fuzzy logic

1. Introduction

The success of construction companies carrying out projects in international markets significantly depends on how the risks that stem from the host country conditions are managed as well as the project-specific risk factors. Successful management of risks requires identification of risks, construction of a risk model which can be used to assess the magnitude of risks and implementation of response strategies so that an acceptable risk-return balance can be achieved. A number of authors have described risks specific to international construction projects [1–8]. Baloi and Price [1] defined risk factors related to the socio-cultural, economic, technological and political environments within which organizations operate as global risk factors. Global risk factors, such as political and economic risk factors, received the highest attention from researchers. For example, Ashley and Bonner [3] analyzed political risks in international projects and developed a political risk analysis approach using influence diagrams which identified primary sources of political risks as well as their impacts on the project success. Kapila and Hendrickson [9] identified financial risk factors associated with international construction and examined the most effective mitigation measures adopted by construction professionals in managing foreign exchange risk. Impacts of cultural difference between multinational project participants [10], regulatory restrictions, contractual arrangements and differences in standards [11] have been discussed for different countries and market conditions.

Although some of the individual risk factors may be more significant than the others, the project success usually depends on the combination of all risks, response strategies used to mitigate risks and a company's ability to manage them. Thus, there exists a need to develop a risk model that

* Corresponding author. Tel.: +90 312 2102470.
E-mail addresses: idikmen@metu.edu.tr (I. Dikmen), birgonul@metu.edu.tr (M.T. Birgonul), sedat.han@gmail.com (S. Han).
[1] Tel.: +90 312 2102427.

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contains the risks of doing business in international markets and factors that affect manageability of these risks. The aim of this paper is to develop a generic risk model that can be used to estimate the cost overrun risk in international projects using influence diagrams and to propose a risk assessment procedure using fuzzy logic. In the forthcoming parts of this paper, application of a company-specific tool which was developed by using the proposed risk model and risk assessment methodology will be discussed.

2. Methods and decision support tools developed for international construction projects

The decisions that have to be made by contractors willing to conduct business in international markets can be grouped under the following four categories:

- *Internationalization decision*. Sometimes, it is defined as international expansion decision [12] or international market entry decision [13] by different researchers. Before assessment of attractiveness of a particular country or a project, contractors should decide whether they have the necessary sources of competitive advantage to carry out projects in international markets or not. If they agree that internationalization is in line with their corporate objectives and they have the required competences, they can start environmental scanning to find an attractive market/project.
- *Market selection decision*. After a contractor decides that he can conduct business in international markets, a candidate country is selected as well as the most appropriate entry mode. A detailed strengths–weaknesses–opportunities–threats (SWOT) analysis and extensive environmental scanning are required to find out risks and opportunities associated with doing business in the target market.
- *Project selection decision*. This is also known as bid/no-bid decision. After screening a list of potential projects, whether a contractor should bid for a project or not is decided by assessing attractiveness of the project and competitiveness of the company. Level of attractiveness is determined by estimating potential profitability and strategic importance of the project for the company. Determination of risk level is a critical task at this stage.
- *Mark-up selection*. After a bid decision is given for a project, bid price has to be determined by estimating costs and deciding on a percent mark-up which is a function of level of uncertainty, probability of winning the bid and expected profitability (or more generally "expected utility" as explained by Ahmad [14]).

Researchers have proposed several decision support tools and methodologies that facilitate the solution of the above explained decision problems. Ahmad [14] developed a model for bid/no-bid decision problems. In that study, a structured methodology is proposed in which a set of attributes have been defined to find out a desirability score that reflects the strength of decision to bid. Gunhan and Arditi [15] focused on the required company strengths associated with international construction as well as opportunities and threats in international markets. They used analytic hierarchy process (AHP) together with Delphi approach to identify the importance of different factors while giving an internationalization decision. Moreover, an international expansion decision model has been developed by Gunhan and Arditi [12], which may be used to support internationalization and market selection decisions. The proposed tool helps a decision maker to conduct internal and external readiness tests for internationalization, to carry out a country specific analysis in a candidate country and to select the most appropriate entry mode. There are also some other models proposed for risk assessment during market and project selection. ICRAM-1 developed by Hastak and Shaked [6] provides a structured approach for evaluating risk indicators involved in an international construction operation. It is designed to estimate the risk level of a specific project in a foreign country. Dikmen and Birgonul [16] proposed a methodology for the quantification of risks and opportunities associated with international projects using AHP so that the decision-maker may compare attractiveness of alternative project options. The "risk-based go/no-go decision-making model" developed and tested by Han and Diekmann [17] applies cross-impact analysis to assess risks associated with international construction. Han et al. [18] also developed a multi-criteria decision making framework for financial portfolio risk management to integrate risk hierarchies at the project and corporate levels. It is clear that, for each type of decision, the most widely used assessment method is multi attribute risk rating where a set of attributes/risk factors are defined and their magnitude are determined by using simple multi attribute rating technique (SMART), AHP or variations of these methods.

Apart from these risk assessment methodologies, decision support systems valid for specific companies or countries have also been developed. A neuronet model has been developed by Dikmen and Birgonul [13] as a decision support tool that can classify international projects with respect to their attractiveness and competitiveness based on the experiences of Turkish contractors in overseas markets. Aleshin [19] developed a decision support tool to guide foreign investors about the risks prevailing in the Russian market and possible response strategies to mitigate them. The study conducted by Tah and Carr [20] has a special place among the decision support tools available in literature due to its knowledge-based approach and a hybrid risk quantification method. They reported the results of a prototype software implementation which uses a generic risk management process model, an information model and a fuzzy knowledge representation model to support quantitative risk analysis.

The procedure proposed in our research has got some differences from the existing methods. In multi-criteria models, usually, a set of risk factors are defined and multi attribute decision-making methods are utilized to quantify overall risk level where it is assumed that risk factors are independent of each other and an additive model can be constructed. The fundamentals and differences of our research from other studies are summarized in the forthcoming section.

3. Research objectives

In this research, sources of cost overrun risk in international projects are defined as well as the factors that may affect risk levels. While assigning risk ratings, usually decision-makers consider an implied factor, which is "controllability". Controllability is usually not considered in risk quantification formulas explicitly but its affect is usually considered under "impact" and "probability" ratings. If a risk factor is within reasonable control of a company or transferable to other parties through contract conditions, a lower risk rating may be assigned. Thus, the ability of a company to manage risk should be considered during risk modelling. Keizer et al. [21] mention the same issue that the magnitude of risk is determined not only by its likelihood and impact but also by a firm's ability to influence risk factors. Importance of this issue is also put forward by Barber [22] in a different way. Barber [22] defines all sources of risk which cannot be blamed on the external world nor on the nature of task as "internally generated risks" and argues that as no project organization is perfect in all its rules, policies, processes, behaviours and cultures, in every project, there will be internally generated risks. In our research, those factors are not defined as risks but factors that affect manageability of risks. It is assumed that experience is one of the indicators of a company's ability to manage internally generated risks and favourability of contract conditions reflects how well a company may mitigate risks by using contract clauses. A more detailed discussion related with necessity of modelling risk sources, consequences and factors that affect magnitude of risks can be found in Dikmen and Birgonul [16] and Dikmen et al. [23]. Based on a similar idea, Tah and Carr [20] constructed "risk structure maps" to model the relationships between risk sources and influencing factors. In this research, influence diagramming method is used to produce a risk model that incorporates relations between project and country level risk sources (global risk) and influencing factors. An influence diagram is simply a diagram which consists of nodes reflecting "variables" and "decisions", and "influence" is reflected by arrows. It acts as a convenient way of expressing the nature of the problem to others and aids general understanding of the factors, risks and decisions affecting the "outcomes". Influence diagrams can be used as the first step in a quantitative risk analysis. Huseby and Skogen [24] used them together with Monte Carlo Simulation for dynamic risk modelling. Consequently, one of the objectives of this research is to construct a sound risk model that can be used to quantify cost overrun risk rating in an international construction project.

Due to lack of previous data and unique, non-repetitive nature of construction projects, usually probabilistic approach cannot be utilized to quantify risks. Baloi and Price [1] argue that as most of the risk analysis tools are founded on statistical decision theory, contractors rarely use them in practice. Rather than probabilities, individual knowledge, experience, intuitive judgment and rules of thumb should be structured to facilitate risk assessment and retrieval by the others. They point out the potential of using fuzzy set theory (FST) for risk assessment and proposed a fuzzy decision support system for the estimation of cost performance. FST provides a useful way to deal with ill-defined and complex problems in a decision-making environment that incorporates vagueness. It enables the decision-makers to quantify imprecise information and make decisions based on incomplete data. During risk assessment, experts usually express their ideas by assigning a rating to each identified risk by referring their own experiences. They usually adjudge that the risk is "low", "high" etc by using linguistic expressions. Linguistic terms can be translated into mathematical measures using FST [25]. In many situations, where assessments are usually described subjectively in linguistic terms, FST is proposed to be used, especially in project-based industries where it is almost impossible to use probabilistic methods due to the unique nature of undertakings. The fuzzy bidding model developed by Lin and Chen [26] is an example of how FST can be applied to an international co-development commercial airplane project. However, there have been limited attempts to exploit fuzzy logic in construction risk management literature, such as Paek et al. [27], Tah and Carr [20,28], Wirba et al. [29], Choi et al. [30]. One of the aims of our research is to adopt FST to facilitate cost overrun risk assessment in international construction projects. Risk factors that affect construction cost are modelled using FST and complex computations of fuzzy numbers are computerized to increase accuracy while reducing time. One of the reasons why FST is not widely used in practice may be attributed to its computational complexity. Thus, the aim of our research is to develop a decision support tool which is tailor-made for a construction company considering its risk policy, attitudes and objectives. After all the necessary information such as fuzzy rules and magnitude of individual risks are fed into the model, company professionals will not carry out the fuzzy calculations by themselves and assessment procedure will be extremely easy.

4. Proposed methodology

Following procedure is followed for fuzzy risk rating:

Step 1. Risk identification and modelling by using influence diagrams.

Step 2. Definition of variables and selection of a "membership function" for each variable: A "membership function" is a curve that defines how the value of a fuzzy variable is mapped to a degree of membership between 0 and 1. In this paper, membership functions are used to calculate the degree of membership of a fuzzy risk score to different sets expressed by linguistic terms such as low risk, low-to-medium risk, medium risk, medium-to-high risk and high risk.

Step 3. Capturing the knowledge of experts about relationships between risks and influencing factors using "aggregation rules", where the risk knowledge is explained in the form of IF...THEN rules: In this study, "aggregation rules" demonstrate how the risk levels change under different scenarios. "Aggregation rules" are the IF...THEN rules that reveal the value of an output variable (risk rating) if values of input variables (risks and influencing factors) are expressed by different linguistic terms.

Step 4. Carrying out fuzzy operations for aggregation of fuzzy rules into a fuzzy cost overrun risk rating.

Step 5. Determination of project risk level by interpreting the final risk rating.

This procedure is a generic one, however, as the fuzzy rules and risk ratings may change with respect to risk attitudes and company preferences, different tools shall be developed for different companies. In the following section, the application of the methodology is demonstrated by referring to a tailor-made tool developed for an international construction company.

5. An application of the proposed methodology

The proposed methodology has been applied to a project that is carried out by a foreign construction company doing business in Turkey. The construction company is a globally well-known company, especially experienced in infrastructure projects. Company has extensive international construction activities all over the world. The aforementioned project covers the dam and hydroelectric power plant construction including necessary services, supply and erection of relevant electromechanical equipment, hydraulic equipment and commissioning of the plant. Full financing of the project is secured by a loan agreement arranged by the project consortium and concluded between the Turkish Prime Ministry Undersecretariat of Treasury and a consortium of banks. Owner of the project is State Hydraulic Works. Project will be carried out by the civil works consortium group, members of which are two Turkish companies and a foreign company. Scheduled duration of civil works is 2100 calendar days (5 years and 9 months). Payment type is lump-sum. Contract price of civil works for the foreign company is around 805 million Austrian Shillings.

In order to carry out the risk assessment procedure explained above, a committee of decision-makers has been formed. The members of the committee are project manager, technical office manager, commercial manager of the Turkey Branch and a legal consultant. Duties of the committee are:

1. *Revision of the risk model*. They are requested to check the risk model prepared by using influence diagramming method, comment on the applicability of the model and propose revisions, if necessary.
2. *Definition of "membership functions" and "aggregation rules"*. Experts are required to define the "aggregation rules" that explain how different values of the influencing factors and risks may be combined to estimate the value of a final risk rating. They should decide how the overall risk ratings may change with different linguistic expressions of risk levels and influencing factors. They should also determine the shape of the "membership functions" based on their subjective judgement about the magnitude of risk factors and how they should be expressed in linguistic terms.
3. *Risk assessment*. They are requested to evaluate the magnitude of risk factors and influencing factors that appear in the risk model.

It is assumed that the group members will carry out necessary brainstorming sessions and reach to a consensus for the required tasks. In other words, rather than asking the same questions to individual members separately, only one response is received from the group and it is believed to represent the democratic majority point of view of the group. Some of the potential bottlenecks of this method are mentioned in Section 6 of this paper.

As it would be very hard for the experts to carry out tedious fuzzy risk assessment calculations themselves, a tool was developed to facilitate the rating process. To clarify the risk assessment process, an example of how the fuzzy computations are carried out by the tool is given in Appendix.

Following are the basic assumptions and steps of this application:

- The risk model that forms the basis of this application is given in Figs. 1–3. The output parameter, which is cost overrun rating, is affected from two categories of risk sources; risks due to country conditions (global risks) and risks due to project conditions. The success of international construction projects is known to be very sensitive to host country conditions such as economic, political and legal factors as well as international relations and cultural differences. Factors that may affect the magnitude of country risk are defined as experience of the company in the host country and existing contract clauses about country risk allocation between the parties. It is expected that as the experience of the company gets higher, the manageability of risk factors increases, thus, impact of risk retained by the company may be lower when compared with that of another company having no experience. Similarly, favourable contract conditions may decrease the cost overrun risk. For

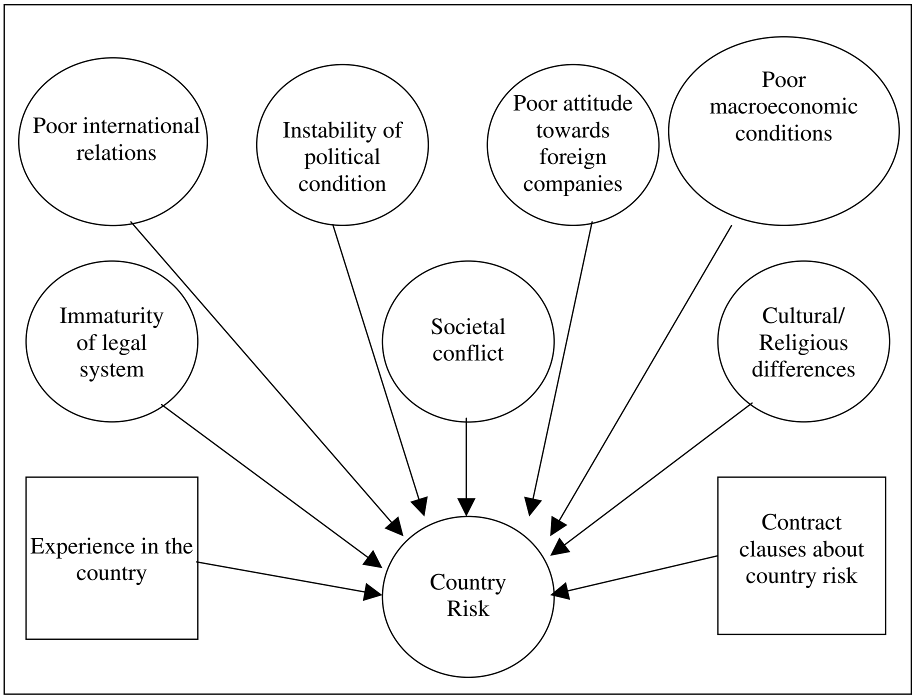


Fig. 1. Influence diagram of country risk.

example, although economic environment is poor and inflation is unpredictable in the future, an escalation formula that is used to adjust the current prices according to actual inflation rate may decrease the risk retained by the company. Similarly, level of project risk depends on construction risk, design risk, payment risk, client risk and subcontractor risk. The influencing factors are defined as experience of the company in similar projects and existing contract clauses about project risk. Committee members state that they did not have any problems in understanding the risk model as the influence diagram provides an effective visual representation of the risk model. However, we would like to note that, risk factors and influencing factors are by no means exhaustive, therefore, new factors may be added according to different company needs. Finally, experts rated the risk factors as well as the influencing factors given in the risk model considering the project and country conditions and company capabilities based on their personal judgment.

- The "membership function" used for all of the risk sources is shown in Fig. 4. The shape of a fuzzy number and scale of a linguistic variable have to be determined according to user needs. Triangular shape, which is commonly used for membership functions (e.g. Tah and Carr [20]) is found satisfactory for this application. Also, the states of linguistic variables are defined as low, low-to-medium, medium, medium-to-high and high. After a risk score is assigned to a risk factor using 1–10 scale, membership levels of this value to different sets are calculated using the predefined membership functions.
- In the risk assessment phase, using the risk model, a stepwise procedure has been followed which is illustrated in Fig. 5. In each risk assessment step, "aggregation rules" are determined and associated decision matrices are prepared as a result of brainstorming between committee members. "Aggregation rules" form the basis of fuzzy operations and control actions. Two examples of decision matrices are depicted in Figs. 6 and 7. These rules reflect the opinions of experts that participated to the brainstorming sessions and they may change with respect to risk attitude of different experts and different corporate policies.
- Aggregation is the process by which the fuzzy sets that represent the output of each rule are combined into a single fuzzy set, denoted by $M_{\text{agg}}(z)$. Defuzzification is the operation of producing a non-fuzzy number, a single value denoted by z, that adequately represents $M_{\text{agg}}(z)$. There are several methods proposed for defuzzification process [31]. In this research, height defuzzification method (HDM) is utilized. In order to simplify the computations of aggregation and defuzzification processes, a decision support tool has been developed so that decision-makers do not have to carry out these calculations themselves. An example is given in Appendix to demonstrate the computations carried out by the tool. Some of the screenshots of this tool are given in Figs. 8 and 9.

The output of the fuzzy risk assessment procedure is a final cost overrun risk rating, which is found to be 5.21 in this specific example. This rating is calculated by using a scale of 1–10. Using Fig. 4, this shows a medium or medium-to-high risk level. This result was considered as

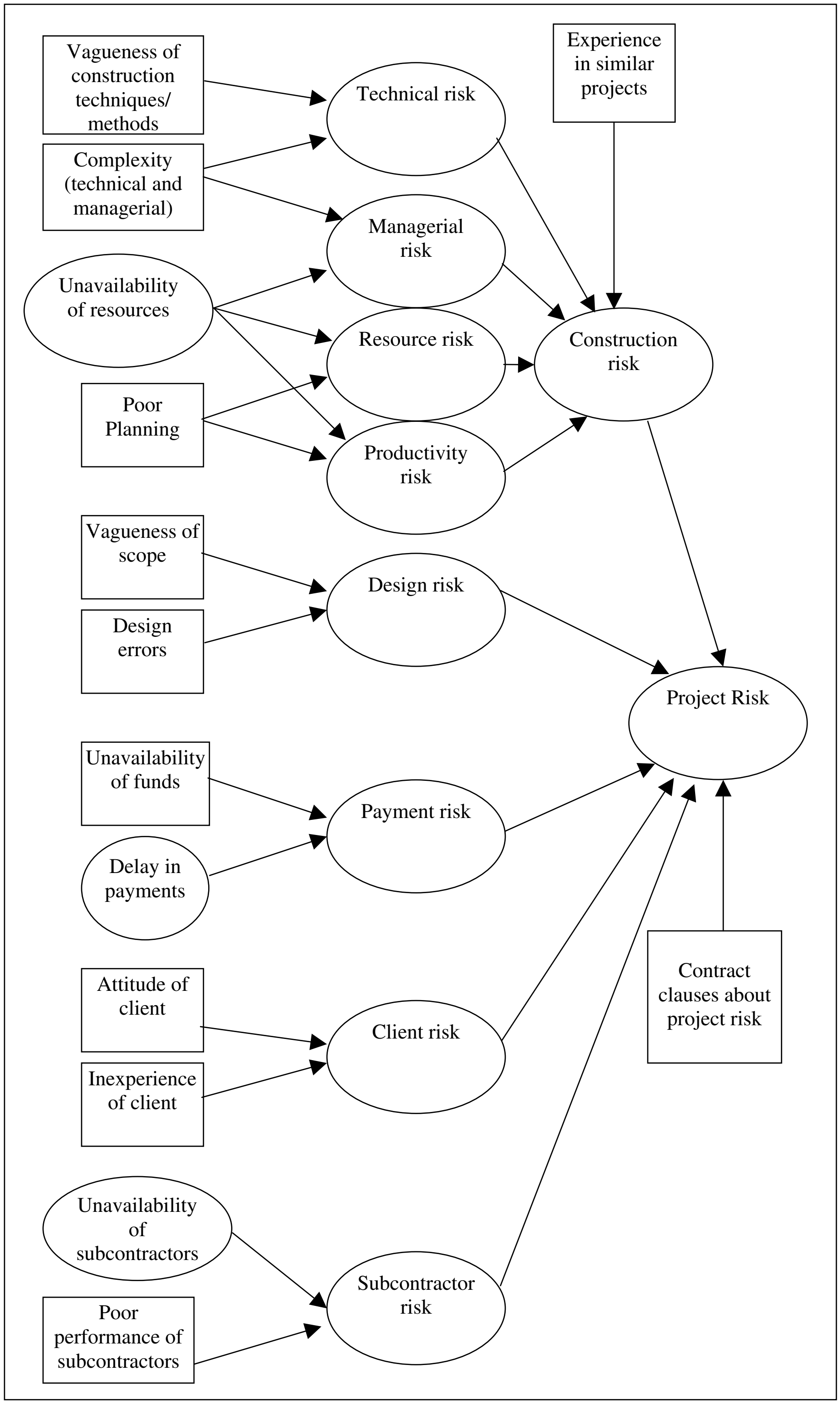


Fig. 2. Influence diagram of construction risk.

satisfactory by the committee members. They argue that although risk factors are significant, their experience in similar projects and markets increases the manageability of risks, thus decreases the overall risk level. It is also clear from Fig. 6 that if favourable contract clauses exist, the overall risk level tends to decrease as some of them may be transferred to other parties or some form of compensation may be possible (escalation formula, advance payments etc.). Fig. 6 demonstrates that for a particular project, although country risk is expected to be high, if favourable contract clauses exit, the overall risk value is assumed to be medium. In the case study, due to the vague-

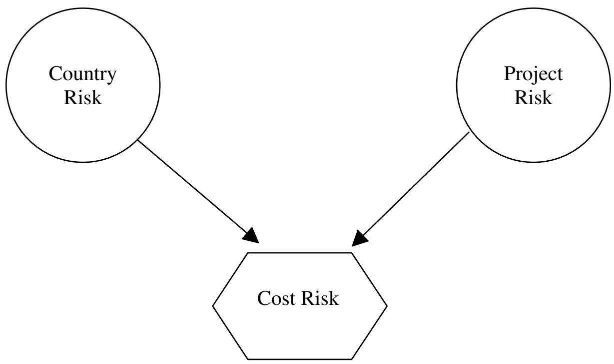


Fig. 3. Influence diagram of cost overrun risk.

ness of contract clauses, a deduction in risk level was not anticipated.

6. Discussions

In this paper we present a methodology that can be used to estimate the risk level at an early phase of a project. It is mainly for qualitative risk assessment at the bidding stage. It is assumed that after this phase, if the company is awarded the project, a more detailed risk analysis will be carried out so that potential risk events are identified, impacts of risks on time and cost can be quantified, specific

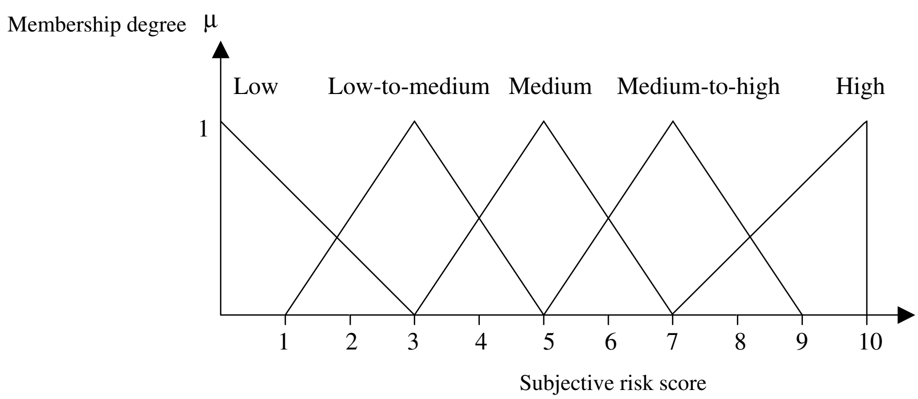
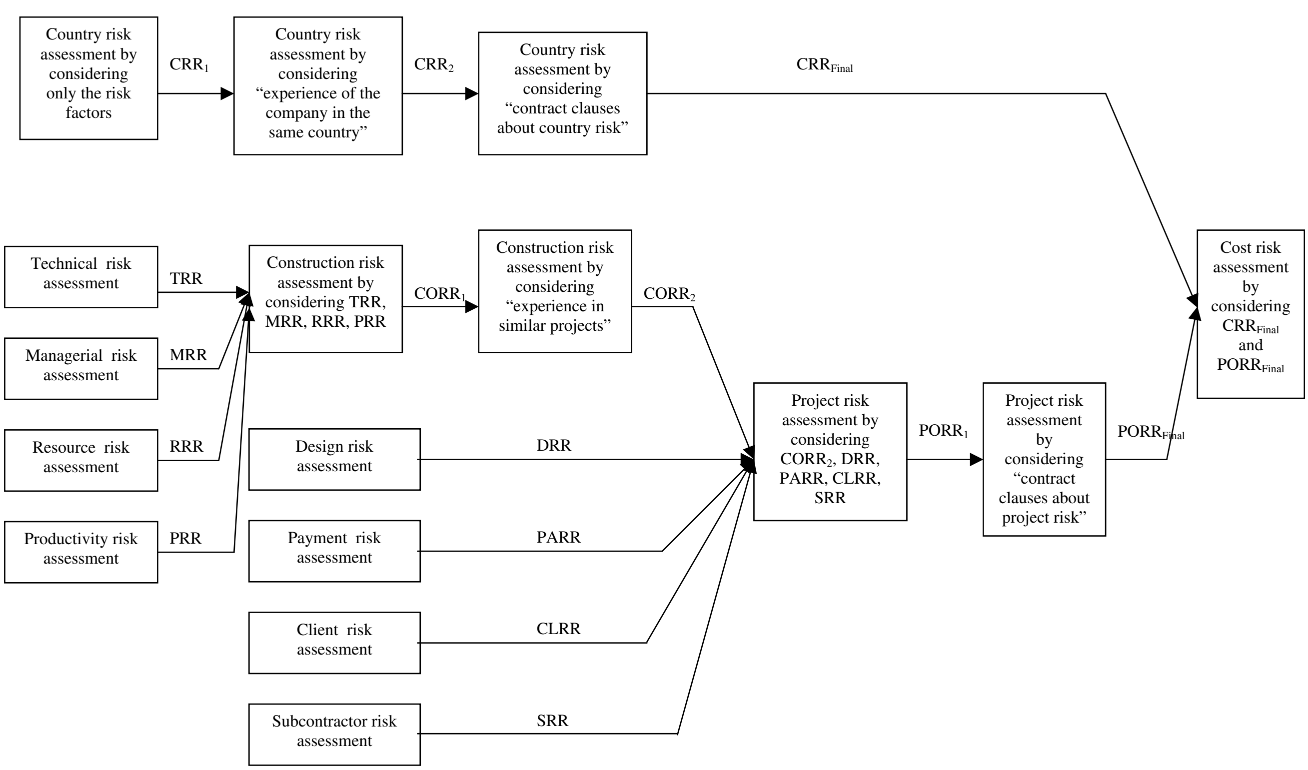


Fig. 4. Membership function for subjective risk scores.



Legend: CRR = Country Risk Rating, TRR =Technical Risk Rating, MRR = Managerial Risk Rating, RRR =Resource Risk Rating, PRR = Productivity risk rating, CORR = Construction Risk Rating, DRR=Design Risk Rating, PARR=Payment Risk Rating, CLRR=Client Risk Rating, SRR=Subcontractor Risk Rating, PORR=Project Risk Rating

Fig. 5. Steps of the risk assessment process.

Favorability of contract clauses about country risk

Country risk rating (CRR_2)	Low (L)	Low-to-medium (LM)	Medium (M)	Medium-to-high (MH)	High (H)
Low (L)	L	L	L	L	L
Low-to-medium (LM)	LM	LM	LM	L	L
Medium (M)	M	M	M	LM	L
Medium-to-high (MH)	MH	MH	MH	M	LM
High (H)	H	H	H	MH	M

Fig. 6. Decision matrix showing aggregation rules combining country risk with impact of contract conditions to produce a final country risk rating.

Experience of the company in similar projects

Construction risk ($CORR_1$)	Low (L)	Low-to-medium (LM)	Medium (M)	Medium-to-high (MH)	High (H)
Low (L)	L	L	L	L	L
Low-to-medium (LM)	LM	LM	LM	L	L
Medium (M)	M	M	M	LM	LM
Medium-to-high (MH)	MH	MH	MH	M	M
High (H)	H	H	H	H	MH

Fig. 7. Decision matrix showing aggregation rules combining construction risk with impact of experience to produce a final construction risk rating.

responses can be generated and a risk management plan can be prepared. As the methodology is proposed mainly for the risk assessment phase to be used at the bidding stage, the influence diagram given in this paper covers only the major sources of risk rather than a complete list of potential risk events. For example, all potential technical problems are considered under a broad category denoted as ‘‘technical risk’’. Risk events such as ‘‘breakdown of machinery’’, ‘‘re-construction of cut-off wall’’ etc. that may fall under this category are not specified. Similarly, only two factors, namely experience and contract conditions, are identified as influencing factors. In a more detailed risk model, which is critical to prepare a good risk management plan, specific response strategies such as ‘‘insurance’’, ‘‘transfer of risk to another party’’, ‘‘taking necessary precautions’’ etc. should be considered. Moreover, individual contract clauses such as ‘‘escalation’’ and ‘‘liquidated damages’’ should be taken into account as they significantly affect the impact of risk factors. Thus, the proposed methodology and the given influence diagram are applicable for only the risk assessment phase and should be followed by a more detailed risk analysis phase in order to prepare a sound risk management plan. The detailed analysis can be based on probabilistic tools or FST depending on the nature (statistical or qualitative data) of available data.

One of the major criticisms of FST is its dependence on subjective judgements. Expert opinions are collected through brainstorming sessions with the contribution of a group of experts. The results generated as a result of group sessions for risk assessment may be biased by the effects introduced through the composition of the group and process they are using [21]. However, effectiveness of the brainstorming sessions may be enhanced by using some strategies. Keizer et al. [21] propose that a step-wise procedure of group sessions, briefings by a risk facilitator, kick-off meetings, individual interviewing of experts, designing and answering questionnaires as prepared by the risk facil-

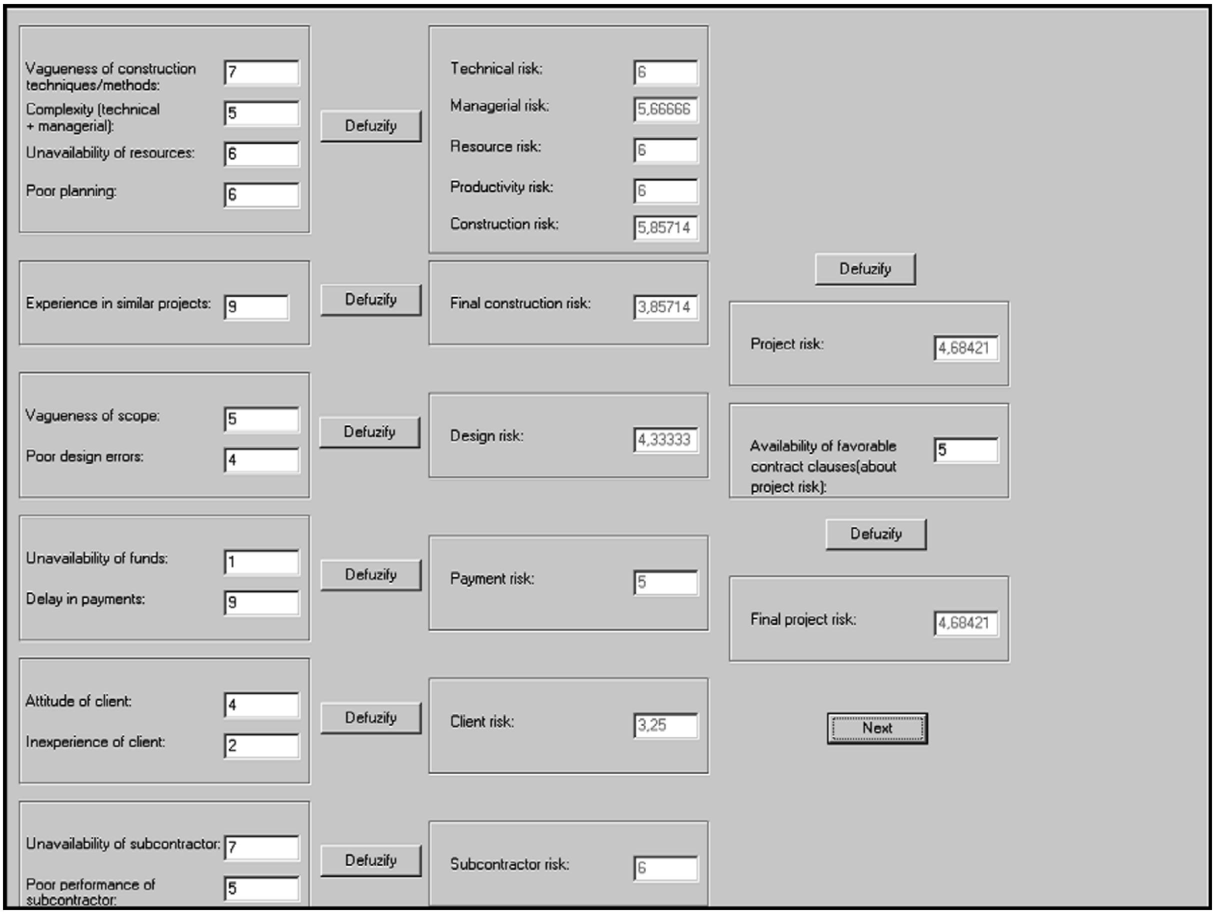


Fig. 8. Project risk rating data.

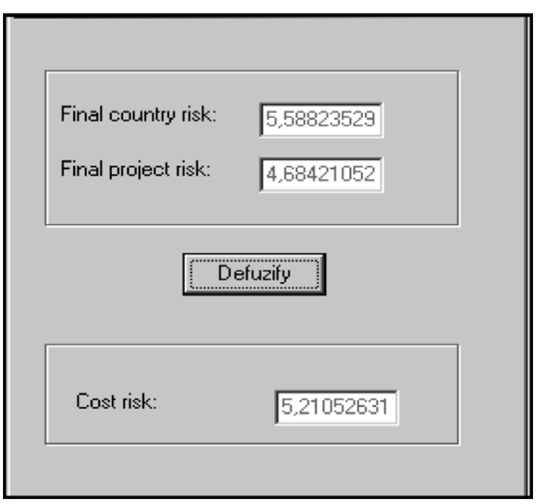


Fig. 9. Cost overrun risk rating.

itator may enhance performance of brainstorming sessions. In our research, information gathering phase could have been affected from the organisational power dynamics within the company and/or possible groupthink. This is one of the shortcomings of our research study.

We would like to note that although the procedure explained in this research is a general one, the presented risk model and developed decision support tool are company-specific. Each company has its own risk knowledge leading to different fuzzy rules and may have different risk attitudes. Thus, the case given in this paper should be treated as an example of how the proposed methodology can be utilized in practice rather than a universally accepted solution for the risk assessment of international construction projects.

Finally, one project may not be enough to validate the reliability of the tool. Company professionals should test it in a number of projects and check whether the output reflects their ideas or not. They should also check validity of the aggregation rules and revise them in the light of lessons learnt when necessary.

7. Conclusions

Fuzzy risk assessment provides a promising tool to quantify risk ratings where the risk impacts are vague and defined by subjective judgments rather than objective data. In this research, a methodology is proposed for risk rating of international construction projects. In the proposed methodology, a fuzzy risk rating approach is utilized together with influence diagramming method for risk identification. Influencing factors and interactions between these factors can easily be modelled by influence diagrams. The major contribution of this work to the risk management literature in construction management domain is modelling risks using influence diagrams together with fuzzy sets and development of a risk assessment methodology based on the proposed risk model. Applicability of the proposed methodology has been tested on a real case. The procedure is implemented in an international construction company that will carry out a project in Turkey. The fuzzy risk rating process is computerized and risk knowledge gathered from the experts is used as an input to the decision support tool. Findings of the case study demonstrate that the proposed methodology can be easily applied by the professionals to quantify risk ratings. The advantage of the tool is that it can provide guidance for the company about the amount of risk premium that should be included in the mark-up. If the tool is used for many projects, a relation between the risk rating calculated at the start of the project and the actual cost overrun value may be found. Therefore, linking actual cost data, risks, influencing factors and calculated risk ratings by statistical analysis (such as structural equation modelling) or artificial intelligence techniques (such as case-based reasoning or neural networks) could be a potential subject for further research.

Another potential advantage is the tool's utilisation as an organisational learning tool. As the experience of the managers are captured in the form of IF…THEN rules and uploaded to the tool, it may help development of a corporate risk memory. Less experienced staff may refer to this risk information while calculating risk premiums in international markets.

Acknowledgement

We thank the anonymous reviewers for their valuable suggestions and constructive comments.

Appendix. An example of the computations that are performed by the risk assessment tool

The risk assessment tool is a fuzzy logic controller that carries out fuzzy computations. Basically, given the shapes of membership functions and IF…THEN rules, the tool carries out aggregation and defuzzification to produce an output value. An example of how the tool calculates a fuzzy rating is explained below.

The example is taken from the case study given within the paper. The "final construction risk rating ($CORR_2$)" is calculated by considering "the experience of the company in similar projects" and "the construction risk rating ($CORR_1$)". The membership function defined for each variable is the same and given in Fig. 4. Considering the expert opinion, 25 fuzzy rules (also given in Fig. 7) have been identified for "final construction risk rating ($CORR_2$)". As an example, five of these rules are given below:

- IF "experience of the company" is *high* and "construction risk" is *low*, THEN the "final construction risk rating" is *low*.
- IF "experience of the company" is *high* and "construction risk" is *low-to-medium*, THEN the "final construction risk rating" is *low*.
- IF "experience of the company" is *high* and "construction risk" is *medium*, THEN the "final construction risk rating" is *low-to-medium*.
- IF "experience of the company" is *high* and "construction risk" is *medium-to-high*, THEN the "final construction risk rating" is medium.
- IF "experience of the company" is *high* and "construction risk" is *high*, THEN the "final construction risk rating" is *medium-to-high*.

In the given example, after aggregating the IF…THEN rules regarding technical, managerial, resource and productivity risk, $CORR_1$ has been calculated as 5.8572 (Fig. 8). By using the membership function given in Fig. 4, following values are found:

For "construction risk ($CORR_1$) " (denoted by x):

$$\mu_L\ (x = 5.8572) = 0,\quad \mu_{LM}\ (x = 5.8572) = 0,$$
$$\mu_M\ (x = 5.8572) = 0.5714,\quad \mu_{MH}\ (x = 5.8572) = 0.4286,$$
$$\mu_H\ (x = 5.8572) = 0$$

For "experience" (denoted by y):

$$\mu_L\ (y = 9) = 0,\quad \mu_{LM}\ (y = 9) = 0,\quad \mu_M\ (y = 9) = 0,$$
$$\mu_{MH}\ (y = 9) = 0,\quad \mu_H\ (y = 9) = 0.6667$$

The output value, which is the final construction risk rating ($CORR_2$) is shown by z. Based on the predefined fuzzy rules, rules for calculating z are given in Fig. A1.

If a rule specifies an AND relationship between the mappings of the two input variables, the "minimum" of the two is used as the combined output value. In this study, all relations in IF…THEN rules are defined as "AND", thus the minimum values are selected as the strengths of the rules.

The strength of a rule or level of firing is denoted by α.

$$\alpha_{11} = \min\ (0.5714, 0) = 0,\quad \alpha_{12} = \min\ (0.5714, 0) = 0,$$
$$\alpha_{13} = \min\ (0.5714, 0.6667) = 0.5714.$$
$$\alpha_{21} = \min\ (0.4286, 0) = 0,\quad \alpha_{22} = \min\ (0.4286, 0) = 0,$$
$$\alpha_{23} = \min\ (0.4286, 0.6667) = 0.4286.$$
$$\alpha_{31} = \min\ (0, 0) = 0,\quad \alpha_{32} = \min\ (0, 0) = 0,\quad \alpha_{33} = \min\ (0, 0.6667) = 0.$$

Control output of each rule is as follows:

Rule 1: $\alpha_{11} \cap \mu_M\ (z) = 0$, Rule 2: $\alpha_{12} \cap \mu_{LM}\ (z) = 0$, Rule 3: $\alpha_{13} \cap \mu_{LM}\ (z) = 0.5714$.
Rule 4: $\alpha_{21} \cap \mu_{MH}\ (z) = 0$, Rule 5: $\alpha_{22} \cap \mu_M\ (z) = 0$, Rule 6: $\alpha_{23} \cap \mu_M\ (z) = 0.4286$.
Rule 7: $\alpha_{31} \cap \mu_H\ (z) = 0$, Rule 8: $\alpha_{32} \cap \mu_H\ (z) = 0$, Rule 9: $\alpha_{33} \cap \mu_{MH}\ (z) = 0$.

Construction risk rating	Experience: $\mu_M(y)=0$	$\mu_{MH}(y)=0$	$\mu_H(y)=0.6667$
$\mu_M(x)=0.5714$	$\mu_M(z)$	$\mu_{LM}(z)$	$\mu_{LM}(z)$
$\mu_{MH}(x)=0.4286$	$\mu_{MH}(z)$	$\mu_M(z)$	$\mu_M(z)$
$\mu_H(x)=0$	$\mu_H(z)$	$\mu_H(z)$	$\mu_{MH}(z)$

Fig. A1. Fuzzy rules for calculating the final construction risk rating.

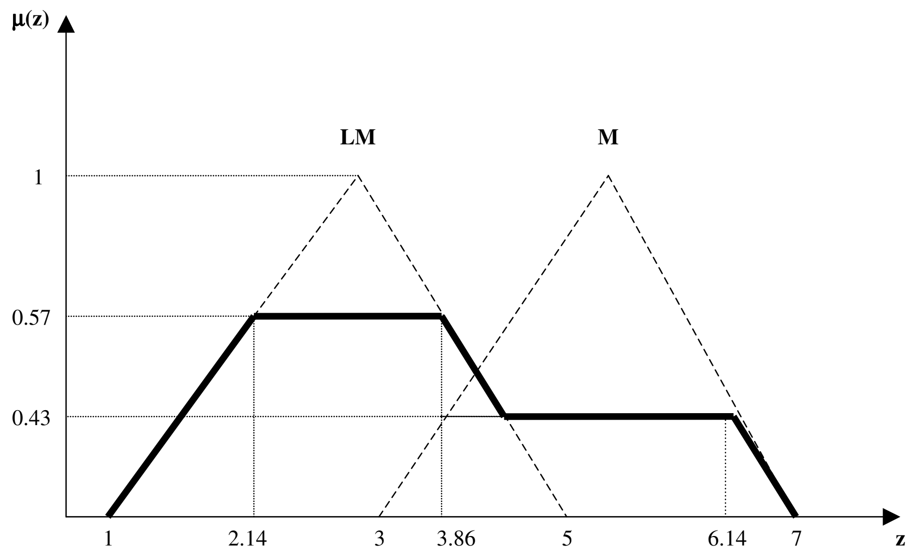


Fig. A2. Aggregated membership function for final construction risk rating.

The outputs of the above given nine rules are aggregated to produce an output with membership function $\mu(z)$. The union operator ($\cup$) is used during aggregation and the maximum values are selected. The general formula for aggregation is as follows:

$$\mu(z) = \{(\alpha_{ij} \cap \mu_{Cij}(z)) \cup (\alpha_{i,j+1} \cap \mu_{Ci,j+1}(z)) \cup (\alpha_{i+1,j} \cap \mu_{Ci+1,j}(z)) \cup (\alpha_{i+1,j+1} \cap \mu_{Ci+1,j+1}(z))\}$$
$$\mu(z) = \max\{(\alpha_{ij} \cap \mu_{Cij}(z)),(\alpha_{i,j+1} \cap \mu_{Ci,j+1}(z)),(\alpha_{i+1,j} \cap \mu_{Ci+1,j}(z)),(\alpha_{i+1,j+1} \cap \mu_{Ci+1,j+1}(z))\}$$

where α is a real number drawn parallel to z axis and $\mu_C(z)$ is the membership function of fuzzy set C.

Shape of $\mu(z)$ calculated for this example is shown in Fig. A2.

The method that the risk assessment tool uses for the defuzzification process is height defuzzification method (HDM) which uses the flat segments as a result of firing rules. For the example project, final construction risk rating is calculated as follows:

$$Z = (0.57 \times ((2.14 + 3.86)/2) + 0.43 \times ((3.86 + 6.14)/2))/(0.57 + 0.43)$$
$$Z = 3.86$$

This value also appears in Fig. 8 as the final construction risk value.

References

[1] Baloi D, Price ADF. Modelling global risk factors affecting construction cost performance. Int J Project Manage 2003;21:261–9.
[2] Zhi H. Risk management for overseas construction projects. Int J Project Manage 1995;13(4):231–7.
[3] Ashley DB, Bonner JJ. Political risks in international construction. ASCE J Constr Eng Manage 1987;113(9):447–67.
[4] Sloan SK, Weisberg JL. Understanding the risk when embarking on an international project. In: Proceedings of the construction congress: managing engineered construction in expanding global markets, Minneapolis, Minnesota, USA; 1997. p. 770–8.
[5] Jaselskis EJ, Talukhaba A. Bidding considerations in developing countries. ASCE J Constr Eng Manage 1998;124(3):185–93.

[6] Hastak M, Shaked A. ICRAM-1: model for international construction risk assessment. ASCE J Manage Eng 2000;16(1):59–69.
[7] Han SH, Diekmann JE. Making a risk-based bid decision for overseas construction projects. J Constr Manage Econ 2001;19: 765–76.
[8] Levitt R, Horii T, Mahalingam A, Orr R, Taylor J. Understanding and managing the effects of institutional differences in global projects. In: Proceedings of the specialty conference on leadership and management in construction, Hilton Head, South Carolina, USA; 2004. p. 7–19.
[9] Kapila P, Hendrickson C. Exchange rate risk management in international construction ventures. ASCE J Manage Eng 2001;17(4): 186–91.
[10] Chan EHW, Tse RYC. Cultural considerations in international construction contracts. ASCE J Constr Eng Manage 2003;129(4): 375–81.
[11] Chua DKH, Wang Y, Tan WT. Impacts and obstacles in East-Asian cross-border construction. ASCE J Constr Eng Manage 2003;129(2): 131–41.
[12] Gunhan S, Arditi D. International expansion decision for construction companies. ASCE J Constr Eng Manage 2005;131(8): 928–37.
[13] Dikmen I, Birgonul MT. Neural network model to support international market entry decisions. ASCE J Constr Eng Manage 2004;130(1):59–66.
[14] Ahmad I. Decision-support system for modelling bid/no-bid decision problem. ASCE J Constr Eng Manage 1990;116(4):595–608.
[15] Gunhan S, Arditi D. Factors affecting international construction. ASCE J Constr Eng Manage 2005;131(3):273–82.
[16] Dikmen I, Birgonul MT. An AHP based model for risk and opportunity assessment of international construction projects. Can J Civil Eng 2006;33(1):58–68.
[17] Han S, Diekmann JE. Approaches for making risk-based go/no-go decision for international projects. ASCE J Constr Eng Manage 2001;127(4):300–8.
[18] Han SH, Diekmann JE, Lee Y, Ock JH. Multicriteria financial portfolio risk management for international projects. ASCE J Constr Eng Manage 2004;130(3):346–56.
[19] Aleshin A. Risk management of international projects in Russia. Int J Project Manage 2001;19:207–22.
[20] Tah JHM, Carr VA. A knowledge-based approach to construction project risk management. ASCE J Comput Civil Eng 2001;15(3): 170–7.
[21] Keizer JA, Halman JIM, Song M. From experience: applying the risk diagnosing methodology RDM. J Prod Innovat Manage 2002;19(3): 213–33.
[22] Barber RB. Understanding internally generated risks in projects. Int J Project Manage 2005;23:584–90.
[23] Dikmen I, Birgonul MT, Arikan AE. A critical review of risk management support tools. In: Proceedings of ARCOM (Association of Researchers in Construction Management) conference, Heriot Watt University, UK, vol. 2; 2004. p. 1145–54.
[24] Huseby AB, Skogen S. Dynamic risk analysis: The DynRisk concept. Int J Project Manage 1992;10(3):160–4.
[25] Zadeh LA. Fuzzy sets. Inform Control 1965;8:338–53.
[26] Lin CT, Chen YT. Bid/no-bid decision-making: a fuzzy linguistic approach. Int J Project Manage 2004;22:585–93.
[27] Paek JH, Lee YW, Ock JH. Pricing construction risk: fuzzy set application. ASCE J Constr Eng Manage 1993;119(4):743–56.
[28] Tah JHM, Carr V. A proposal for construction project risk assessment using fuzzy logic. J Constr Manage Econ 2000;18: 491–500.
[29] Wirba EN, Tah JHM, Howes R. Risk interdependencies and natural language computations. J Eng, Constr Architect Manage 1996;3(4): 215–69.
[30] Choi H, Cho H, Seo JW. Risk assessment methodology for underground construction projects. ASCE J Constr Eng Manage 2004;130(2):258–72.
[31] Hellendoorn H, Thomas C. Defuzzification in fuzzy controllers. J Intell Fuzzy Syst 1993;1:109–23.