

Research on Decision-Making Method of Bid Evaluation for Engineering Projects Based on Fuzzy DEA and Grey Relation

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Abstract: At present, bid evaluation in China mainly adopts the method of traditional comprehensive scoring. And the method of analytic hierarchy process or fuzzy synthetic assessment is also in common use. However, those methods have their own weaknesses, *e.g.*, having a strong subjectivity, lacking in analysis of quantitative indicators, and being unable to reflect the defects of the bidders and reasons for ineffectiveness, etc. This paper integrated fuzzy theory, data envelopment analysis (DEA) and grey relational analysis and proposed a systematic decision-making method of bid evaluation based on fuzzy DEA and grey relation for choosing proper bidders. For qualitative indicators, the method took matrix of optimal objective function values as matrix of qualitative indicator values by constructing C^2R model on basis of membership matrix; for quantitative indicators, the method took matrix of correlative coefficients as matrix of quantitative indicator values by using the grey system theory. At last, this paper introduced a case study to confirm the rationality and feasibility of the decision-making method of bid evaluation, being valuable and helpful for assessment applications in other areas.

Keywords: Bid evaluation, engineering projects, fuzzy DEA, grey relation.

1. INTRODUCTION

As the development of China's construction project bidding system, a growing number of projects tend to determine the contractor through bidding. Therefore bid evaluation methods become a main concern. Bid evaluation is the core of the bidding, and the premise and indispensable step of scientific decision, which is an essential part of bidding. To some degree, scientificity and reasonability of the assessment method is of great significance in bidding and directly related to the success or failure of the entire bidding activity. Following the principles of scientificity, rationality, fairness, openness and impartiality, on the premise of satisfying the substantive requirements of the tender documents as well as possible, bid evaluation should conduct a full assessment of all aspects of the bidders, including quotation, schedule, quality, consumption of main material, plan of construction technology, performance, reputation, and preferential terms, etc. Instead of merely following the principle of the lowest price, bidding is a multi-attribute decision-making activity in essence.

Since bidding started quite late in China, its actual operation still faces many problems, especially in the aspects of bid evaluation method lacking research in theory and lacking experience in practice. Therefore, it is of great theoretic and realistic significance to study bid evaluation methods for engineering projects and establish a scientific, practical and feasible assessment model. At present, bid evaluation in China mainly adopts the method of traditional comprehensive

scoring [1, 2]. However this method does not have a rigorous mathematical reasoning, and relying on the subjective estimation of the experts, it is difficult for this method to avoid errors caused by artificial factors, which is against impartiality. The method of analytic hierarchy process [3-7] and fuzzy synthetic assessment [8] are also applied in bid evaluation [9-12]. But there are also weaknesses in these methods, *e.g.*, having strong subjectivity, having illogical analysis of quantitative indicators, and failing to reflect the defects of the bidders and reasons for ineffectiveness, etc. In order to resolve these issues mentioned above, this paper integrated fuzzy theory, data envelopment analysis and grey relational analysis and proposed a systematic decision-making method of bid evaluation based on fuzzy DEA and grey relation for choosing proper bidders. For qualitative indicators, the method took matrix of optimal objective function values as matrix of qualitative indicator values by constructing C^2R model on basis of membership matrix; for quantitative indicators, the method took matrix of correlative coefficients as matrix of quantitative indicator values by using the grey system theory. Finally, this paper introduced a case study to confirm the rationality and feasibility of the decision-making method of bid evaluation, being valuable and helpful for assessment applications in other areas.

The outline of the paper is as follows: The first part is to analyze and summarize the background and significance of the study; the second part is to establish a decision-making model of bid evaluation according to fuzzy DEA and grey relation; the third part shows the feasibility and rationality of the decision-making model of bid evaluation based on example analysis; the fourth part is the conclusion.

2. DECISION-MAKING MODEL OF BID EVALUATION BASED ON FUZZY DEA AND GREY RELATION

2.1. Establishing Indicators System of Bid Evaluation

Selecting the assessment indicators is a very significant work. In the practical synthetic assessment activities, it is common to apply methods of Delphi, minimum mean square error, mini-max dispersion and correlative coefficient to choose indicators [13]. In this paper, Delphi method is applied to get the idea that the indicators system of bid evaluation is composed of five parts: Project Quotation, Project Duration, Project Quality, Construction Technology and Corporate Reputation.

2.2. Determining the Matrix of Qualitative Indicator Values

As for qualitative indicators like Project Quality, Construction Technology and Corporate Reputation, they are difficult to be described using appropriate mathematical language since they belong to the fuzzy variables and have the feature of unclear boundaries. Therefore, fuzzy theory should be employed in this study [14-18]. However, in actual applications, the method of fuzzy synthetic assessment merely reflect virtues or defect degree of various bidders, failing to reflect the defects of the bidders and reasons for ineffectiveness. On account of the reasons mentioned above, this paper tried to combine the method of fuzzy synthetic assessment with data envelopment analysis for such qualitative indicators. The specific procedures are shown as follows.

2.2.1. Determining Qualitative Indicators Set and Assessment Grades Set

It is assumed that $A = \{A_1, A_2, \dots, A_i, \dots, A_m\}$ ($i = 1, 2, \dots, m$) is the appraisal objects set and m is the number of objects for assessment.

It is assumed that $B = \{B_1, B_2, \dots, B_j, \dots, B_g, B_{g+1}, B_{g+2}, \dots, B_n\}$ ($j = 1, 2, \dots, g, g+1, g+2, \dots, n$) is the assessment indicators set and n is the number of assessment indicators. Among them, $B^1 = \{B_1, B_2, \dots, B_g\}$ ($j = 1, 2, \dots, g$) is the qualitative indicators set and g is the number of qualitative indicators; $B^2 = \{B_{g+1}, B_{g+2}, \dots, B_n\}$ ($j = g+1, g+2, \dots, n$) is the quantitative indicators set and $n-g$ is the number of quantitative indicators.

It is assumed that $C = \{C_1, C_2, \dots, C_h, \dots, C_d\}$ ($h = 1, 2, \dots, d$) is the assessment grades set. It expresses the condition of each qualitative indicator. d is the number of assessment grades and commonly divided into three to five levels, e.g., very poor, poor, medium, good, excellent.

2.2.2. Building Membership Matrixes of Qualitative Indicators

Aiming at each qualitative indicator B_j ($j = 1, 2, \dots, g$), we build a fuzzy relation matrix R_j ($j = 1, 2, \dots, g$), which is the membership matrix of the qualitative indicator B_j . As for the appraisal object A_i ($i = 1, 2, \dots, m$), It is assumed that the membership of the qualitative indicator B_j can be assessed as the grade C_h ($h = 1, 2, \dots, d$) is r_{ijh} . Accordingly, we can obtain the assessment vector r_{ij} of the simple object A_i : $r_{ij} = (r_{ij1}, r_{ij2}, \dots, r_{ijd})$ ($i = 1, 2, \dots, m$), therefore m -objects assessment vectors form a overall membership matrix R_j shown as follows:

$$R_j = \begin{bmatrix} r_{1j} \\ r_{2j} \\ \vdots \\ r_{mj} \end{bmatrix} = \begin{bmatrix} r_{1j1} & r_{1j2} & \cdots & r_{1jd} \\ r_{2j1} & r_{2j2} & \cdots & r_{2jd} \\ \vdots & \vdots & \ddots & \vdots \\ r_{mj1} & r_{mj2} & \cdots & r_{mjd} \end{bmatrix} \quad (j = 1, 2, \dots, g) \quad (1)$$

2.2.3. Constructing Fuzzy DEA Model

On basis of the concept of “relative efficiency”, DEA is a systematic method of assessing relatively effectiveness of decision-making units of the same type in accordance with the multi-indicators input and multi-indicators output [19-25]. It is not only able to assess the relative effectiveness of each appraisal object, but also able to indicate the defects of each appraisal object and reasons for ineffectiveness. This paper will establish the most extensively used model C^2R based on the membership matrix of the qualitative indicators.

Aiming at each qualitative indicator B_j ($j = 1, 2, \dots, g$), every appraisal object $\{A_i\}$ ($i = 1, 2, \dots, m$) is selected as a decision-making unit of DEA model, with each grade $\{C_h\}$ ($h = 1, 2, \dots, d$) being the input or output of DEA model, and the transpose matrix R_j^T ($j = 1, 2, \dots, g$) of the membership matrix R_j ($j = 1, 2, \dots, g$) of the qualitative indicator B_j being input data and output data of decision-making units [26]. Aiming at each decision-making unit A_i , we suppose it has p -type input and q -type output, and the corresponding input vector is $X_i = (x_{1i}, x_{2i}, \dots, x_{si}, \dots, x_{pi})^T$ ($s = 1, 2, \dots, p$), and the corresponding output vector is $Y_i = (y_{1i}, y_{2i}, \dots, y_{ti}, \dots, y_{qi})^T$ ($t = 1, 2, \dots, q$). Therefore $p + q = d$, with d being the number of the assessment grades. At the same time, we present the input weights vector $V = (v_1, v_2, \dots, v_s, \dots, v_p)^T$ and the output weights vector $U = (u_1, u_2, \dots, u_t, \dots, u_q)^T$.

As for the qualitative indicator B_1 , the efficiency of decision-making unit A_1 will be assessed. The optimized model will be established, with the efficiency indicator h_{11} of the decision-making unit A_1 being the objective function and the efficiency indicators of all the decision-making units (including the decision-making unit A_1) being constraints. The initial C^2R model is a fractional mathematical plan. By applying the changes of Charnes-Cooper [27], a linear programming model can be got as follows:

$$\begin{aligned} \max h_{11} &= \sum_{t=1}^q u_t y_{t1} \\ \text{s.t.} \sum_{s=1}^p v_s x_{si} - \sum_{t=1}^q u_t y_{ti} &\geq 0 \quad i=1,2,\dots,m \\ \sum_{s=1}^p v_s x_{s1} &= 1 \\ v &= (v_1, v_2, \dots, v_s, \dots, v_p)^T \geq 0 \\ u &= (u_1, u_2, \dots, u_t, \dots, u_q)^T \geq 0 \end{aligned} \quad (2)$$

By resolving the linear programming model mentioned above, we can get the optimal objective function h_{11} of the decision-making unit A_1 as for the qualitative indicator B_1 . It is the manifestation of the decision-making unit A_1 in the aspect of the qualitative indicator B_1 and a decimal between 0 and 1. Accordingly, we can obtain the manifestation vector of every decision-making unit in the aspect of the qualitative indicator B_1 : $H_1 = (h_{11}, h_{21}, \dots, h_{m1})^T$, so that we can obtain the manifestation matrix H of every decision-making unit $\{A_i\}$ ($i=1,2,\dots,m$) on each qualitative indicator B_j ($j=1,2,\dots,g$), which is regarded as the matrix of qualitative indicator values (also the matrix of optimal objective function values) shown as follows:

$$H = (H_1, H_2, \dots, H_g) = (h_{ij})_{m \times g} = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1g} \\ h_{21} & h_{22} & \dots & h_{2g} \\ \vdots & \vdots & \ddots & \vdots \\ h_{m1} & h_{m2} & \dots & h_{mg} \end{bmatrix} \quad (3)$$

2.3. Determining the Matrix of Quantitative Indicator Values

The values of quantitative indicators like Project Quotation and Project Duration can be defined in accordance with the initial indicator values. This paper tried to use the grey system theory [28], taking the matrix of correlation coefficients as the matrix of quantitative indicator values.

It is assumed that the initial indicator values matrix Z of the $n - g$ quantitative indicators B_j ($j = g + 1, g + 2, \dots, n$) of m -objects A_i ($i = 1, 2, \dots, m$) is shown as follows:

$$Z = (z_{ij})_{m \times (n-g)} = \begin{bmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_m \end{bmatrix} = \begin{bmatrix} z_{1,g+1} & z_{1,g+2} & \dots & z_{1n} \\ z_{2,g+1} & z_{2,g+2} & \dots & z_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ z_{m,g+1} & z_{m,g+2} & \dots & z_{mn} \end{bmatrix} \quad (4)$$

2.3.1. Determining the Optimal Indicator Values Set

It is assumed that the optimal indicator values set is $Z_0 = (z_{0,g+1}, z_{0,g+2}, \dots, z_{0n})$ and z_{0j} ($j = g + 1, g + 2, \dots, n$) is the optimal value of the quantitative indicator B_j ($j = g + 1, g + 2, \dots, n$).

When the assessment indicator is cost, $z_{0j} = \min(z_{1j}, z_{2j}, \dots, z_{mj})$; When the assessment indicator is effective, $z_{0j} = \max(z_{1j}, z_{2j}, \dots, z_{mj})$. The matrix D can be constructed after selecting the optimal indicator values set as follows:

$$D = \begin{bmatrix} Z_0 \\ Z_1 \\ Z_2 \\ \vdots \\ Z_m \end{bmatrix} = \begin{bmatrix} z_{0,g+1} & z_{0,g+2} & \dots & z_{0n} \\ z_{1,g+1} & z_{1,g+2} & \dots & z_{1n} \\ z_{2,g+1} & z_{2,g+2} & \dots & z_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m,g+1} & x_{m,g+2} & \dots & x_{mn} \end{bmatrix} \quad (5)$$

2.3.2. Standardizing Assessment Indicator Values

Assessment indicators often have different dimensions and magnitude, so they are not directly comparable. In order to ensure the reliability of the results, we need normalize the matrix D . Methods of normalization processing, efficacy coefficient and extremum processing are generally used in this process. This paper adopts the extremum processing method.

It is assumed that $M_j = \max(z_{0j}, z_{1j}, z_{2j}, \dots, z_{mj})$; $m_j = \min(z_{0j}, z_{1j}, z_{2j}, \dots, z_{mj})$

For cost indicators,

$$z_{ij}^* = \frac{M_j - z_{ij}}{M_j - m_j} \quad (j = g + 1, g + 2, \dots, n) \quad (6)$$

For effective indicators,

$$z_{ij}^* = \frac{z_{ij} - m_j}{M_j - m_j} \quad (j = g + 1, g + 2, \dots, n) \quad (7)$$

Standardization matrix F can be got as follows:

$$F = \begin{bmatrix} Z_0^* \\ Z_1^* \\ Z_2^* \\ \vdots \\ Z_m^* \end{bmatrix} = \begin{bmatrix} z_{0,g+1}^* & z_{0,g+2}^* & \dots & z_{0n}^* \\ z_{1,g+1}^* & z_{1,g+2}^* & \dots & z_{1n}^* \\ z_{2,g+1}^* & z_{2,g+2}^* & \dots & z_{2n}^* \\ \vdots & \vdots & \ddots & \vdots \\ z_{m,g+1}^* & z_{m,g+2}^* & \dots & z_{mn}^* \end{bmatrix} \quad (8)$$

2.3.3. Determining the Matrix of Correlation Coefficients

According to the grey relation method, the correlation coefficient of the quantitative indicator B_j ($j = g + 1, g + 2, \dots, n$) of the appraisal object A_i ($i = 1, 2, \dots, m$) with the optimal indicator B_{0j} can be obtained as follows:

$$e_{ij} = \frac{\min_i \min_j |z_{ij}^* - z_{ij}| + \rho \max_i \max_j |z_{ij}^* - z_{ij}|}{|z_{ij}^* - z_{ij}| + \rho \max_i \max_j |z_{ij}^* - z_{ij}|} \quad (9)$$

ρ is the distinguish coefficient and generally taken $\rho = 0.5$. It is clear that the correlation coefficient matrix E which is regarded as the matrix of quantitative indicator values can be attained as follows:

$$E = (e_{ij})_{m \times (n-g)} = \begin{bmatrix} e_{1,g+1} & e_{1,g+2} & \dots & e_{1n} \\ e_{2,g+1} & e_{2,g+2} & \dots & e_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ e_{m,g+1} & e_{m,g+2} & \dots & e_{mn} \end{bmatrix} \quad (10)$$

2.4. Determining the Matrix of Assessment Indicator Values

The matrix G of assessment indicator values can be constructed on basis of the matrix H of qualitative indicator values and the matrix E of quantitative indicator values shown as follows:

$$G = [H, E] = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1g} & e_{1,g+1} & e_{1,g+2} & \dots & e_{1n} \\ h_{21} & h_{22} & \dots & h_{2g} & e_{2,g+1} & e_{2,g+2} & \dots & e_{2n} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ h_{m1} & h_{m2} & \dots & h_{mg} & e_{m,g+1} & e_{m,g+2} & \dots & e_{mn} \end{bmatrix} \quad (11)$$

2.5. Determining Assessment Indicator Weight Vector

The determination of assessment indicator weight always uses methods of Delphi, AHP, G_1 and G_2 . This paper adopts the method of Delphi.

Assume $W = \{w_1, w_2, \dots, w_g, w_{g+1}, w_{g+2}, \dots, w_n\}^T$ as the assessment indicator weights vector.

2.6. Determining Comprehensive Assessment Results

The matrix K can be determined according to the matrix G of assessment indicator values and the assessment indicator weights vector W as follows:

$$K = G \times W = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1g} & e_{1,g+1} & e_{1,g+2} & \dots & e_{1n} \\ h_{21} & h_{22} & \dots & h_{2g} & e_{2,g+1} & e_{2,g+2} & \dots & e_{2n} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ h_{m1} & h_{m2} & \dots & h_{mg} & e_{m,g+1} & e_{m,g+2} & \dots & e_{mn} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \vdots \\ \delta_m \end{bmatrix} \quad (12)$$

The maximum value of δ_i ($i = 1, 2, \dots, m$) will be taken as the successful bidder.

3. CASE STUDY

3.1. Case Profile

We suppose that there is a project bidding. After the verification of the qualification, four bidders $A = \{A_1, A_2, A_3, A_4\}$ enter the last bid evaluation phase. By Delphi method, we determine that the assessment indicators set is consisted of the five indicators, namely $B = \{\text{Project Quality } (B_1), \text{Construction Technology } (B_2), \text{Corporate Reputation } (B_3), \text{Project Quotation } (B_4), \text{Project Duration } (B_5)\}$, among which the quantitative indicators set is $B^1 = \{B_1, B_2, B_3\}$ and the qualitative indicators set is $B^2 = \{B_4, B_5\}$. The initial indicator values for quantitative indicators are displayed in Table 1 below:

Table 1. Original indicator values of quantitative indicator.

Bidders	Project Quotation (B_4) (million-yuan)	Project Duration (B_5) (Days)
A ₁	25	545
A ₂	24	480
A ₃	23.5	500
A ₄	24.8	520

3.2. Determining the Matrix of Qualitative Indicator Values

3.2.1. Determining Qualitative Indicators Set and Assessment Grades Set

It is easy to ascertain that the qualitative indicators set $B^1 = \{\text{Project Quality } (B_1), \text{Construction Technology } (B_2), \text{Corporate Reputation } (B_3)\}$, while assessment levels set $C = \{\text{very poor } (C_1), \text{poor } (C_2), \text{medium } (C_3), \text{good } (C_4), \text{excellent } (C_5)\}$ can also be determined. We invited nine experts of bid evaluation to make a fuzzy assessment of 4 bidders' manifestation on each qualitative indicator. The results are listed in Tables 2-4.

3.2.2. Building the Membership Matrix of Qualitative Indicator

The membership matrix R_j ($j = 1, 2, 3$) can be constructed aiming at each qualitative indicator B_j ($j = 1, 2, 3$) according to the equation (1) on basis of the Table 2 ~ 4 as follows:

Table 2. Assessment valuation results of quality (B₁).

Quality (B ₁)	C ₁	C ₂	C ₃	C ₄	C ₅
A ₁	0	1	2	3	3
A ₂	1	3	4	1	0
A ₃	2	3	3	1	0
A ₄	0	3	3	2	1

Table 3. Assessment valuation results of technology (B₂).

Technology (B ₂)	C ₁	C ₂	C ₃	C ₄	C ₅
A ₁	1	4	3	1	0
A ₂	0	2	2	3	2
A ₃	3	3	2	1	0
A ₄	0	2	4	2	1

Table 4. Assessment valuation results of reputation (B₃).

Reputation (B ₃)	C ₁	C ₂	C ₃	C ₄	C ₅
A ₁	2	4	2	1	0
A ₂	0	4	3	1	1
A ₃	0	2	3	2	2
A ₄	1	2	5	1	0

$$R_1 = \begin{bmatrix} 0 & 0.111 & 0.223 & 0.333 & 0.333 \\ 0.111 & 0.333 & 0.445 & 0.111 & 0 \\ 0.223 & 0.333 & 0.333 & 0.111 & 0 \\ 0 & 0.333 & 0.333 & 0.223 & 0.111 \end{bmatrix}$$

$$R_2 = \begin{bmatrix} 0.111 & 0.445 & 0.333 & 0.111 & 0 \\ 0 & 0.222 & 0.222 & 0.334 & 0.222 \\ 0.333 & 0.333 & 0.223 & 0.111 & 0 \\ 0 & 0.222 & 0.445 & 0.222 & 0.111 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0.222 & 0.445 & 0.222 & 0.111 & 0 \\ 0 & 0.445 & 0.333 & 0.111 & 0.111 \\ 0 & 0.222 & 0.334 & 0.222 & 0.222 \\ 0.111 & 0.222 & 0.556 & 0.111 & 0 \end{bmatrix}$$

3.2.3. Constructing Fuzzy DEA Model

We choose very poor (C₁), poor (C₂), medium (C₃) as input and good (C₄) and excellent (C₅) as output of the DEA model. Meanwhile, we take all bidders A_i (i=1,2,3,4) as the decision-making units of DEA model, and present the input

weights vector $V = (v_1, v_2, v_3)^T$ and the output weights vector $U = (u_1, u_2)^T$.

As for qualitative indicator “Project Quality (B₁)”, we use the transpose matrix R_1^T of its membership matrix R_1 as input data and output data of decision-making unit. Now efficiency of the bidder A₁ will be assessed. According to the model (2), we can construct the following linear programming model:

$$\begin{aligned} \max h_{11} &= 0.333u_1 + 0.333u_2 \\ \text{s.t.} & 0.111v_2 + 0.223v_3 - 0.333u_1 - 0.333u_2 \geq 0 \\ & 0.111v_1 + 0.333v_2 + 0.445v_3 - 0.111u_1 \geq 0 \\ & 0.223v_1 + 0.333v_2 + 0.333v_3 - 0.111u_1 \geq 0 \\ & 0.333v_2 + 0.333v_3 - 0.223u_1 - 0.111u_2 \geq 0 \\ & 0.111v_2 + 0.223v_3 = 1 \\ & V = (v_1, v_2, v_3)^T \geq 0 \\ & U = (u_1, u_2)^T \geq 0 \end{aligned}$$

Using LINDO software, we can get $h_{11} = 1.0000$, and this is the manifestation of the project bidders A_1 in the aspect of project quality B_1 , which is also the optimal objective function value. Accordingly, we can get the manifestation of the other three bidders in the aspect of project quality B_1 : $h_{21} = 0.1670$, $h_{31} = 0.2232$, $h_{41} = 0.4485$. Thus we can know the manifestation of all decision-making units in the aspect of project quality (B_1):

$$H_1 = (h_{11}, h_{21}, h_{31}, h_{41})^T = (1.0000, 0.1670, 0.2232, 0.4485)^T.$$

Similarly, as for the construction technology (B_2), all decision-making units' manifestation on it can be shown in:

$$H_2 = (h_{12}, h_{22}, h_{32}, h_{42})^T = (0.2216, 1.0000, 0.3308, 0.6647)^T$$

As for corporate reputation (B_3), all decision-making units' manifestation on it can be shown in:

$$H_3 = (h_{13}, h_{23}, h_{33}, h_{43})^T = (0.7500, 0.5000, 1.0000, 0.5023)^T$$

Therefore the manifestation matrix H of every decision-making unit A_i ($i = 1, 2, 3, 4$) on each qualitative indicator B_j ($j = 1, 2, 3$) can be displayed according to the equation (3), which is also the matrix of optimal objective function value shown as follows:

$$H = (H_1, H_2, H_3) = (h_{ij})_{4 \times 3} = \begin{bmatrix} 1.0000 & 0.2216 & 0.7500 \\ 0.1670 & 1.0000 & 0.5000 \\ 0.2232 & 0.3308 & 1.0000 \\ 0.4485 & 0.6647 & 0.5023 \end{bmatrix}$$

3.3. Determining the Matrix of quantitative Indicator Values

The initial indicator values matrix Z of the quantitative indicators B_4 and B_5 can be got according to the equation (4) on basis of the table 1 shown as follows:

$$Z = (z_{ij})_{4 \times 2} = \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \end{bmatrix} = \begin{bmatrix} 2500 & 545 \\ 2400 & 480 \\ 2350 & 500 \\ 2480 & 520 \end{bmatrix}$$

3.3.1. Determining the Optimal Indicator Values Set

The quantitative indicators B_4 and B_5 are cost indicators, so the optimal indicator values set is $Z_0 = (2350, 480)$. The matrix D can be constructed according to the equation (5) as follows:

$$D = \begin{bmatrix} Z_0 \\ Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \end{bmatrix} = \begin{bmatrix} 2350 & 480 \\ 2500 & 545 \\ 2400 & 480 \\ 2350 & 500 \\ 2480 & 520 \end{bmatrix}$$

3.3.2. Standardizing Assessment Indicator Values

The quantitative indicators B_4 and B_5 are cost indicators, so the Standardization matrix F can be constructed according to the equation (6) and (8) as follows:

$$F = \begin{bmatrix} Z_0^* \\ Z_1^* \\ Z_2^* \\ Z_3^* \\ Z_4^* \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 0 & 0 \\ 0.6667 & 1 \\ 1 & 0.6923 \\ 0.1333 & 0.3846 \end{bmatrix}$$

3.3.3. Determining the Matrix of Correlation Coefficients

Firstly, it is easy to determine that

$$|z_{ij}^* - z_{ij}| = \begin{bmatrix} 0 & 0 \\ 1 & 1 \\ 0.3333 & 0 \\ 0 & 0.3077 \\ 0.8667 & 0.6154 \end{bmatrix}$$

Secondly, it is easy to determine that

$$\min_i \min_j |z_{ij}^* - z_{ij}| = 0, \quad \max_i \max_j |z_{ij}^* - z_{ij}| = 1 \quad \text{and} \quad \rho \text{ is}$$

generally taken $\rho = 0.5$, so e_{ij} can be obtained according to the equation (9) as follows:

$$e_{ij} = \frac{\min_i \min_j |z_{ij}^* - z_{ij}| + \rho \max_i \max_j |z_{ij}^* - z_{ij}|}{|z_{ij}^* - z_{ij}| + \rho \max_i \max_j |z_{ij}^* - z_{ij}|} = \frac{0.5}{|z_{ij}^* - z_{ij}| + 0.5}$$

Finally, the matrix E of correlation coefficients which is regarded as the matrix of quantitative indicator values can be attained according to the equation (10) as follows:

$$E = (e_{ij})_{4 \times 2} = \begin{bmatrix} 0.3333 & 0.3333 \\ 0.6000 & 1.0000 \\ 1.0000 & 0.6190 \\ 0.3658 & 0.4483 \end{bmatrix}$$

3.4. Determining the Matrix of Assessment Indicator Values

The matrix G of assessment indicator values can be constructed on basis of the matrix H of qualitative indicator values and the matrix E of quantitative indicator values according to the equation (11) as follows:

$$G = [H, E] = \begin{bmatrix} 1.0000 & 0.2216 & 0.7500 & 0.3333 & 0.3333 \\ 0.1670 & 1.0000 & 0.5000 & 0.6000 & 1.0000 \\ 0.2232 & 0.3308 & 1.0000 & 1.0000 & 0.6190 \\ 0.4485 & 0.6647 & 0.5023 & 0.3658 & 0.4483 \end{bmatrix}$$

3.5. Determining Assessment Indicator Weight Vector

The assessment indicator weight vector can be attained by adopting the method of Delphi as follows:
 $W = \{w_1, w_2, w_3, w_4, w_5\}^T = \{0.20, 0.15, 0.05, 0.40, 0.20\}^T$.

3.6. Determining Comprehensive Assessment Results

The comprehensive assessment vector K can be attained based on assessment indicator values matrix G and the assessment indicator weight vector W according to the equation (12) as follows:

$$K = G \times W = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \end{bmatrix}$$

$$= \begin{bmatrix} 1.0000 & 0.2216 & 0.7500 & 0.3333 & 0.3333 \\ 0.1670 & 1.0000 & 0.5000 & 0.6000 & 1.0000 \\ 0.2232 & 0.3308 & 1.0000 & 1.0000 & 0.6190 \\ 0.4485 & 0.6647 & 0.5023 & 0.3658 & 0.4483 \end{bmatrix} \times \begin{bmatrix} 0.20 \\ 0.15 \\ 0.05 \\ 0.40 \\ 0.20 \end{bmatrix}$$

$$= \begin{bmatrix} 0.4704 \\ 0.6484 \\ 0.6681 \\ 0.4505 \end{bmatrix}$$

It is easy to determine that " $\delta_3 > \delta_2 > \delta_1 > \delta_4$ ", so we take the bidder A_3 as the successful bidder.

CONCLUSION

(1) Bid evaluation is the core of the bidding, and the premise and indispensable step of scientific decision. This paper integrated fuzzy theory, data envelopment analysis and grey relational analysis and proposed a systematic decision-making method of bid evaluation based on fuzzy DEA and grey relation for choosing proper bidders. This approach can not only quantify the qualitative indicators and analyze the qualitative indicators and the quantitative indicators, but also can assess the relative effectiveness of each appraisal object and find out their defects and reasons for ineffectiveness.

(2) The greatest feature is that the method doesn't have a strict requirement to the size of the sample and needn't typical regularities of distribution. The most prominent feature of this method is that it has no strict requirements for the amount of samples and does not need the typical distribution rule. Its calculation method is simple, and has rigorous logical reasoning and mathematical foundation. And at the same time it has some reference value for the assessment in other application domains.

(3) In actual bidding evaluation activities, we need consider a large number of assessment indicators. This paper

only considered several typical function indicators, which can also be subdivided, so the assessment indicators system should be further perfected.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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