Bid Decision Making with Prospect Game Theory

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Purpose This study proposes a new bidding decision model (Prospect Game Theory Model for Bidding Decision, BD-PGTM) for construction companies to set optimal bidding prices. **Method** This study has successfully integrated fuzzy preference relations (FPR) with fuzzy rating (FR), cumulative prospect theory (CPT) and game theory (GT). FPR was employed to forecast implementation probability for bidding strategies, and to simplify and overcome traditional reliance on evaluator experience in prediction. FR was introduced to forecast value functions and probability weight functions of competitor's primary decision maker (PDM), and to solve the problems of inability to elicit competitor's preference functions. CPT was included to calculate the prospect value of all companies' PDM for all bidding strategy combinations. Lastly, GT was used to analyze PDM-determined bidding strategy. The optimal bidding prices derived from the proposed approach will be able to secure both the contract award and be as profitable as possible. **Results & Discussion** This study has verified the proposed BD-PGTM by using actual bidding projects from construction companies in Vietnam. It has also helped PDM to get exact optimal bidding prices.

Keywords: *bidding decision making, cumulative prospect theory, game theory*

INTRODUCTION

A significant amount of construction projects is apply a competitive bidding process, and award the lowest bidding price one which meet the stated specification. Bid price typically includes construction cost and profit, the latter can present as mark-up size multiplied by construction cost. The profit is the primary incentive of winning and executing contracts[11]. The winning contractor must be able to set a mark-up size that secures the contract while sustaining profitable[33]. So in the bidding decision process, after deciding to submit a bid, the bidders must decide what mark-up size to use on the submitted bid[13]. Due to high uncertainty, intense competition, and difficulty in quantifying risks, the process of deciding mark-up size is very complex, which requires simultaneous assessment of a large number of highly interrelated variables to reach a decision. But for the limitations of rational and information process, the decision makers can not consider all relevant variables[10]. In practice, contractors usually make bid decisions in a highly subjective manner that may actually lack a foundation in reason[3]. And the decision is based on a mixture of "guts" feelings, experiences and guesswork[2]. The typically emphasize factors like contractor experience, intuition, and personal preference, which are not conducive to approach standardization[8]. In light of such, there is a practical need for a mark-up size decision-making model to fit the construction company's practices. Early mark-up scale estimation models employed probability theory to predict the probability of winning a particular contract[14]. Recently, expert system[1], case-based reasoning[9], neural network[20], analytical hierarchy process[5], and fuzzy set theory[18] are adopted in bidding decision making. A BD-MCPM model was proposed[7], which combination FPR with CPT to help primary decision maker (PDM) determine which projects should be bid and the optimal mark-up size. This study combined game theory (GT), cumulative prospect theory (CPT), fuzzy preference relations (FPR), and fuzzy ratting to create a new decision model named Prospect Game Theory Decision Model for Bidding Decision (BD-PGTM). This model can help the construction company's PDM to determine the appropriate bidding price in a multi-competitor condition.

LITERATURE REVIEW

Fuzzy Preference Relationships

Many important decision models have been developed which focus mainly on: (1) multiplicative preference relations (MPR) and (2) FPR[17]. In MPR, an expert assigns a value which reflects the degree of preference to each pair of alternatives. For a set of alternatives X is represented by matrix $A=[a_{ij}]\subset X\times X$, $a_{ij}=[1/9,\ 9]$ and $a_{ij}\cdot a_{ji}=1$ for $i,j\in\{1.\ \ldots,\ n\}$. When $a_{ij}=9$ denotes that x_i is preferred absolutely to x_j, and $a_{ij}=1$represents no difference in preference between x_i and x_j. A FPR on a set of alternatives X is represented by a matrix B. Matrix B are a fuzzy set on product set $X\times X$ that is characterized by membership function $\mu_B{:}X\times X\rightarrow[0,1]$. Therefore, in $B=[b_{ij}]$ and $b_{ij}=\mu_B(x_i,\ x_j)$ for $i,j\in\{1,\ \ldots,\ n\}$, where μ_B is a membership function, and b_{ij} is the preference ratio of the alternative x_i over x_j. While b_{ij}=0.5 denotes that x_i and x_j are indifferent, and b_{ij}=1 represents that x_i is preferred absolutely to x_j. Matrix A can be transferred into matrix B by using transform equation $b_{ij}=(1+\log_9 a_{ij})/2$. The relative weights w_i for all alternative i can be obtained by using function $w_i = \sum_j b_{ij} \Big/ \sum_i \sum_j b_{ij}$ .Previous studies[25] have given significant attention to fuzzy preference relations.

Cumulative Prospect Theory

Tversky and Kahneman proposed the CPT to describe individual preferences or subjective consciousness needed to choose among risky prospects[23].

Consider a prospect X with outcomes $x_1 \le \ldots \le x_k \le 0 \le x_{k+1} \le \ldots \le x_n$ that is associated with probabilities $p_1, \ldots, p_n$. Cumulative prospect theory predicts that people will choose prospects based on the prospect value generated by :

$$V_{CPT}(X) = \sum_{i=1}^{k} \pi_i \lambda v(x_i) + \sum_{j=k+1}^{n} \pi_j v(x_j) \cdot$$

Where v(x) is the utility function, λ is a loss-aversion parameter, and π represents decision weights calculated by "cumulative" probabilities p_i associated with outcomes x_i. The function of v(x) is not changed from the original prospect theory[16], show as below:

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

Decision weights employed in CPT are obtained by:

$$\pi_i = \sum_{j=1}^{i} w^{-}(p_j) - \sum_{j=1}^{i-1} w^{-}(p_j),\ 2 \le i \le k$$

and

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

The boundary decision weights are $\pi_1=w^{-}(p_1)$ and $\pi_n=w^{+}(p_n)$. The probability weighting function w^{-} and w^{+} are represented the condition of losses and gains individually. Such may be estimated experimentally by using the following formulae[6, 23, 39] :

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

and

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

CPT was successfully applied for medical decision making[4].

Game theory

GT has been widely used in the social sciences (most notably in economics) as well as in biology, engineering, political science, international relations, computer science, social psychology, philosophy and management. The theory attempts to explain behavior in strategic situations or games mathematically by recognizing that successful decision-making depends on the choices of others[21]. A game consists of a set of players (i.e., decision makers), a set of strategies which are available to those players, and payoffs for each combination of strategies. The players will use strategies to maximize their payoffs, and the winner will receive a positive payoff and others will earn either negative or zero payoffs. A game is considered cooperative or non-cooperative and depends on the binding commitments of players exist or not.

In a normal competitive bidding, there is no binding commitment to all players, and the sum of their payoff (i.e., contract profit) will not be zero. This study adopted a non-zero, non-cooperative game to the bidding game framework and used the Nash equilibrium[22] to seek the solution.

CONSTRUCTING A PROSPECT GAME THEORY MODEL FOR BIDDING DECISION

The flowchart of BD-PGTM is shown in Fig. 1.

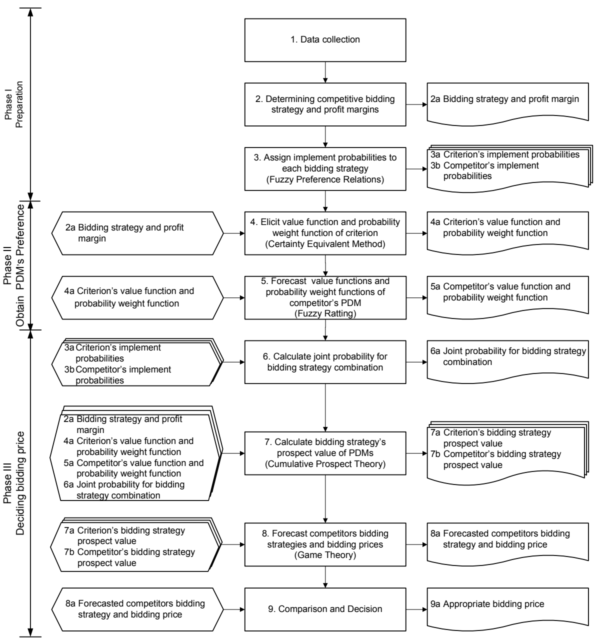

Fig. 1. Flowchart of BD-PGTM

Phase I – Preparation

The aim of phase I is to identify the companies whom may participate the bidding, the type of bidding strategy, submitted bidding price to each bidding strategy and its implement probability.

Data Collection

The BD-PGTM model is applied to case studies to demonstrate the potential effectiveness of the approach in practice. In the case, three companies (A, B, and C) will participate in the competitive bid and submit a bid prices. The decision makers of those companies were considered homogeneous, as all were qualified professionals in the construction field and had prior experience in bidding strategies and bidding procedures. The PDM of each company has decided the company's ultimate bidding price. Company A will use BD-PGTM to forecast what bidding strategies and bidding prices that the competitors may adopted.

Determining competitive bidding strategy and profit margins

The cost estimated by each construction companies may be very similar and the variations in competitors' bids are due mainly to their selected mark-up size[20]. Prior to the forecasting, this study set what bidding strategies and its mark-up size the competitors would potentially adopt. The bidding strategy was classified into five categories[14], include S1: Lowest profit to secure the project; S2: Minimize company profit to strengthen competitiveness; S3: Average construction market profit margin; S4: Higher-than-average profit margin; and S5: highest profit margin. The company A determined the mark-up size for each bidding strategy is 3%, 4%, 5%, 7%, and 10%. In the collected actual case, the construction cost calculated by company A was $17954×10^3$ USD, and the expected profit (unit: 10^3 USD) of each bidding strategy was \$538.62, \$718.16, \$897.70, \$1256.78, and \$1795.40.

Assign implement probabilities to each bidding strategy

In order to assign an implement probability for each bidding strategy to all participants, this study adopted FPR to estimate the relative importance of the bidding strategies to each participant. The linguistic terms used in FPR were AH: Absolutely important, VH: Very highly important, SH: Strongly important, WH: Weakly important, EQ: Equally important, WL: Weakly less important, SL: Strongly less important, VL: Very strongly less important, and AL: Absolutely less important. All of them are associated with real numbers {9, 7, 5, 3, 1, 1/3, 1/5, 1/7, 1/9} to compare to corresponding neighboring factors. Five evaluators of company A adopt foregoing linguistic terms to assess the relative importance of the bidding strategy to company A, B, and C. For example, the assessment of company A were {VL, EQ, WH, SH}, {AL, WL, EQ, AH}, {VL, WL, WH, VH}, {AL, EQ, EQ, AH} and {SL, EQ, WH, AH}, via the computational process[7], relative weights can be calculated as {0.1086, 0.2644, 0.2964, 0.2491, 0.0815}. In the same manner, company A also can forecast the relative weights of bidding strategies to company B and C as {0.1146, 0.2255, 0.3059, 0.2534, 0.1006} and {0.2648, 0.3007, 0.2183, 0.1441, 0.0721}. Table1. shows the forecasted results.

Bidding strategy	Profit ($ $\times 10^3$USD)	Probability of implementation (%)		
		Company A	Company B	Company C
S1	538.62	10.86	11.46	26.48
S2	718.16	26.44	22.55	30.07
S3	897.70	29.64	30.59	21.83
S4	1256.78	24.91	25.34	14.41
S5	1795.40	8.15	10.06	7.21

Table 1. Forecasted results of company A's PDM

This study assumes that the relative weight of a bidding strategy is correlated to probability of implementation.

Phase II – Obtain PDM's preference

Goals of this section are to elicit the value function and probability weighting function of the "criterion" (Company A) to forecast the value function and probability weighting function of competitors (Company B and C).

Elicit value function and probability weighting function of criterion

This certainty equivalent method[15,23] is used to elicit the value function and probability weighting function of company A's PDM. In the method, a two outcomes (win and lose) prospect may be expressed as [*x*, *p*; 0, 1-*p*], with "*x*" representing gain of win and "*p*" representing the objective probability of win. The subjects (PDM of company A) will be asked to provide a certain value $y(x, p)$, in which $y(x, p)$~[x, p; 0, 1-p]. It is difficulties for the subject to directly assessing the value of y [24], this study using the bisection method[12,24] to assess the value. Table 2 shows elicited results for Company A's PDM.

$y(x,p)$ $\times 10^3$		p (%)				
		10	25	50	75	90
x (\$USD) $\times 10^3$	100	14	32	39	67	86
	250	25	84	99	107	213
	500	48	166	170	170	400
	1000	103	377	298	634	791
	2000	201	568	900	1291	1666
	4000	400	1334	1667	2666	3334

Table 2. Elicited results of company A's PDM

For only two gain outcomes' prospect [x_1, p_1; x_2, p_2], $V_{CPT}(X)$ will transform into:

$$V_{CPT}\left[x_1,p_1;\ x_2,p_2\right]=\pi_1^+\cdot v\left(x_1\right)+\pi_2^+\cdot v\left(x_2\right)$$

Substitute x, p and $y(x, p)$ into above equation and three known conditions $w^+(p=0)=0$, $w^+(p=1)=1$ and $v(x=0)=0$, then will get :

$$w^+\left(p\right)\times v\left(x\right)=v\left(y\left(x,\ p\right)\right)$$

Substitute the value function and probability weighting function in gain condition into above equation, then adopt regression analysis to obtain α=0.8932 and γ=0.7484. Fig. 3 shows the elicited value function and probable weight function of company A's PDM.

Forecast competitor's value function and probability weighting function

The competitive situation of contract bids makes it impossible to obtain value functions and probability weighting functions directly from competitor PDMs. This study assumes the PDM's value functions and probability weighting functions will also adhere to the form proposed by Tversky and Kahneman[23]. Owing to the value function and probability weighting functions for company A's PDM are known, this study employed fuzzy rating method to evaluate the differences ratio in emphasis on money and risk attitudes between two companies' (competitor and company A) PDM to forecast competitors' value functions and probability weighting function. In consider the evaluator's rating cognition, this study first adopt five linguist variables {VL: Very low, L: Low, I: Indifference, H: High, VH: Very high} to evaluate the difference rate from -20% to 20%. This study employ a questionnaire to survey evaluators and use the fuzzy statistic analysis method[6] to obtain a fuzzy number membership function, Fig. 2 shows the results.

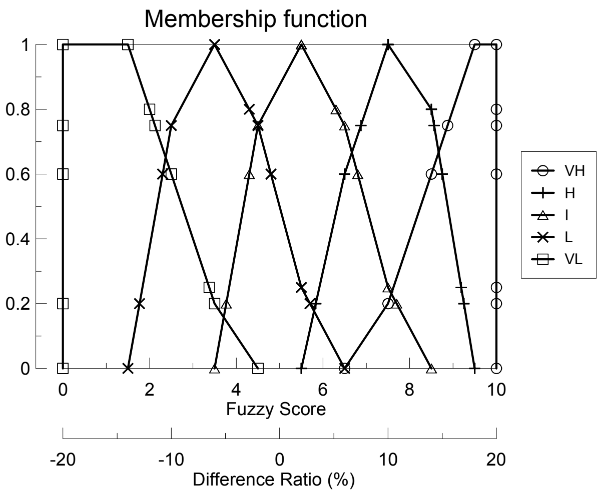

Fig. 2. Membership function for fuzzy rating

To forecast value function, the evaluators adopt linguistic variables to evaluate the difference ratio in the emphasis on money between competitor's and company A's PDM. Then apply fuzzy number's addition operator and multiplication operator[17] to calculate the integrated fuzzy numbers. Next, use the center of gravity method to defuzzify the integrated fuzzy numbers and the linear conversion to obtain the difference ratio in the emphasis on money. The area under the value function curve was obtain by integration the amount of money (x-axis) and the value of money (y-axis), which can represent the attitude of emphasis on money within a specific monetary range. If a competitor's PDM places more emphasis on money than the criterion, then the area below the value function curve will be comparatively larger. Otherwise the area below the value function curve will be comparatively smaller. The difference in the area can be regarded as the difference in emphasis on money. In Fig. 3 the figure on the left shows the concept of forecast competitor's value function. For example, company A's five evaluators compare the PDM of company B with the PDM of company A, the evaluated results are {H, I, L, I, VH}. Through the defuzzification process, a fuzzy rating was obtained as 6.3090; by the way of linear transformation method can obtained a difference rate of 5.24%. As the area under the value function curve of company A's PDM was 27113823, the corresponding area of company B's PDM should be 27113822×(1+5.24%)=28533484. A trial and error procedure then obtained the parameter α of value function was 0.8958. In the same manner can forecast the value function of company C's PDM, and the parameter α=0.8857. In Fig. 3 the figure on the right shows the forecasted value function of PDMs'.

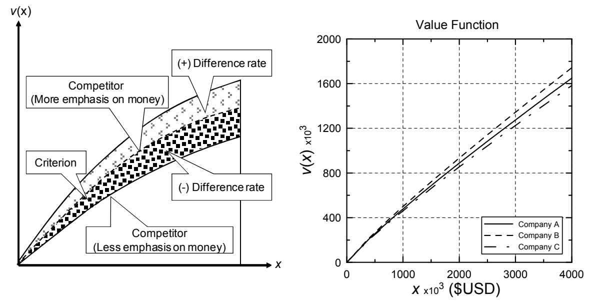

Fig. 3. Concept of forecast competitor PDM's value function and forecasted result

In CPT, the probability weighting function is an inverse-S-curve. The intersection point between the probability weighting function and riskless line ($w(p)=p$) is called the point of risk neutral (PRN). The shape of the probability weighting function on the left side of PRN is convex-down, which over-weights the probability $w(p)\geq p$. On the contrary, the shape of the probability weighting function on the right side of PRN is concave-up, with an underweighted probability $w(p)\leq p$. If risk attitude is more risk seeking than the criterion, the overweighting range will be widened and the PRN will move right. A risk attitude with less risk averse than the criterion will cause the PRN to move left. In Fig. 4 the figure on the left shows the concept of forecast competitor's probability weighting function. This study use the same fuzzy rating process to evaluate the difference ratio of risk attitude in risk seeking between competitor's and company A's PDM. For example, company A's five evaluators adopted the linguistic variables to compare the company B's PDM with the company A's PDM, the evaluated results are {L, I, L, I, VL}. Via the processes of calculating the integrated fuzzy numbers, defuzzification, and linear transformation, obtained evaluator fuzzy ratings of difference rate in risk attitude is 6.76%. The probability of PRN for the probability weighting function of company A's PDM is 0.4043. Thus, the probability of PRN for company

B's PDM should move to 0.4043×(1+6.76%)=0.4309. Trial and error procedure was then used to obtain the parameter γ of probability weighting function is 0.8139. In the same manner, can obtain γ=0.7283 for company C's PDM. In Fig. 4 the figure on the right shows the forecasted probability weighting function of PDMs'.

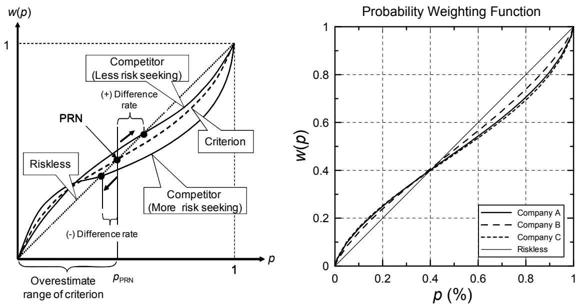

Fig. 4. Concept of forecast the competitor PDM's probability weighting function and forecasted result

Phase III – Deciding bidding price

Bidder takes the presumed strategies of competitor bidders into consideration before formulating a bid strategy and setting a bid price. This study adopts non-cooperative games to describe the analysis process and use the prospect value of each bidding strategy to represent game payoffs.

Calculate joint probability for bidding strategy combination

In competitive bidding, the bidder can adopt different bidding strategy and form bidding strategy combination. The probability of the combination achieving can be represented by the joint probability of PDMs adopted strategy. For example, the probability of companies A, B and C all adopt bidding strategy S1, the probability for this situation occurred can be calculated as 10.86%x11.46%x26.48%=0.33%. Table 3 shows the probability of implementation for various bidding strategy combinations.

Company A: S_1 10.86 (%)

P_{joint} (%), Company B \ Company C	S_1 26.48 (%)	S_2 30.07 (%)	S_3 21.83 (%)	S_4 14.41 (%)	S_5 7.21 (%)
S_1 11.46 (%)	0.33	0.37	0.27	0.18	0.09
S_2 22.55 (%)	0.65	0.74	0.53	0.35	0.18
S_3 30.59 (%)	0.88	1.00	0.73	0.48	0.24
S_4 25.34 (%)	0.73	0.83	0.60	0.40	0.20
S_5 10.06 (%)	0.29	0.33	0.24	0.16	0.08

Company A: S_2 26.44 (%)

P_{joint} (%), Company B \ Company C	S_1 26.48 (%)	S_2 30.07 (%)	S_3 21.83 (%)	S_4 14.41 (%)	S_5 7.21 (%)
S_1 11.46 (%)	0.80	0.91	0.66	0.44	0.22
S_2 22.55 (%)	1.58	1.79	1.30	0.86	0.43
S_3 30.59 (%)	2.14	2.43	1.77	1.17	0.58
S_4 25.34 (%)	1.77	2.02	1.46	0.97	0.48
S_5 10.06 (%)	0.70	0.80	0.58	0.38	0.19

Company A: S_3 29.64 (%)

P_{joint} (%), Company B \ Company C	S_1 26.48 (%)	S_2 30.07 (%)	S_3 21.83 (%)	S_4 14.41 (%)	S_5 7.21 (%)
S_1 11.46 (%)	0.90	1.02	0.74	0.49	0.24
S_2 22.55 (%)	1.77	2.01	1.46	0.96	0.48
S_3 30.59 (%)	2.40	2.73	1.98	1.31	0.65
S_4 25.34 (%)	1.99	2.26	1.64	1.08	0.54
S_5 10.06 (%)	0.79	0.90	0.65	0.43	0.22

Company A: S_4 24.91 (%)

P_{joint} (%), Company B \ Company C	S_1 26.48 (%)	S_2 30.07 (%)	S_3 21.83 (%)	S_4 14.41 (%)	S_5 7.21 (%)
S_1 11.46 (%)	0.76	0.86	0.62	0.41	0.21
S_2 22.55 (%)	1.49	1.69	1.23	0.81	0.41
S_3 30.59 (%)	2.02	2.29	1.66	1.10	0.55
S_4 25.34 (%)	1.67	1.90	1.38	0.91	0.46
S_5 10.06 (%)	0.66	0.75	0.55	0.36	0.18

Company A: S_5 8.15 (%)

P_{joint} (%), Company B \ Company C	S_1 26.48 (%)	S_2 30.07 (%)	S_3 21.83 (%)	S_4 14.41 (%)	S_5 7.21 (%)
S_1 11.46 (%)	0.25	0.28	0.20	0.13	0.07
S_2 22.55 (%)	0.49	0.55	0.40	0.26	0.13
S_3 30.59 (%)	0.66	0.75	0.54	0.36	0.18
S_4 25.34 (%)	0.55	0.62	0.45	0.30	0.15
S_5 10.06 (%)	0.22	0.25	0.18	0.12	0.06

Table 3. Joint probability of bidding strategy combinations

Calculate PDM's prospect value of bidding strategy

The prospect value V_{CPT} for a bidding strategy which the PDM adopted can obtain by prospect value equation. In the equation, the $v(x)$ and $w^{+}(p)$ stand for the PDM's value function and probability weighting function. The x is the expected profit of adopted bidding strategy, while p is the joint probability of bidding strategy combination. Both values are elicited and forecasted in the previous section, and shows in Table 1 and Table 2. For example, the joint probability is 0.33% for the PDMs of companies A, B, and C all select bidding strategy S1. Under such a scenario, a company will earn an estimated profit of 538.62×10^{3} if it wins the bid or 0 if it loses. The prospect values of PDM of Company A, B, and C are 3.8×10^{3}, 2.7×10^{3}, and 4.1×10^{3}. Table 4 shows the normal form of bidding game. The first entry in each cell is company A's prospect value V_{CPT} for the corresponding strategy combination, the second is company B's, and the third is company C's.

A's V_{CPT} / B's V_{CPT} / C's V_{CPT} ($\times10^{3}$); Company A: S1

Company B \ Company C	S1	S2	S3	S4	S5
S1	3.8 2.7 4.1	4.1 2.9 5.8	3.3 2.3 5.6	2.4 1.6 5.6	1.4 0.9 4.7
S2	6.2 5.9 6.6	6.8 6.6 9.3	5.4 5.1 9.1	4.0 3.6 9.1	2.4 2.1 7.6
S3	7.7 9.2 8.2	8.5 10.2 11.6	6.7 7.9 11.3	5.0 5.7 11.3	3.0 3.2 9.5
S4	6.7 10.7 7.2	7.4 11.9 10.2	5.9 9.2 9.9	4.3 6.6 9.9	2.6 3.8 8.3
S5	3.4 7.0 3.7	3.8 7.8 5.3	3.0 6.0 5.1	2.2 4.3 5.1	1.3 2.5 4.2

Company A: S2

Company B \ Company C	S1	S2	S3	S4	S5
S1	9.4 5.4 7.7	10.3 6.0 10.9	8.1 4.7 10.6	6.0 3.3 10.6	3.6 1.9 8.9
S2	15.3 12.1 12.4	16.7 13.3 17.4	13.3 10.3 17.0	9.8 7.4 17.1	5.9 4.3 14.4
S3	19.0 18.8 15.3	20.8 20.7 21.5	16.6 16.1 21.0	12.3 11.6 21.2	7.4 6.6 17.9
S4	16.6 21.8 13.4	18.2 24.2 18.9	14.5 18.7 18.5	10.7 13.4 18.6	6.5 7.7 15.6
S5	8.5 14.4 7.0	9.3 15.9 9.9	7.4 12.3 9.6	5.4 8.8 9.7	3.3 5.0 8.1

Company A: S3

Company B \ Company C	S1	S2	S3	S4	S5
S1	12.4 5.9 8.3	13.6 6.6 11.8	10.8 5.1 11.4	8.0 3.7 11.5	4.8 2.1 9.6
S2	20.2 13.2 13.4	22.2 14.6 18.9	17.6 11.3 18.4	13.0 8.1 18.6	7.9 4.7 15.6
S3	25.2 20.5 16.5	27.6 22.7 23.3	21.9 17.6 22.8	16.3 12.7 23.0	9.8 7.3 19.4
S4	22.0 23.9 14.5	24.1 26.4 20.5	19.2 20.5 20.0	14.2 14.7 20.2	8.6 8.5 17.0
S5	11.3 15.7 7.6	12.4 17.4 10.7	9.8 13.5 10.4	7.2 9.7 10.5	4.3 5.5 8.8

Company A: S4

Company B \ Company C	S1	S2	S3	S4	S5
S1	14.8 5.2 7.4	16.2 5.7 10.4	12.8 4.4 10.1	9.5 3.2 10.2	5.7 1.8 8.5
S2	24.1 11.5 11.9	26.4 12.7 16.7	21.0 9.9 16.3	15.5 7.1 16.4	9.3 4.1 13.8
S3	30.0 17.9 14.7	32.9 19.8 20.7	26.2 15.3 20.2	19.4 11.0 20.4	11.7 6.3 17.1
S4	26.2 20.8 12.9	**28.8** **23.0** **18.1**	22.8 17.9 17.7	16.9 12.8 17.8	10.2 7.4 15.0
S5	13.4 13.7 6.7	14.7 15.2 9.5	11.7 11.7 9.2	8.6 8.4 9.3	5.2 4.8 7.7

Company A: S5

Company B \ Company C	S1	S2	S3	S4	S5
S1	8.9 2.1 3.3	9.8 2.3 4.7	7.7 1.8 4.6	5.7 1.3 4.6	3.4 0.7 3.8
S2	14.7 4.7 5.4	16.1 5.2 7.6	12.8 4.0 7.4	9.4 2.9 7.4	5.6 1.6 6.2
S3	18.4 7.3 6.7	20.2 8.1 9.5	16.0 6.3 9.2	11.8 4.5 9.2	7.1 2.6 7.7
S4	16.0 8.5 5.9	17.6 9.4 8.3	13.9 7.3 8.0	10.2 5.2 8.1	6.1 3.0 6.7
S5	8.1 5.6 3.0	8.9 6.2 4.3	7.0 4.8 4.2	5.2 3.4 4.1	3.1 1.9 3.5

Table 4. Normal form of bidding game

Forecast competitors bidding strategies and bid prices

This study use the static non-cooperative game to forecast the PDMs adopted bidding strategies and bidding prices. The pay-off of games is the PDM's prospect value of bidding strategies, which were calculated in last section. This study adopted best-response analysis method[19] to find the Nash equilibriums. In Table 4, the payoff set in bold face type is the Nash equilibrium. From the results of the game, this study forecast that companies A, B, and C would adopt bidding strategies S4, S4, and S2, respectively.

Comparison and Decision Making

Forecast results shows that company C's bidding price was the lowest. Therefore, if company A wants to win the project, it should submit a bidding price lower than 18672160($USD).

Conclusions

This study develops a Prospect Game Theory Model for Bidding Decision (BD-PGTM) to help construction companies determine appropriate bidding prices. Research contributions include:

1. BD-PGTM integrates fuzzy rating, fuzzy preference relations (FPR), cumulative prospect theory (CPT) and game theory (GT), provide construction companies a systematic decision model to help them make optimal bidding strategy decisions and set appropriate bidding prices.
2. Use FPR to simplified the process of forecasting implementation probability for bidding strategies

and overcome traditional reliance on evaluator experience and guesswork.

3. Adopt fuzzy rating to forecast value functions and probability weighting functions of competitor PDMs, which may reduce inherent uncertainty in evaluator ratings and also eliminate the predicament of being unable to obtain value functions and probability weighting functions directly from competitor PDMs.
4. Use CPT to calculate PDMs' preference values in terms of value functions and probability weighting functions for assigned mark-up scales and implemented bidding strategy probabilities based on prior forecasts.
5. Adopt Game Theory to analyze PDM-determined bidding strategy. Analysis's results allow Company A to set an optimal bidding price able to secure both the contract award and as high a profit as possible.
6. This study validated the BD-PGTM using actual bidding projects obtained from construction companies in Vietnam and successfully helped the PDM to decide on optimal bidding prices.

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