JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT
ISSN 1392-3730 print/ISSN 1822-3605 online
2011 Volume 17(3): 424–436
doi:10.3846/13923730.2011.598337

BIDDING DECISION MAKING FOR CONSTRUCTION COMPANY USING A MULTI-CRITERIA PROSPECT MODEL

Min-Yuan Cheng[1], Chia-Chi Hsiang[2], Hsing-Chih Tsai[3], Hoang-Linh Do[4]

Department of Construction Engineering, National Taiwan University of Science and Technology, Keelung Rd., Taipei, Taiwan, R. O. C. 106

E-mails: [1]myc@mail.ntust.edu.tw; [2]chiachi@cycu.edu.tw (corresponding author); [3]tsaihsingchih@gmail.com; [4]hoanglinhmonitor@yahoo.com

Received 08 Oct. 2009; accepted 26 Nov. 2010

Abstract. Two critical decisions faced by bidders in competitive bidding include, firstly, whether or not to submit a bid, and secondly (if the answer to the first is 'yes') what markup value should be used on the submitted bid. In the construction industry, government agencies and private sector clients typically adopt competitive bidding to determine contract awards. Contractors also apply the same approach to bidding decisions. There are many variables that affect contractor decisions regarding whether to bid and the markup scale, which complicate the bidding decision process. This study proposes a Multi-Criteria Prospect Model for Bidding Decision (BD-MCPM) to assist contractors to make decisions on bid/no bid and markup scale. Key factors of influence that impact bidding decisions were identified first. Second, Fuzzy Preference Relations (FPR) was employed to assess factor weights and determine bid/no bid. Finally, if a decision to bid is given, then the Multi-Criteria Prospect Model (MCPM), which links Fuzzy Preference Relations (FPR) and Cumulative Prospect Theory (CPT), is deployed to determine the markup scale that best conforms to primary decision maker (PDM) preferences. The applicability of this model was demonstrated in a real case study.

Keywords: bidding decision making, bid/no bid, markup scale, bidding strategy, multi-criteria prospect model, cumulative prospect theory, fuzzy preference relations.

1. Introduction

In the construction industry contractors typically earn construction contracts through either direct negotiation or competitive bidding. Government agencies and private sector clients most often employ competitive bidding, which commonly use the lowest bid price as the main award criterion. Usually the bid price includes cost of construction and a markup, the scale of which is typically determined using a percentage of construction costs. Size of markup impacts upon the profit, which serves as the primary motivator for a contractor to win and execute a contract (Dikmen *et al*. 2007). Research in the area of competitive bidding strategy models has been conducted since the 1950s (Friedman 1956). Numerous models have been developed, some of which were designed specifically for the construction industry. Despite the number of competitive bidding strategy models that have been developed, few of these are used in practice, largely as they do not address the practical needs of construction contractors (Hegazy and Moselhi 1995; Shash 1995). Therefore, there is a perceived need for models designed in line with actual construction contractor practices. In the bid process, once a determination is made to bid, the next step is to select an appropriate markup (Egemen and Mohamed 2008). A successful contractor is the one that selects the most optimal bid markup that secures both the contract and contract profitability (Shash and Abdul-Hadi 1992). Bid markup decisions currently follow no accepted standards or formal procedures, but rather consider contractor experience, intuition, and personal preferences, which are not conducive elements for building an effective approach for achieving the optimal bid markup (Chua and Li 2000).

Cumulative prospect theory was proposed by Tversky and Kahneman (1992). Different from the classical theory, CPT adopted a concave-shaped utility function (UF) for gains and convex for losses and an inverse S-shaped probability weighting function (PWF) to describe individual preferences for choosing between risky prospects. Wakker and Deneffe (1996) proposed a trade-off (TO) method to improve probability distortions and misconceptions in utility elicitation. Many studies (Wu and Gonzalez 1996; Gonzalez and Wu 1999) have worked to elicit the PWF for particular subjects. Abdellaoui (2000) used TO method concepts to propose a parameter-free method to elicited subjects' UF and PWF. Bleichrodt and Pinto (2000) also leveraged the concept to propose a parameter-free method somewhat different from Abdellaoui's study, which they applied successfully to medical decision making. Determining the relative weight of influencing factors is important in multi-criteria decision making (MCDM). For uncertain events, the decision maker will find it difficult to form a judgment by relying on exact numerical values. FPR is a useful tool to express decision maker's uncertain preference information and define the relative weight of influencing factors. Significant attention has been given to fuzzy preference relations in previously studies (Orlovsky 1978; Nurmi 1981; Tanino 1984; Kacprzyk 1986; Chiclana *et al*. 1998, 2001, 2003; Fan *et al*. 2002; Xu and Da 2002, 2005; Herrera-Viedma *et al*. 2004). Wang and Chang (2007) adopted FPR to forecast the probability of successful knowledge management.

The usual practice is to make bid decisions based on 'intuition', which can be described as a derivation of 'gut feelings', experience and guesswork (Ahmad 1990). This research combined FPR, CPT and MCDM to propose a Multi-Criteria Prospect Model for Bid Decision making (BD-MCPM) to help construction company decision makers derive optimal bid decisions. The proposed model incorporates three phases. Phase I identifies the factors that affect bidding decisions (i.e., bid/no bid and markup scale). Phase II introduces FPR to determine bid/no bid. Phase III uses FPR and CPT to calculate CPT values for given markup scale, then selects the markup scale with the highest CPT value.

2. Literature review

2.1. Currently available decision making models

Contractors currently make bidding decisions using several relevant models. Early mark-up scale estimation models (e.g., Friedman 1956; Gates 1967; Carr 1982) employed probability theory to predict the probability of winning a particular contract. However, as the bidding decision is a complex decision-making process affected by numerous factors, probability theory is unable to describe interactions between factors.

Researchers have recently introduced bidding decision support systems based on artificial intelligence (AI), which permit consideration of identified factors of importance. Such systems include the expert system (ES) (Ahmad and Minkarah 1988; Tavakoli and Utomo 1989), case-based reasoning (CBR) (Chua *et al.* 2001), neural network (NN) (Li 1996; Moselhi *et al*. 1993; Hegazy and Moselhi 1994; Dias and Weerasinghe 1996; Li and Love 1999; Li *et al*. 1999; Wanous *et al*. 2003), analytical hierarchy process (AHP) (Seydel and Olson 1990; Cagno *et al*. 2001), and fuzzy set theory (Eldukair 1990; Fayek 1998; Lai *et al*. 2002; Lin and Chen 2004). The ES is one of rule-based systems. The process of bid decisions are highly unstructured, uncertainty, and subjectivity. It's too complicated to creating a set of clear rules that would be suitable for all/most cases. CBR requires a reasonably large set of cases data from which to draw knowledge to avoid generating inaccurate results. NN, also called artificial neural network (ANN), is similar to the CBR, with an important exception that the inference process is concealed from the decision maker. For such reasons, NN-derived conclusions are sometimes not particularly convincing to decision makers. AHP is a decision-making approach that structures multiple-choice criteria into a hierarchy and assesses relative importance of each. Unfortunately, AHP employs a complicated process to obtain consistent assessment results, which makes it unwieldy in practice.

The complexity and hard-to-define nature of competitive situations necessitates that most bid decisions rely heavily on decision maker intuition, experience and guesswork (Ahmad 1990). Fuzzy set theory provides a useful tool to handle decisions in which phenomena are imprecise and vague. Eldukair (1990) integrated fuzzy set theory with a multi-criteria model to select bidding cases. Subsequently, Fayek (1998) and Lai *et al*. (2002) used fuzzy set theory to choose optimal mark-up scales. Lin and Chen (2004) proposed an approach using fuzzy set theory to obtain a linguistics suggestion result for a bid/no-bid selection.

Fuzzy preference relations (FPRs), which integrate fuzzy logic and AHP concepts, greatly improve on AHP in terms of relative weight evaluation. In BD-MCPM, the FPR is used to determine the relative weights of influencing factors, and the CPT is used to evaluate the PDM's preference. The BD-MCPM handles factors marked by relatively higher levels of vagueness to make complicated bidding decisions and determine PDM risk preference. Results conform to actual bid decisions generated based on decision maker intuition, experience and guesswork. Therefore, BD-MCPM can assist decision makers to identify projects with the greatest profit potential and set an optimal mark-up scale.

2.2. Fuzzy preference relations

Most decision processes are based on preference relations (PR), the most common representation of information in decision making. In PR, an expert assigns a value to each pair of alternatives that reflects the degree of preference for the first alternative over the second. Many important decision models have been developed using mainly two preference relation types: (1) Multiplicative Preference Relations (MPR) and (2) Fuzzy Preference Relations (FPR).

Most decision processes are based on preference relations, the most common representation of information in decision making. An expert assigns a value to each pair of alternatives that reflects degree of preference B as an alternative over others. Many important decision models have been developed using mainly: (1) multiplicative preference relations and (2) fuzzy preference relations (Herrera-Viedma *et al*. 2004).

A multiplicative preference relation on a set of alternatives X is represented by matrix A, with A usually assumed a multiplicative reciprocal:

$$A = [a_{ij}] \subset X \times X \; ; \tag{1}$$

$$a_{ij} \cdot a_{ji} = 1 \qquad \forall i, j \in \{1, \;\ldots,\; n\} . \tag{2}$$

The a_{ij} indicate the preference ratio of alternative x_i to x_j. Saaty (1980, 1994) suggested measuring a_{ij} using a ratio scale 1–9. When $a_{ij} = 1$ indicates indifference between x_i and x_j, and $a_{ij} = 9$ indicates that x_i is absolutely preferred to x_j, then $a_{ij} \in [1/9, 9]$.

Fuzzy preference relation B on a set of alternatives X is a fuzzy set on the product set $X \times X$, characterized by membership function $\mu_B: X \times X \rightarrow [0,1]$. Therefore:

$$B = [b_{ij}] \quad b_{ij} = \mu_B(x_i, x_j) \quad \forall i, j \in \{1, \ ..., \ n\}; \quad (3)$$

$$b_{ij} + b_{ji} = 1 \quad \forall i, j \in \{1, \cdots, n\}, \quad (4)$$

where μ_B is a membership function and b_{ij} is the preference ratio of alternative x_i over x_j. A b_{ij} at 0.5 denotes that x_i and x_j are indifferent, and a b_{ij} at 1 represents that x_i is preferred absolutely to x_j.

The method (Herrera-Viedma *et al*. 2004) to transformation multiplicative preference relations A to fuzzy preference relations B and obtain relative weights presents the following:

(1) Get (n–1) values $\{a_{12}, a_{23}, \ldots, a_{(n-1)n}\}$ of multiplicative preference relations A;

(2) Diagonal elements of A are values at 1.0, using the equation (5) to calculate the remaining elements in the upper right part of the diagonal:

$$a_{ij} = \frac{a_{i(j-1)} \times a_{(i+1)j}}{a_{(i+1)(j-1)}}. \quad (5)$$

Elements in the lower left part of the diagonal in were calculated using the equation shown below:

$$a_{ij} = \frac{1}{a_{ji}}; \quad (6)$$

(3) Let $Z = \max[A]$, then transfer multiplicative preference relations A to a consistently MPR matrix C with a normal to interval [1/9, 9] with equation (7):

$$c_{ij} = \left(a_{ij}\right)^{1/\log_9 Z}; \quad (7)$$

(4) Apply equation (8) to transform the consistent MPR matrix C to FPR matrix B:

$$b_{ij} = g(c_{ij}) = (1 + \log_9 c_{ij})/2. \quad (8)$$

2.3. Cumulative prospect theory

Consider a prospect (mutual fund) X with outcomes $x_1 \leq \ldots \leq x_k \leq 0 \leq x_{k+1} \leq \ldots \leq x_n$ that are associated with probability $p_1, \cdots, p_k, p_{k+1}, \cdots, p_n$. Cumulative prospect theory predicts that people will choose prospects based on the value (Tversky and Kahneman 1992):

$$V(X) = \sum_{i=1}^{k} \pi_i^{-} \lambda v(x_i) + \sum_{i=k+1}^{n} \pi_i^{+} v(x_i), \quad (9)$$

where $\lambda > 0$ is a loss-aversion parameter and π are decision weights calculated based on "cumulative" probabilities associated with the outcomes. In particular, prospect theory assumes a probability weighting function $w^+ : [0; 1] \rightarrow [0; 1]$ for gains and a probability weighting function $w^- : [0; 1] \rightarrow [0; 1]$ for losses. In CPT the utility function $v(x)$ is unchanged from the original PT (Tversky and Kahneman 1992; Tversky and Fox 1995; Gonzalez and Wu 1999), which is concave for gains and convex for losses, with the loss function assumed to be steeper than the gain function ($\beta > 1$):

$$v(x) = \begin{cases} x^{\alpha} \\ -\beta(-x)^{\alpha} \end{cases}. \quad (10)$$

The decision weights employed in CPT are given by Tversky and Kahneman (1992):

$$\pi_1 = w^-(p_1) \text{ and } \pi_n = w^+(p_n); \quad (11)$$

$$\pi_i^- = \sum_{j=1}^{i} w^-(p_j) - \sum_{j=1}^{i-1} w^-(p_j) \text{ for } 2 \leq i \leq k$$

and (12)

$$\pi_i^+ = \sum_{j=i}^{n} w^+(p_j) - \sum_{j=i+1}^{n} w^+(p_j) \text{ for } k+1 \leq i \leq n-1,$$

where probability weighting functions w^- and w^+ are defined for probabilities associated with losses and gains, respectively, which may be experimentally estimated using the following formulae (Tversky and Kahneman 1992; Camerer and Ho 1994; Wu and Gonzalez 1996):

$$w^-(x) = \frac{x^{\delta}}{\left(x^{\delta} + \left(1 - x^{\delta}\right)\right)^{1/\delta}}$$

and (13)

$$w^+(x) = \frac{x^{\gamma}}{\left(x^{\gamma} + \left(1 - x^{\gamma}\right)\right)^{1/\gamma}}.$$

For only gain conditions, equations (9) will transform to:

$$V[p_1, x_1; p_2, x_2] = \sum_{j=1}^{2} \pi_j^+ \cdot v(x_j) = \pi_1^+ \cdot v(x_1) + \pi_2^+ \cdot v(x_2). \quad (14)$$

3. Constructing a multi-criteria prospect model for bidding decisions

3.1. Multi-criteria prospect model for bidding decision

This study adopted BD-MCPM, which combined FPR and CPT, to modeling the construction company's bidding decision processes using the three phases shown in Fig. 1.

3.2. Phase I – preparation

The bidding decision process generates two decisions: whether to submit or not submit a bid (bid/no bid) and, if so, the scale of the markup component of the bid (markup) (Egemen and Mohamed 2008). Many factors affect decision making in each phase. Phase I should first identify the key factors that influence a bidding decision and, based on such factors, collect and organize relevant project data/information.

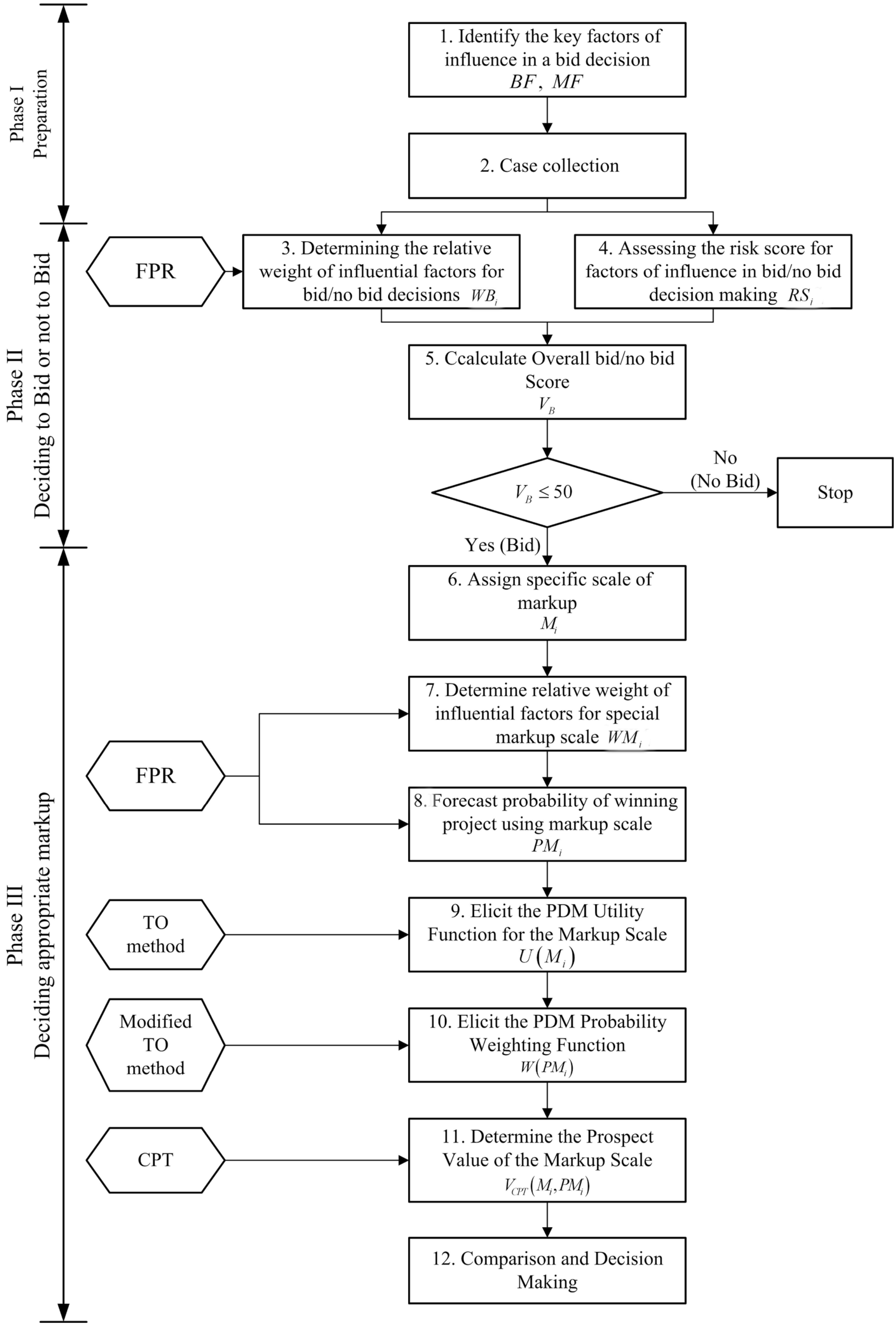

Fig. 1. Flowchart of BD-MCPM

Table 1. Key influencing factors of bid/no bid decision

Category	No.	Inferential Factor	Literatures										Questionnaire survey	
			1	2	3	4	5	6	7	8	9	10	Average Score	Factor
Client	1	**Reputation of client**				●	●	●	●	●		●		
	2	**Relationship with client**	●			●		●	●		●	●	**6.55**	***BF_6***
	3	Financial capability of the client						●	●	●				
	4	Client requirements				●		●						
	5	Fostering good relationship with regular clients										●		
Other	6	Proportions to be subcontracted				●		●		●				
	7	Reputation of other consultants						●		●				
	8	Relationship with other consultants						●	●		●			
Project	9	**Nature of project**	●	●			●	●		●	●	●		
	10	**Project size**	●				●	●	●	●			**7.10**	***BF_3***
	11	Project period				●		●	●			●		
	12	**Project complexity**		●		●		●	●	●			**6.25**	***BF_7***
	13	**Project location**	●	●		●	●	●	●					
Resources	14	**Experience for similar project**					●	●	●	●	●	●	**7.15**	***BF_2***
	15	Professional demands of the contract									●	●		
	16	Physical resources necessary to carry out project						●						
	17	**Availability of qualified/experienced staff**					●	●	●	●	●		**5.85**	***BF_8***
	18	Financial resources necessary to carry out project						●						
Tender	19	**Time available for tender preparation**	●			●	●	●	●	●				
	20	Cost of bidding			●			●				●		
	21	Tender conditions				●			●	●				
	22	Tendering method					●	●		●				
	23	Adequacy of tender information		●		●	●	●						
	24	Current workload in bid preparation								●				
Contract	25	Type of contract				●	●	●						
	26	**Contractual conditions**	●	●		●	●		●		●		**6.75**	***BF_4***
Company	27	Compliance with business strategy						●				●		
	28	**Current work load**					●	●	●	●		●	**6.70**	***BF_5***
	29	**Availability of other projects**	●				●	●	●	●	●			
	30	Promoting reputation						●		●				
	31	Operational capacity								●		●		
Competitors	32	**Number of competitors**				●	●	●	●			●	**5.25**	***BF_9***
	33	Competence of the expected competitors						●	●					
	34	Degree of competition	●					●	●					
	35	Perceived chances of being successful			●			●						
Financial	36	Client budget		●					●					
	37	Financial situation				●		●		●		●		
	38	**Expected profitability**			●		●	●	●			●	**7.20**	***BF_1***
	39	Expected cash flow					●	●	●					
	40	Confidence in the cost estimate							●	●				
	41	Projected break-even point for the contract						●						
Culture	42	Local customs							●		●			
Market	43	**Market conditions**	●	●		●				●	●			
Risk	44	**Expected risk**	●		●		●		●		●		**5.10**	***BF_{10}***

Note: Literature (1) Cook (1985); (2) Skitmore (1985); (3) Marsh (1989); (4) Cooke (1992); (5) Shash (1993); (6) Odusote and Fellows (1992); (7) Wanous *et al.* (2000); (8) Chua and Li (2000); (9) Han and Diekmann (2001); (10) Lewis (2003)

3.2.1. Identify the key factors of influence in a bid decision

Many studies designed to identify the factors that influence bidding decisions have been conducted in recent years. Some have adopted a contractor perspective. Others have focused on conditions limited to a particular, localized situation. Still others have taken a multinational perspective. All have worked to identify key factors of influence at work on local contractor bid decisions. The purpose of Phase I in the BD-MCPM was to identify, respectively, the key factors influencing bid/no bid and markup decisions. The identification process was a two step process, which first reduced the total potential number of factors by identifying and choosing only those referenced consistently in the literature in order to identify a shortlist of 'pre-adapted' factors. The second step incorporated these pre-adapted factors into a questionnaire, which was send to local contractors who were asked to assess the importance of each factor on a scale from 1 to 9 (1:very unimportant, 9:very important). Each factor was then assigned an importance score based on an average of submitted scores. Table 1 shows 44 factors identified in the literature as affecting bid/no bid decision making (Cook 1985; Skitmore 1985; Marsh 1989; Cooke 1992; Odusote and Fellows 1992; Shash 1993; Wanous *et al*. 2000; Chua and Li 2000; Han and Diekmann 2001; Lewis 2003). Sixteen of these factors were prioritized as they were mentioned in five or more of the referenced articles. Ten of these prioritized factors received average scores of importance equal to or greater than 5, and were ranked from highest to lowest.

Similarly, Table 2 shows the eight factors identified in the literature as affecting markup decisions (Odusote and Fellows 1992; Dozzi *et al*. 1996; Li 1996; Dulaimi and Shah 2002). A shortlist of those that were mentioned in two or more articles was then made, and those from the shortlist with average earned scores of importance equal or greater than 5 were ranked.

Table 2. Key influencing factors for markup scale decision

Category	Inferential factor	Factor
Project	**Project size**	MF_5
Resources	**Experience in similar project**	MF_6
Company	**Need for work**	MF_1
	Current workload	MF_3
Competitors	**Number of competitors**	MF_4
Financial	**Expected profitability**	MF_8
Market	**Overall economy**	MF_7
Risk	**Expected risk**	MF_2

3.2.2. Case collection

A case study to test the ability of the BD-MCPM model to solve the above problem was conducted to illustrate the effectiveness of the approach in practice. The background of research participants were considered to be homogeneous in the sense that they were all qualified professionals in construction field with previous knowledge of bidding strategies and bidding procedures. Table 3 presents a summary of data collected on three actual projects.

Table 3. Case study data

Item	Case 1	Case 2	Case 3
Owner	Housing and Urban Development Corporation (HUD)	Hanoi city people's committee	Infrastructure Development and Construction Corporation (LICOGI)
Project	Housing project	Housing project	Housing project
	2 units – 14 floors and 21 floor	1 unit – 21 floor	2 units – 14 floors and 17 floor
	Total Floor area 21960 m^2	Total Floor area 19950 m^2	Total Floor area 19558 m^2
	Basement area 1588 m^2	Basement area 1800 m^2	Basement area 1500 m^2
Location	Hanoi city, Vietnam	Hanoi city, Vietnam	HaiPhong city, Vietnam
Estimated cost	Approx. US $17,954,000	Approx. US $4,228,000	Approx. US$9,735,000
Total duration	30 months	18 months	24 months
Bidding system	Open competitive bid	Open competitive bid	Open competitive bid
Fund	Self, customer mobilization fund, Agri Bank	Self (government)	Self, government, Viet Com Bank
Contract type	Lump sum	Lump sum	Lump sum
Payment methods	Local currency (VND)	Local currency (VND)	Local currency (VND)
Timing of payments	2.5 months	2 months	2 months
Prior project markup scale	Common markup 3–6%	Common markup 3–6%	Common markup 3–6%
	The best case 20% gain	The best case 20% gain	The best case 20% gain
	The worst case 15% loss	The worst case 15% loss	The worst case 15% loss

3.3. Phase II – deciding to bid or not to bid

The goal of Phase II was to make a decision whether or not to bid on a particular project. The 10 key factors that affect the bid/no bid decision were identified in Section 3.2.1. By assessing the relative weights and risk scores for these factors, a bid/no bid score may be obtained, which can then be used to make the decision whether to bid or not.

3.3.1. Determining the relative weight of influencing factors for bid/no bid decisions

The seven steps employed to determine the relative weight of identified factors of influence are described as follows:

Step 1: Define linguistic variables. This study used 9 linguistic terms {AM: Absolutely more important, VM: Very strongly more important, SM: Strongly more important, WM: Weakly more important, EQ: Equally important, WL: Weakly less important, SL: Strongly less important, VL: Very strongly less important, AL: Absolutely less Important } associated with real number {5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5} to compare corresponding neighboring factors.

Step 2: Obtain questionnaire input. Ten factors of influence $[BF_i(i=1,2,\ldots,10)]$ were considered in making the bid / no bid decision. Via a questionnaire survey or interviews, the k^{th} evaluator assessed the relative intensity of importance of the two adjoining factors BF_i and BF_j to obtain 9 grades of importance $\left[a_{ij}^k(i=1,2,\ldots,9,\ j=i+1)\right]$, where $a_{ij}^k=1$ means indifference between two factors, $a_{ij}^k=2,3,4,5$ shows that factor BF_i is relatively important to factor BF_j, $a_{ij}^k=1/2,1/3,1/4,1/5$ and indicates that factor BF_i is less important than factor BF_j. Table 4 presents the relative importance of bid/no bid decision factors assessed by evaluator 1.

Table 4. Questionnaire sheet for importance of influencing factors of evaluator 1

Factor BF_i	Intensity of importance									Factor BF_j
	AM	VM	SM	WM	EQ	WL	SL	VL	AL	
BF_1		X								BF_2
BF_2					X					BF_3
BF_3								X		BF_4
BF_4							X			BF_5
BF_5					X					BF_6
BF_6							X			BF_7
BF_7				X						BF_8
BF_8							X			BF_9
BF_9			X							BF_{10}

Step 3: Construct the MPR matrix. To construct the k^{th} evaluator's MPR matrix A^k, we first translated the linguistic terms of questionnaire results into real numbers a_{ij}^k to fill proper diagonal elements, using Eqs (5) and (6) to calculate the remaining elements of MPR matrix.

For example, from Table 4 we can obtain a set of 9 values $\{a_{12}^1=4,\ a_{23}^1=1,\ a_{34}^1=1/4,\ a_{45}^1=1/3,\ a_{56}^1=1,\ a_{67}^1=1/3,\ a_{78}^1=2,\ a_{89}^1=1/2,\ a_{9\,10}^1=3\}$, the MPR matrix of evaluator 1's may be constructed as follows:

$$A^1=\begin{bmatrix} 1 & 4 & 4.00 & 1.00 & 0.33 & 0.33 & 0.11 & 0.22 & 0.11 & 0.33 \\ 0.25 & 1 & 1 & 0.25 & 0.08 & 0.08 & 0.03 & 0.06 & 0.03 & 0.08 \\ 0.25 & 1.00 & 1 & 1/4 & 0.08 & 0.08 & 0.03 & 0.06 & 0.03 & 0.08 \\ 1.00 & 4.00 & 4.00 & 1 & 1/3 & 0.33 & 0.11 & 0.22 & 0.11 & 0.33 \\ 3.00 & 12.00 & 12.00 & 3.00 & 1 & 1 & 0.33 & 0.67 & 0.33 & 1.00 \\ 3.00 & 12.00 & 12.00 & 3.00 & 1.00 & 1 & 1/3 & 0.67 & 0.33 & 1.00 \\ 9.00 & 36.00 & 36.00 & 9.00 & 3.00 & 3.00 & 1 & 2 & 1.00 & 3.00 \\ 4.50 & 18.00 & 18.00 & 4.50 & 1.50 & 0.50 & 0.50 & 1 & 1/2 & 1.50 \\ 9.00 & 36.00 & 36.00 & 9.00 & 3.00 & 1.00 & 1.00 & 2.00 & 1 & 3 \\ 3.00 & 12.00 & 12.00 & 3.00 & 1.00 & 0.33 & 0.33 & 0.67 & 0.33 & 1 \end{bmatrix}.$$

Let $Z=\max[A^k]$, a consistently MPR matrix C^k with a normal to interval [1/5, 5], the transform function show in Eq. (15) will change to Eq. (16) :

$$c_{ij}^k=\left(a_{ij}^k\right)^{1/\log_5 Z}. \tag{15}$$

For example, the maximum value of evaluator 1's A^1 MPR matrix was 36. Applying Eq. (15), a consistently MPR matrix C^1 may be obtained as follows:

$$C^1=\begin{bmatrix} 1.00 & 1.86 & 1.86 & 1.00 & 0.61 & 0.61 & 0.37 & 0.51 & 0.37 & 0.61 \\ 0.54 & 1.00 & 1.00 & 0.54 & 0.33 & 0.33 & 0.20 & 0.27 & 0.20 & 0.33 \\ 0.54 & 1.00 & 1.00 & 0.54 & 0.33 & 0.33 & 0.20 & 0.27 & 0.20 & 0.33 \\ 1.00 & 1.86 & 1.86 & 1.00 & 0.61 & 0.61 & 0.37 & 0.51 & 0.37 & 0.61 \\ 1.64 & 3.05 & 3.05 & 1.64 & 1.00 & 1.00 & 0.61 & 0.83 & 0.61 & 1.00 \\ 1.64 & 3.05 & 3.05 & 1.64 & 1.00 & 1.00 & 0.61 & 0.83 & 0.61 & 1.00 \\ 2.68 & 5.00 & 5.00 & 2.68 & 1.64 & 1.64 & 1.00 & 1.37 & 1.00 & 1.64 \\ 1.97 & 3.66 & 3.66 & 1.97 & 1.20 & 1.20 & 0.73 & 1.00 & 0.73 & 1.20 \\ 2.68 & 5.00 & 5.00 & 2.68 & 1.64 & 4.64 & 1.00 & 1.37 & 1.00 & 1.64 \\ 1.64 & 3.05 & 3.05 & 1.64 & 1.00 & 1.00 & 0.61 & 0.83 & 0.61 & 1.00 \end{bmatrix}.$$

Step 4: Transform the consistent MPR matrix to a fuzzy preference relation matrix. The consistent MPR matrix $c_{ij}^k\in[1/5,5]$, the transform function shown in Eq. (8) will change to Eq. (16) shown below:

$$b_{ij}=g(a_{ij})=(1+\log_5 c_{ij})/2. \tag{16}$$

Applying Eq. (16), the evaluator 1's FPR matrix B^1 may be obtained as follows:

$$B^1=\begin{bmatrix} 0.50 & 0.69 & 0.69 & 0.50 & 0.35 & 0.35 & 0.19 & 0.29 & 0.19 & 0.35 \\ 0.31 & 0.50 & 0.50 & 0.31 & 0.15 & 0.15 & 0.00 & 0.10 & 0.00 & 0.15 \\ 0.31 & 0.50 & 0.50 & 0.31 & 0.15 & 0.15 & 0.00 & 0.10 & 0.00 & 0.15 \\ 0.50 & 0.69 & 0.69 & 0.50 & 0.35 & 0.35 & 0.19 & 0.29 & 0.19 & 0.35 \\ 0.65 & 0.85 & 0.85 & 0.65 & 0.50 & 0.50 & 0.35 & 0.44 & 0.35 & 0.50 \\ 0.65 & 0.85 & 0.85 & 0.65 & 0.50 & 0.50 & 0.35 & 0.44 & 0.35 & 0.50 \\ 0.81 & 1.00 & 1.00 & 0.81 & 0.65 & 0.65 & 0.50 & 0.60 & 0.50 & 0.65 \\ 0.71 & 0.90 & 0.90 & 0.71 & 0.56 & 0.56 & 0.40 & 0.50 & 0.40 & 0.56 \\ 0.81 & 1.00 & 1.00 & 0.81 & 0.65 & 0.65 & 0.50 & 0.60 & 0.50 & 0.65 \\ 0.65 & 0.85 & 0.85 & 0.65 & 0.50 & 0.50 & 0.44 & 0.44 & 0.35 & 0.50 \end{bmatrix}.$$

Step 5: Aggregate the FPR matrix for all evaluators. The opinions of different evaluators were aggregated to obtain an aggregated weight for each factor of influence. b_{ij}^{k} was employed to denote the fuzzy preference relationship value of the k^{th} evaluator to assess factors *i* and *j*. This study used an average value method to integrate the judgment values of *m* evaluators and obtain the averaged FPR matrix $\overline{B}$. The average function is shown below:

$$\overline{b_{ij}} = \frac{1}{m}\left(b_{ij}^{1} + b_{ij}^{2} + \ldots + b_{ij}^{m}\right). \tag{17}$$

For example, b_{ij}^{k} for 3 evaluators were $b_{12}^{1} = 0.69$, $b_{12}^{2} = 0.72$, and $b_{12}^{3} = 0.78$. Equation (17) was then applied to generate $\overline{b}_{12} = 0.73$. The same approach was used to obtain an averaged FPR matrix $\overline{B}$, as follows:

$$\overline{B} = \begin{bmatrix} 0.50 & 0.73 & 0.85 & 0.69 & 0.50 & 0.54 & 0.54 & 0.64 & 0.49 & 0.62 \\ 0.27 & 0.50 & 0.62 & 0.46 & 0.26 & 0.31 & 0.31 & 0.41 & 0.26 & 0.38 \\ 0.15 & 0.38 & 0.50 & 0.34 & 0.14 & 0.19 & 0.19 & 0.29 & 0.14 & 0.26 \\ 0.31 & 0.54 & 0.66 & 0.50 & 0.30 & 0.35 & 0.34 & 0.45 & 0.30 & 0.42 \\ 0.50 & 0.74 & 0.86 & 0.70 & 0.50 & 0.55 & 0.54 & 0.65 & 0.50 & 0.62 \\ 0.46 & 0.69 & 0.81 & 0.65 & 0.45 & 0.50 & 0.50 & 0.60 & 0.45 & 0.57 \\ 0.46 & 0.69 & 0.81 & 0.66 & 0.46 & 0.50 & 0.50 & 0.61 & 0.45 & 0.58 \\ 0.36 & 0.59 & 0.71 & 0.55 & 0.35 & 0.40 & 0.39 & 0.50 & 0.35 & 0.47 \\ 0.51 & 0.74 & 0.86 & 0.70 & 0.50 & 0.55 & 0.55 & 0.65 & 0.50 & 0.62 \\ 0.38 & 0.62 & 0.74 & 0.58 & 0.38 & 0.43 & 0.43 & 0.53 & 0.38 & 0.50 \end{bmatrix}.$$

Step 6: Normalize the aggregated FPR matrix. Using *R* to indicate the normalized aggregate FPR matrix, the value of element r_{ij} can be obtained using the function shown below:

$$r_{ij} = \frac{\overline{b_{ij}}}{\sum_{i=1}^{10} \overline{b_{ij}}}, \quad j = 1, 2, \cdots, 10. \tag{18}$$

For $\overline{b}_{12} = 0.73$, $\sum_{i=1}^{10} \overline{b_{ij}} = 6.21$ when $j = 2$, applying equation (18), we can then get r_{12}=0.118 and, in the same manner, obtain normalize averaged FPR matrix *R* as follows:

$$R = \begin{bmatrix} 0.128 & 0.118 & 0.115 & 0.119 & 0.129 & 0.125 & 0.123 & 0.121 & 0.129 & 0.122 \\ 0.069 & 0.081 & 0.084 & 0.079 & 0.069 & 0.072 & 0.070 & 0.077 & 0.068 & 0.076 \\ 0.038 & 0.061 & 0.067 & 0.059 & 0.037 & 0.044 & 0.042 & 0.055 & 0.037 & 0.052 \\ 0.079 & 0.087 & 0.089 & 0.086 & 0.078 & 0.081 & 0.078 & 0.084 & 0.078 & 0.083 \\ 0.129 & 0.118 & 0.115 & 0.120 & 0.130 & 0.127 & 0.124 & 0.122 & 0.130 & 0.123 \\ 0.117 & 0.111 & 0.109 & 0.112 & 0.118 & 0.116 & 0.113 & 0.113 & 0.118 & 0.113 \\ 0.119 & 0.112 & 0.110 & 0.112 & 0.119 & 0.117 & 0.114 & 0.114 & 0.119 & 0.114 \\ 0.091 & 0.095 & 0.096 & 0.094 & 0.091 & 0.092 & 0.090 & 0.094 & 0.091 & 0.093 \\ 0.131 & 0.119 & 0.116 & 0.120 & 0.131 & 0.128 & 0.125 & 0.122 & 0.131 & 0.124 \\ 0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.121 & 0.099 & 0.099 & 0.099 \end{bmatrix}.$$

Step 7: Obtain relative weights. Given that WB_i denotes the priority weight of influencing factor *i*, the priority weight of each factor may be obtained using the following function:

$$WB_i = \frac{\sum_{j=1}^{10} r_{ij}}{\sum_{i=1}^{10}\sum_{j=1}^{10} r_{ij}}. \tag{19}$$

In Case 1, $\sum_{i=1}^{10}\sum_{j=1}^{10} r_{ij}$=10 and $\sum_{j=1}^{10} r_{ij}$=1.228 for $i = 1$, applying equation (19) obtains a relative weight for influencing factor BF_1 of 0.123. Following the same process, the relative weights of influencing factors in Case 1 as assessed using three evaluators were obtained as WB_i={0.123, 0.074, 0.049, 0.082, 0.124, 0.114, 0.115, 0.093, 0.125, 0.101}.

3.3.2. Assessing the risk score for factors of influence in bid/no bid decision making

Risk score RS_i represents the degree of risk in the factor of influence BF_i, which has been subjectively established by PDM using predetermined scores {0 – No risk, 25 – Low risk, 50 – Moderate risk, 75 – High risk, 100 – Prohibitive risk}. For Case 1, the value of risk associated with influencing factors using PDM is illustrated in Table 5.

Table 5. Risk assessment by PDM on influencing factors of Case 1

No	Influencing factor	RS_i				
		0	25	50	75	100
1	Expected profitability			**X**		
2	Experience for similar project		**X**			
3	Project size			**X**		
4	Contractual conditions		**X**			
5	Current workload				**X**	
6	Relationship with client		**X**			
7	Project complexity				**X**	
8	Availability of qualified/experienced staff		**X**			
9	Number of competitors		**X**			
10	Expected risk			**X**		

3.3.3. Deciding to or not to submit a bid

A total bid/no bid score may then be calculated by summing degrees of significance:

$$V_B = \sum_{i=1}^{10} WB_i \times RS_i. \tag{20}$$

If $V_B \leq 50$, then a "bid" decision is recommended. Applying equation (20) to bid/no bid scores for cases 1 through 3 returned, respectively, total scores of 43.8, 52.9 and 45.3. As such, the contractor should bid on Case 1 and Case 3 and proceed to Phase III (the markup phase) for both.

3.4. Phase III – deciding appropriate markup

Once a decision to bid has been made, the next step is to determine appropriate markup sizes for bidding projects. Firstly, the PDM assign a set of markup scales. The evaluator then determines the relative weight of each factor of influence (see also Section 3.2.1) for each special markup scale. The resulting assess the probability of winning project for specify markup scale. The determining process is illustrated below.

3.4.1. Assign specific scale of markup

In construction projects, the scale of a markup is determined based on relevant contractor policies and project type. In general, markups tend to represent 3% ~ 7% of a project's total estimated cost, although in certain cases, markups may be in the 10% ~ 15% range or higher. This study adopted 5 frequently used markup scales {M_1=3%, M_2=4%, M_3=5%, M_4=7%, M_5=10%} as examples.

3.4.2. Determine relative weight of influencing factors for special markup scale

The eight key factors previously identified as affecting markup scale decision making (MF_i) are listed in Table 2. These also represent factors of influence on outcome implementation. Assigning weights to each factor is done in the same manner as that described in Section 3.3.1. The only difference was the associated factors of influence used. The relative weight of each influencing factor MF_i, assessed using 3 evaluators, were obtained and represented as WM_i ={0.078, 0.078, 0.064, 0.123, 0.191, 0.118, 0.150, 0.198}.

3.4.3. Forecast probability of winning project using markup scale

As bids typically involve multiple potential contractors, assessing the probability of bid success over competitors at a particular markup level is critical. Of course, markup scale may be expected to correlate inversely to probability of bid success. FPR was used here to forecast project bid success in the same manner as in Section 3.3.1.

For each case and defined markup scale, evaluators used linguistic terms to judge subjectively the relative importance of each factor in winning a bid and in losing a bid MF_i.

For example, in Case 1, when the markup was set to 3%, Evaluator 1 assessed the relative importance to win/lose case probability to be $b^1_{uv} = \{5, 4, 4, 3, 5, 4, 5, 4\}$. Using questionnaire results, a 2×2 pair-wise comparison MPR matrix could then be constructed with two outcomes ("win" and "lose") for each factor of influence. The pair-wise comparison MPR matrix B^k for each influencing factor was then constructed (see Table 6 below).

Applying the same process described from step 4 to 7 in Section 3.3.1., derived the average rating PR_i, which described the potential for winning in light of the identified factors of influence MF_i. For example, in Case 1, at a markup of 3%, win probability ratings for relevant factors of influence MF_i may be obtained using PR_i ={0.81, 0.76, 0.79, 0.69, 0.78, 0.76, 0.83, 0.76}.

Table 6. Evaluator 1's pair-wise comparison MPR matrix for case 1 and markup scale 3%

Influencing factor	MPR B^k		
		Win	Lose
MF_1	Win	1	**5**
	Lose	**1/5**	1
MF_2	Win	1	**4**
	Lose	**1/4**	1
MF_3	Win	1	**4**
	Lose	**1/4**	1
MF_4	Win	1	**3**
	Lose	**1/3**	1
MF_5	Win	1	**5**
	Lose	**1/5**	1
MF_6	Win	1	**4**
	Lose	**1/4**	1
MF_7	Win	1	**5**
	Lose	**1/5**	1
MF_8	Win	1	**4**
	Lose	**1/4**	1

Finally, for a specify markup scale, the forecast probability of winning PM may be obtained using the following function:

$$PM = \sum_{i=1}^{8} WM_i \times PR_i \, , \tag{21}$$

where WM_i and PR_i denote the relative weights and the probability ratings of winning for identified markup scale factors of influence $MF_i \, , i \in (1, 2, \cdots, 8)$.

Using the example of Case 1 at a 3% markup and the value for WM_i obtained in Section 3.4.2., we may apply equation (21) to obtain a win probability forecast PM = 78%. In the same manner, the win probability forecast at 4%, 5%, 7% and 10% markups were 71%, 63%, 43% and 25%, respectively, for Case 1. In Case 3, win probability forecasts were 77%, 68%, 60%, 46% and 28% for defined markups in the 3~10% range.

As defined in the model construct, probability of winning a project is kept and probability of losing a project is ignored, the latter yields a prospect value equal to 0.

3.4.4. Elicit the PDM utility function for the markup scale

This study adopted the TO method proposed by Wakker and Deneffe (1996) to elicit the PDM utility function for the markup scale. This paper will not describe the mechanisms by which such was accomplished, as the method has been described previously in the literature (Bleichrodt and Pinto 2000; Abdellaoui 2000; Abdellaoui *et al.* 2005). The elicited result for the PDM utility function is shown in Fig. 2.

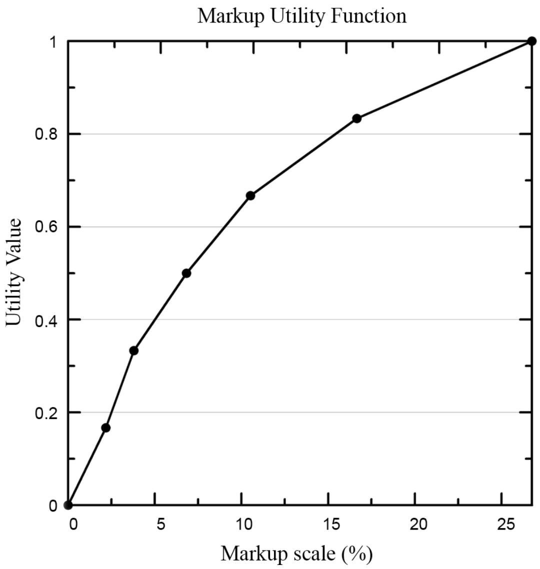

Fig. 2. Elicited PDM's Utility function curve of Markup scale

3.4.5. Elicit the PDM probability weighting function

Bleichrodt and Pinto (2000) proposed a method to elicit PWF based on the TO method. This method first set $p' \le 0.5$ for low probabilities and $p' > 0.5$ for high probabilities, then chose two prospects which were queried to subjects in order to assess an outcome. For probabilities $p' \le 0.5$, subjects were asked to assess an outcome z_y such that the difference between $\left[p',\ x_i;\ 1-p',x_j\right]$ and $\left[p',\ x_k;\ 1-p',z_r\right]$ with $x_k \ge x_i \ge x_j$, x_k, x_i, and x_j are elements of the standard sequence elicited in 3.4.4. The weighting of probabilities $w(p')$ were determined using:

$$w(p') = \frac{u(x_j)-u(z_r)}{\left[u(x_j)-u(z_r)\right]+\left[u(x_k)-u(x_i)\right]}. \quad (22)$$

For probabilities $p' > 0.5$, subjects were asked to assess an outcome z_s such that there is indifference between $\left[p',\ x_m;\ 1-p',x_n\right]$ and $\left[p',\ z_s;\ 1-p',x_q\right]$ with $x_m \ge x_n \ge x_q$, x_m, x_n, and x_q are elements of the standard sequence. Weighting of probabilities $w(p')$ were determined by:

$$w(p') = \frac{u(x_n)-u(x_q)}{\left[u(z_s)-u(x_m)\right]+\left[u(x_n)-u(x_q)\right]}. \quad (23)$$

This study used the same probabilities $p' = \{0.10, 0.25, 0.50, 0.75, 0.90\}$ as those in Bleichrodt's study to elicit PDM's PWF. In the elicitation procedure, the PDM may be used to assess an outcome for the two prospects in probabilities that range from 0.10 to 0.90. If the first assumption assumes a low setting probability p', then the PDM will be asked to assess z_y for the prospect of $\left[p',\ x_i;\ 1-p',x_j\right]$ and $\left[p',\ x_k;\ 1-p',z_r\right]$, and apply equation (23) to calculate $w(p')$. If $w(p') \ge 0$ and $p' \ge w(p')$, then p' represents a low probability. Otherwise, p' should be high probability, and PDM will be asked in the same p' again to assess z_s with prospects $\left[p',\ x_m;\ 1-p',x_n\right]$ and $\left[p',\ z_s;\ 1-p',x_q\right]$, and apply equation (28) to calculate $w(p')$. Other probabilities of p' are assumed at a high probability to elicit $w(p')$. Fig. 3 shows the elicited PWF of the PDM in this study.

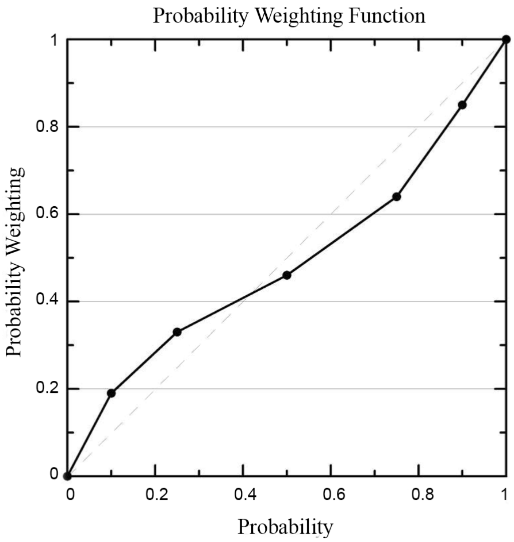

Fig. 3. Elicited PDM's probability weighting curve

3.4.6. Determine the prospect value of the markup scale

Under CPT and FPR, the Prospect Value $V_{CPT}(M_i)$ at a specified markup scale M_i may be determined using the CPT equation:

$$V_{CPT}(M_i) = U(M_i) \times W(PM_i), \quad (24)$$

where $U(M_i)$ and $W(PM_i)$ may be found by interpolation:

$$U(M_i) = \frac{M_i - M_j}{M_{j+1} - M_j}\left[U(M_{j+1}) - U(M_j)\right] + U(M_j); \quad (25)$$

$$W(PM_i) = \frac{PM_i - PM_j}{PM_{j+1} - PM_j}\left[W(PM_{j+1}) - W(PM_j)\right] + W(PM_j). \quad (26)$$

The calculated CPT value for each markup scale in Case 1 and Case 3 were listed in Table 7.

3.4.7. Comparison and decision making

Selecting the highest markup scale CPT value (Table 7) determined the markup scale in each case (i.e., 5% for Case 1 and 7% for Case 3). Estimated profit and bid price for Cases 1 and 3 were calculated and are shown in Table 8. Under circumstances in which contractors may only choose one case on which to bid, other consideration factors may be brought into play (e.g., duration, funding requirements, etc.).

Table 7. CPT value for each markup scale of Case 1 and Case 3

Case	Markup scale $M(n)$	Markup scale Utility Value $U(M(n))$	Probability of Winning $P(M(n))$	Probability Weight $PW(M(n))$	Prospect Value V_{CPT}	Decision Markup scale
1	3%	0.252	78%	0.682	0.172	**5%**
	4%	0.345	71%	0.611	0.211	
	5%	0.400	63%	0.554	**0.221**	
	7%	0.508	43%	0.424	0.215	
	10%	0.643	25%	0.330	0.212	
3	3%	0.252	77%	0.668	0.168	**7%**
	4%	0.345	68%	0.590	0.203	
	5%	0.400	60%	0.532	0.213	
	7%	0.508	46%	0.439	**0.223**	
	10%	0.643	28%	0.345	0.222	

Table 8. Profit and bid price for Case 1 and Case 3

Case	Estimated Cost (USD)	Decision Markup scale	Profit (USD)	Bid price (USD)
1	17,954,000	**5%**	897,700	18,851,700
3	9,735,000	**7%**	681,450	10,416,450

4. Discussions

BD-MCPM was used successfully to help PDM determine which case(s) should be bid and the optimal markup. Knowing competitor markup scales prior to tender submission would be helpful in modifying the markup recommendations generated by BD-MCPM and allow for adjustments critical to winning the bid (markup adjustment downward) or increasing profit (markup adjustment upward). In practice, however, it is difficult to elicit a competitor's UF and PWF. Therefore, an effective methodology with which to infer such represents a valuable direction for future research.

5. Conclusions

This study developed a Multi-Criteria Prospect Model for Bidding Decision (BD-MCPM) to help contractors determine whether to submit a bid and, when the answer is in the affirmative, set an optimal markup scale. Research contributions include:

1. Identification of ten and eight key influencing factors used by contractors in Vietnam to make decisions, respectively, on bid/no bid and mark-up scales using literature review and questionnaire survey techniques.

2. Introduction of a new Multi-Criteria Prospect Model for Bidding Decision (BD-MCPM), which combines fuzzy preference relations (FPR), cumulative prospect theory (CPT), and Multi-Criteria Prospect Model (MCPM). The BD-MCPM is a systematic bidding model designed to help construction companies make strategic bid / no bid decisions and to determine the optimal markup scale for each project bid.

3. FPR using only a small number of expert input variables provides consistency in fuzzy preference relations that simplifies the process of evaluating relative factor weights to deciding bid/no bid phase and forecast probability project win for specific mark-up size. Moreover, applying FPR to evaluation and forecasting can connote the characteristic of evaluator's "experience" and "guesswork".

4. CPT evaluates the primary decision maker's risk prospects in terms of utility functions and probability weighting functions. CPT calculates preference values for assigned mark-up scales and probability of a project win based on prior forecasts. It further selects the mark-up scale delivering the optimal preference value so that the decision maker can make an optimal decision that takes into account the PDM's intuition.

5. The study validated the BD-MCPM using actual bidding projects obtained from construction companies in Vietnam and successfully helping the PDM to select cases on which to bid and to set optimal markup scale.

References

Abdellaoui, M. 2000. Parameter-free elicitation of utility and probability weighting functions, *Management Science* 46(11): 1497–1512. doi:10.1287/mnsc.46.11.1497.12080

Abdellaoui, M.; Vossmann, F.; Weber, M. 2005. Choice-based elicitation and decomposition of decision weights for gains and losses under uncertainty, *Management Science* 51(9): 1384–1399. doi:10.1287/mnsc.1050.0388

Ahmad, I. 1990. Decision support system for modeling bid/no bid decision problem, *Journal of Construction Engineering and Management* ASCE 116(4): 595–608. doi:10.1061/(ASCE)0733-9364(1990)116:4(595)

Ahmad, I.; Minkarah, I. 1988. An expert system for selecting bid markups, in *Proc. of the Fifth Conference on Computing in Civil Engineering: Microcomputers to Supercomputers* ASCE, 229–238.

Bleichrodt, H.; Pinto, J. L. 2000. A parameter-free elicitation of the probability weighting function in medical decision analysis, *Management Science* 46(11): 1485–1496. doi:10.1287/mnsc.46.11.1485.12086

Cagno, E.; Caron, F.; Perego, A. 2001. Multi-criteria assessment of the probability of winning in the competitive bidding process, *International Journal of Project Management* 19(6): 313–324. doi:10.1016/S0263-7863(00)00020-X

Camerer, C. F.; Ho, T.-H. 1994. Violations of the betweenness axiom and nonlinearity in probability, *Journal of Risk and Uncertainty* 8(2): 167–196. doi:10.1007/BF01065371

Carr, R. I. 1982. General bidding model, *Journal of the Construction Division* ASCE 108 (4): 639–650.

Chiclana, F.; Herrera, F.; Herrera-Viedma, E. 1998. Integrating three representation models in fuzzy multipurpose decision making based on fuzzy preference relations, *Fuzzy Sets and Systems* 97(1): 33–48. doi:10.1016/S0165-0114(96)00339-9

Chiclana, F.; Herrera, F.; Herrera-Viedma, E. 2001. Integrating multiplicative preference relations in a multipurpose decision-making model based on fuzzy preference relations, *Fuzzy Sets and Systems* 122(2): 277–291. doi:10.1016/S0165-0114(00)00004-X

Chiclana, F.; Herrera, F.; Herrera-Viedma, E.; Martínez, L. 2003. A note on the reciprocity in the aggregation of fuzzy preference relations using OWA operators, *Fuzzy Sets and Systems* 137(1): 71–83. doi:10.1016/S0165-0114(02)00433-5

Chua, D. K. H.; Li, D. 2000. Key factors in bid reasoning model, *Journal of Construction Engineering and Management* ASCE 126(5): 349–357. doi:10.1061/(ASCE)0733-9364(2000)126:5(349)

Chua, D. K. H.; Li, D. Z.; Chan, W. T. 2001. Case-based reasoning approach in bid decision making, *Journal of Construction Engineering and Management* ASCE 127(1): 35–45. doi:10.1061/(ASCE)0733-9364(2001)127:1(35)

Cooke, B. 1992. *Contract Planning and Contractual Procedures*. 3rd Ed. Palgrave Macmillan. 259 p.

Cook, P. J. 1985. *Bidding for the General Contractor*, Kingston, Mass.: R. S. Means. 224 p.

Dias, W. P. S.; Weerasinghe, R. L. D. 1996. Artificial neural network for construction bid decisions, *Civil Engineering and Environmental Systems* 13(3): 239–253. doi:10.1080/02630259608970200

Dikmen, I.; Birgonul, M. T.; Gur, A. K. 2007. A case-based decision support tool for bid mark-up estimation of international construction projects, *Automation in Construction* 17(1): 30–44. doi:10.1016/j.autcon.2007.02.009

Dozzi, S. P.; AbouRizk, S. M.; Schroeder, S. L. 1996. Utility theory model for bid markup decisions, *Journal of Construction Engineering and Management* ASCE 122(2): 119–124. doi:10.1061/(ASCE)0733-9364(1996)122:2(119)

Dulaimi, M. F.; Shah, H. G. 2002. The factors influencing bid markup decisions of large- and medium-size contractors in Singapore, *Construction Management and Economics* 20(7): 601–610. doi:10.1080/01446190210159890

Egemen, M.; Mohamed, A. 2008. SCBMD: A knowledge-based system software for strategically correct bid/no bid and mark-up size decisions, *Automation in Construction* 17(7): 864–872. doi:10.1016/j.autcon.2008.02.013

Eldukair, Z. A. 1990. Fuzzy decisions in bidding strategies, in *Proc. of the First International Symposium on Uncertainty Modeling and Analysis*, Maryland, USA, 3–5 December, 1990, 591–594.

Fan, Z.-P.; Ma, J.; Zhang, Q. 2002. An approach to multiple attribute decision making based on fuzzy preference information on alternatives, *Fuzzy Sets and Systems* 131(1): 101–106. doi:10.1016/S0165-0114(01)00258-5

Fayek, A. 1998. Competitive bidding strategy model and software system for bid preparation, *Journal of Construction Engineering and Management* ASCE 124(1): 1–10. doi:10.1061/(ASCE)0733-9364(1998)124:1(1)

Friedman, L. 1956. A Competitive Bidding Strategy, *Operations Research* 4(1): 104–112. doi:10.1287/opre.4.1.104

Gates, M. 1967. Bidding strategy and probabilities, *Journal of the Construction Division, Proceedings of the American Society of Civil Engineers* 93 (CO1): 75–107.

Gonzalez, R.; Wu, G. 1999. On the shape of the probability weighting function, *Cognitive Psychology* 38(1): 129–166. doi:10.1006/cogp.1998.0710

Han, S. H.; Diekmann, J. E. 2001. Making a risk-based bid decision for overseas construction projects, *Construction Management and Economics* 19(8): 765–776. doi:10.1080/01446190110072860

Hegazy, T.; Moselhi, O. 1994. Analogy-based solution to markup estimation problem, *Journal of Computing in Civil Engineering* ASCE 8(1): 72–87. doi:10.1061/(ASCE)0887-3801(1994)8:1(72)

Hegazy, T.; Moselhi, O. 1995. Elements of cost estimation: A survey in Canada and the United States, *Cost Engineering* 37(5): 27–33.

Herrera-Viedma, E.; Herrera, F.; Chiclana, F.; Luque, M. 2004. Some issues on consistency of fuzzy preference relations, *European Journal of Operational Research* 154(1): 98–109. doi:10.1016/S0377-2217(02)00725-7

Kacprzyk, J. 1986. Group decision making with a fuzzy linguistic majority, *Fuzzy Sets and Systems* 18(2): 105–118. doi:10.1016/0165-0114(86)90014-X

Lai, K. K.; Liu, S. L.; Wang, S. 2002. Bid Markup Selection Models by Use of Multiple Criteria, *IEEE Transactions on Engineering Management* 49(2): 155–160. doi:10.1109/TEM.2002.1010883

Lewis, H. 2003. *Bids, tenders & proposals: Writing business through best practice*. London, Sterling, VA: Kogan Page Ltd. 276 p.

Li, H. 1996. Neural network models for intelligent support of markup estimation, *Engineering, Construction and Architectural Management* 3(1/2): 69–81. doi:10.1108/eb021023

Li, H.; Love, P. E. D. 1999. Combining rule-based expert systems and artificial neural networks for mark-up estimation, *Construction Management and Economics* 17(2): 169–176. doi:10.1080/014461999371664

Li, H.; Shen, L. Y., Love, P. E. D. 1999. Ann-based mark-up estimation system with self-explanatory capacities, *Journal of Construction Engineering and Management* ASCE 125 (3): 185–189. doi:10.1061/(ASCE)0733-9364(1999)125:3(185)

Lin, C.-T.; Chen, Y.-T. 2004. Bid/no-bid decision-making – a fuzzy linguistic approach, *International Journal of Project Management* 22(7): 585–593. doi:10.1016/j.ijproman.2004.01.005

Marsh, P. D. V. 1989. *Successful bidding and tendering*, England: Wildwood House. 171 p.

Moselhi, O.; Hegazy, T.; Fazio, P. 1993. DBID: Analogy-based DSS for bidding in construction, *Journal of Construction Engineering and Management* 119(3): 466–479. doi:10.1061/(ASCE)0733-9364(1993)119:3(466).

Nurmi, H. 1981. Approaches to collective decision making with fuzzy preference relations, *Fuzzy Sets and Systems* 6(3): 249–259. doi:10.1016/0165-0114(81)90003-8

Odusote, O. O.; Fellows, R. F. 1992. An examination of the importance of resource considerations when contractors make project selection decisions, *Construction Management and Economics* 10(2): 137–151. doi:10.1080/01446199200000013

Orlovsky, S. A. 1978. Decision-making with a fuzzy preference relation, *Fuzzy Sets and Systems* 1(3): 155–167. doi:10.1016/0165-0114(78)90001-5

Saaty, T. L. 1980. *The Analytic Hierarchy Process*. McGraw-Hill, New York. 287 p.

Saaty, T. L. 1994. *Fundamentals of Decision Making and Priority Theory with the AHP*. RWS Publications, Pittsburgh. 447 p.

Seydel, J.; Olson, D. L. 1990. Bids considering multiple criteria, *Journal of Construction Engineering and Management* ASCE 116(4): 609–623. doi:10.1061/(ASCE)0733-9364(1990)116:4(609)

Shash, A. A. 1993. Factors considered in tendering decisions by top UK contractors, *Construction Management and Economics* 11(2): 111–118.

Shash, A. A. 1995. Competitive bidding system, *Cost Engineering* 37(2): 19–20. doi:10.1080/01446199300000004

Shash, A. A.; Abdul-Hadi, N. H. 1992. Factors affecting a contractor's markup size decision in Saudi Arabia, *Construction Management and Economics* 10(5): 415–429. doi:10.1080/01446199200000039

Skitmore, R. M. 1985. *The influence of professional expertise in construction price forecasts*. Department of Civil Engineering, University of Salford, UK. 250 p.

Tanino, T.; 1984. Fuzzy preference orderings in group decision making, *Fuzzy Sets and Systems* 12(2): 117–131. doi:10.1016/0165-0114(84)90032-0

Tavakoli, A.; Utomo, J. L. 1989. Bid markup assistant: An expert system, *Cost Engineering* 31(6): 28–33.

Tversky, A.; Fox, C. R. 1995. Weighing risk and uncertainty, *Psychological Review* 102(2): 269–283. doi:10.1037/0033-295X.102.2.269

Tversky, A.; Kahneman, D. 1992. Advances in prospect theory: Cumulative representation of uncertainty, *Journal of Risk Uncertainty* 5(4): 297–323. doi:10.1007/BF00122574

Wakker, P.; Deneffe, D. 1996. Eliciting von Neumann-Morgenstern utilities when probabilities are distorted or unknown, *Management Science* 42(8): 1131–1150. doi:10.1287/mnsc.42.8.1131

Wang, T.-C.; Chang, T.-H. 2007. Forecasting the probability of successful knowledge management by consistent fuzzy preference relations, *Expert Systems with Applications* 32(3): 801–813. doi:10.1016/j.eswa.2006.01.021

Wanous, M.; Boussabaine, A. H.; Lewis, L. 2000. To bid or not to bid: a parametric solution, *Construction Management and Economics* 18(4): 457–466. doi:10.1080/01446190050024879

Wanous, M.; Boussabaine, A. H.; Lewis, J. 2003. A neural network bid/no bid model: the case for contractors in Syria, *Construction Management and Economics* 21(7): 737–744. doi:10.1080/0144619032000093323

Wu, G.; Gonzalez, R. 1996. Curvature of the probability weighting function, *Management Science* 42(12): 1676–1690. doi:10.1287/mnsc.42.12.1676

Xu, Z. S.; Da, Q. L. 2002. The uncertain OWA operator, *International Journal of Intelligent Systems* 17(6): 569–575. doi:10.1002/int.10038

Xu, Z.; Da, Q. 2005. A least deviation method to obtain a priority vector of a fuzzy preference relation, *European Journal of Operational Research* 164(1): 206–216. doi:10.1016/j.ejor.2003.11.013

STATYBOS ĮMONĖS APSISPRENDIMAS DALYVAUTI KONKURSE NAUDOJANT DAUGIAKRITERINĮ PERSPEKTYVŲ MODELĮ

M.-Y. Cheng, C.-C. Hsiang, H.-C. Tsai, H.-L. Do

Santrauka

Ketinantiems dalyvauti konkurse reikia priimti du lemiamus sprendimus: ar teikti pasiūlymą ir kokį antkainį nurodyti pasiūlyme. Statybų sektoriuje valstybės įstaigos ir klientai iš privačiojo sektoriaus paprastai konkursus skelbia siekdami išrinkti laimėtoją, su kuriuo pasirašoma sutartis. Rangovai sprendimus dalyvauti konkurse vertina taip pat. Rangovų apsisprendimą dalyvauti konkurse ir pasirinktą antkainį lemia ne vienas kintamasis, ir tai apsunkina apsisprendimo dalyvauti konkurse procesą. Šiame tyrime pristatomas daugiakriterinis perspektyvų modelis apsisprendimui dalyvauti konkurse (BD-MCPM), kuris rangovams padės apsispręsti, ar dalyvauti konkurse ir kokį antkainį pasirinkti. Pirmiausia buvo nustatyti pagrindiniai veiksniai, kurie daro įtaką apsisprendimui dalyvauti konkurse. Po to, naudojant neraiškiuosius prioritetinius ryšius (angl. *Fuzzy Preference Relations*, FPR), buvo įvertinti veiksnių reikšmingumai ir nustatyta, dalyvauti ar nedalyvauti konkurse. Pagaliau, jeigu nusprendžiama dalyvauti konkurse, naudojant daugiakriterinį perspektyvų modelį (MCPM), kuris neraiškiuosius prioritetinius ryšius susieja su kaupiamąja perspektyvos teorija (angl. *Cumulative Prospect Theory*, CPT), nustatomas antkainio lygis, kuris labiausiai atitinka pagrindinio sprendimus priimančio asmens pageidavimus. Praktinis šio modelio naudingumas pademonstruotas atliekant atvejo tyrimą.

Reikšminiai žodžiai: apsisprendimas dalyvauti arba nedalyvauti konkurse, antkainio lygis, pasiūlymų teikimo strategija, daugiakriterinis perspektyvų modelis, kaupiamoji perspektyvos teorija, neraiškieji prioritetiniai ryšiai.

Min-Yuan CHENG. Professor in Department of Construction Engineering at National Taiwan University of Science and Technology (NTUST), Taiwan. He is a Board of Directors member of International Association for Automation and Robotics in Construction (IAARC). His research interests include geographic information system, construction automation and e-business, management information system, business process reengineering, artificial intelligence, knowledge management, and their applications.

Chia-Chi HSIANG. Lecturer in Department of Civil Engineering at Chung Yuan Christian University (CYCU), Taiwan. He is a Ph.D. candidate in Department of Construction Engineering at National Taiwan University of Science and Technology, Taiwan. His research interests include prospect theory, fuzzy theory, game theory, construction management, and bidding strategy.

Hsing-Chih TSAI. Assistant professor at National Taiwan University of Science and Technology, Taiwan. His research interests include computational mechanics, swarm intelligence, construction management, RFID Application, high-order neural networks, and soft programming engineering.

Hoang-Linh DO. He received his master's degree in Department of Construction Engineering, National Taiwan University of Science and Technology in 2008. His research interests include prospect theory, fuzzy theory, and bidding strategy.