Improvement of bidding procurement model of engineering materials based on analytical hierarchy process and Delphi method

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Abstract

The bidding procurement of engineering materials aims at selecting cost-effective materials and better suppliers in a fair, just, and open way but the current material bidding procurement model is very unreasonable. This paper will analyse the current bidding procurement model, point out its unreasonableness, and offer suggestions for improvement based on Analytical Hierarchy Process and Delphi method.

Keywords: Engineering Materials bid ; Procurement model; Analytical Hierarchy Process ;Delphi method

1 Introduction

In the current process of construction engineering, the procurement of engineering materials by invitation to bid is to select ideal materials and material suppliers from a number of bidders. Procurement by inviting bids is relatively fair, just, and reasonable among many material procurement models [1]. At present, most of the bidding procurement of engineering materials imitates the single project bidding mode and its scoring method. But the characteristics of engineering materials determines the particularity of engineering materials, so blindly copying the single project bidding mode will bring unreasonableness and negative effects on the bidding procurement of engineering materials, which influences the justice and fairness of invitation for bids and impedes the selection of satisfactory materials and material suppliers. Thus certain optimization and improvement of current material bidding procurement model is needed.

2 Problems of Current Engineering Materials Bidding Procurement

In the process of compiling documents for engineering materials bidding procurement, the weight distribution of each sub-item is unreasonable and too subjective in the scoring rubrics of bidding documents. In the context of engineering materials bidding documents, scoring rubrics play a decisive role since they are the basis on which judges give marks, the gauge of documentation for bidders, and the concentrated expression of bidding materials from bid-inviting units. Their content may directly affect the final rankings of bidders [2]. In the process of compiling the scoring rubrics of bidding documents, however, weight of each sub-item is mainly determined by tenderers subjectively instead of by applying objective and scientific methods in accordance with particularity of different materials, which contributes to the unreasonable evaluation of bids and leaves room for illegal operations and makes it possible to deliberately choose the successful bidders..

Judges give marks in a too subjective way, the scores may be too scattered and the actual scores and theoretically deserved scores may have deviations. In the current scoring process of engineering materials bid inviting, the score of each sub-item is determined by the average of judges' marks. Since every judge has different grasp of scoring scale and is often affected by subjective cognizance and preferences of individuals, the scoring process is too subjective and the scores are not necessarily able to objectively and accurately reflect the true performance of each bidding units. Some judges may give scores which are very different from theoretical scores or scores given by other judges. Although we often employ the method of removing the highest and lowest points and then averaging the remaining points [3], this practice cannot solve the problems that second highest and second lowest scores may also be too subjective and unscientific and furthermore, removing the highest and lowest points may also be limited by the number of the judges.

The scoring rubrics of commercial bids are difficult to determine. In the single project bidding, it is possible to calculate pre-tender or the base number of a tender according to bills of quantities and then use the price as a measure of commercial bids' quotation to calculate the scores of commercial bids. But the price gap will be very

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large due to the unique features of materials and the differences in quality, performance, and the levels of materials of different brands. In the current material bidding mode, the scoring rubrics for commercial bids are generally divided into two types, namely: the lowest scoring method and the average scoring method [4]. The former is that the bidder with the lowest quoted price achieves the highest score. The latter is first to add all tender offers and then calculate the average offer and the bidder whose quoted price is most close to the average wins the highest score. Both rating methods have certain drawbacks. Though sometimes the lowest scoring method can reduce the cost, it neglects the cost-performance of materials and equipment and tend to select low-level products whose cost performance may be relatively low [5] and it is difficult to pick out cost-efficient materials of high quality. The average scoring method may make some product suppliers whose prices used to be relatively low become opportunistic and deliberately raise the price close to the average price in order to get the chance of winning the bidding [6].

3 Improvement of the Current Material Bidding Procurement Model

3.1 THE PROBLEM OF DETERMINING THE SUB-ITEMS OF THE SCORING RUBRICS IN THE BIDDING DOCUMENTS.

Delphi method can be applied to determine the content of sub-items. After asking experts for advice on the content of scoring rubrics of bidding documents, we then collate, summarize, and analyse the advice and then give feedbacks to experts anonymously for advice again. Concentration of advice and feedback is redone until the consensus is achieved. This method corrects the defect that some experts may yield to the authority or blindly subordinate to the majority in the ordinary discussion and can effectively eliminate the mutual interference between members so as to give full play to the wisdom, knowledge and operations of experts and finally arrive at an outcome which can better reflect the groups' will [7]. The specific process is shown in Figure 1.

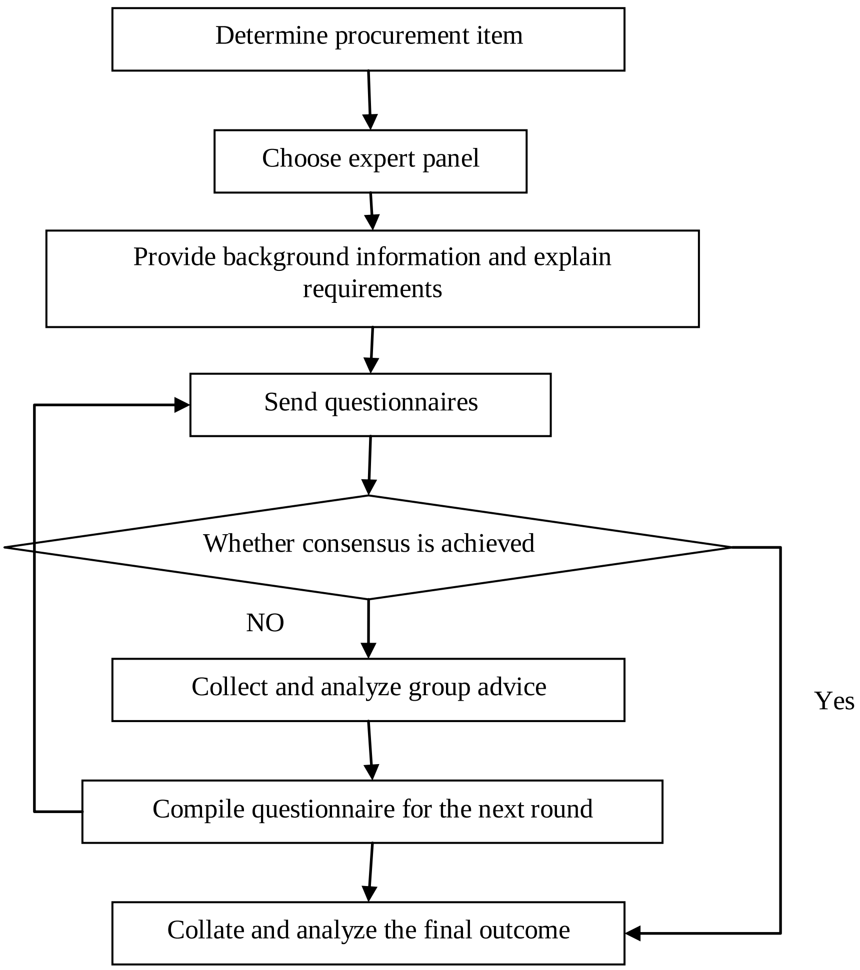

FIGURE 1 Steps of Delphi Method

3.2 IMPROVE THE UNREASONABLE WEIGHT DISTRIBUTION IN THE SCORING RUBRICS OF BIDDING DOCUMENTS.

When the scoring rubrics in bidding documents are compiled, many factors should be taken into consideration as well as their correlations, which provide the basis to conduct the evaluation of comprehensive effectiveness of performance. Analytical Hierarchy Process (AHP) [8] is introduced. This is a multi-objective decision method which combines qualitative and quantitative analysis. It divides the complicated scoring system into several component elements, builds a hierarchy based on dominance relation, determines relative importance of elements by making pairwise comparisons and then calculates the weight of each element. Based on this, the quantification of scoring rubrics can be achieved.

Supposing the scoring rubrics have n sub-items, then its set is:

$$D=\{W_1,W_2,\cdots,W_i,\cdots,W_n\} \tag{1}$$

Build the set of the pairwise comparison of Set D, namely Matrix A:

$$A=\begin{bmatrix} \frac{W_1}{W_1} & \frac{W_1}{W_2} & \cdots & \frac{W_1}{W_n} \\ \frac{W_2}{W_1} & \frac{W_2}{W_2} & \cdots & \frac{W_2}{W_n} \\ \vdots & \vdots & & \vdots \\ \frac{W_n}{W_1} & \frac{W_n}{W_2} & \cdots & \frac{W_n}{W_n} \end{bmatrix}=(a_{ij})_{n\times n} \tag{2}$$

Judging the structure of matrix is the focus of AHP and also the characteristic of the appliance of AHP to material bid inviting. After building construction matrix, professionals or management experts are invited to make pairwise comparisons of the importance of every sub-item and turn it into judgment matrix according to scale. AHP adopts a scale of 0 to 4, as presented in Chart 1.

TABLE 1 The Grading of Pairwise Comparison and its Scale

Pairwise Comparison	Scale (a_{ij})	Scale (a_{ji})
a_{ij} is far more important than a_{ji}	4	0
a_{ij} is more important than a_{ji}	3	1
a_{ij} is as important as a_{ji}	2	2
a_{ij} is less important than a_{ji}	1	3
a_{ij} is far less important than a_{ji}	0	4

Matrix A is a positive reciprocal matrix. In the Matrix A: 1. a_{ij} values in 0, 1, 2, 3, and 4; 2. $a_{ij}+a_{ji}=4$; 3. $a_{ii}=a_{jj}=2, i=j, (i,j=1,2,\ldots,n)$

The algebraic sum of components of vectors in each row is

$$a_i=\sum_{j=1}^{n}a_{ij}, i=1,2,\cdots,n; j=1,2,\cdots,n. \tag{3}$$

$$\omega_i=a_i/\sum_{i=1}^{n}\sum_{i=1}^{n}a_{ij}, i=1,2,\cdots,n; j=1,2,\cdots,n. \tag{4}$$

$$f_i=\bar{x}_i*\omega_i. \tag{5}$$

f_i: the i[th] analysis function appraisal coefficient;

$\bar{x}_i$: The average of scores given by several experts on the i[th] sub-item for every bidding unit;

ω_i: The weight taking up by the i[th] function in function comprehensive evaluation ($0<\omega_i<1$)

a_i: the sub-item of scoring rubrics, $i=1,2,\ldots,n$. n is the total number of score sub-items

By applying AHP, the importance of each sub-item can be compared and quantized and the weight of each sub-item can finally be calculated, which has high reliability and small errors. But in this method, the factors of the evaluated object, namely the sub-items of scoring rubrics, cannot be too many, usually less than 9 [9].

3.3 JUDGES GIVE MARK TOO SUBJECTIVELY AND SCORES ARE TOO SCATTERED.

In order to solve this problem, we first find out the sub-items with large deviations through mathematical model analysis and then after group discussion among judges, find subjective reasons for marking deviations and remark this sub-item to eliminate scoring deviations so as to achieve the fairness, justice, and reasonableness of scoring.

Namely build mathematical models after comparing dispersion of scores by all judges.

$$S_i=\sqrt{\frac{1}{m}\sum_{j=1}^{m}(x_{ij}-\bar{x}_i)^2} \tag{6}$$

$$\bar{x}_i=\frac{x_{i1}+x_{i2}+\ldots\ldots+x_{im}}{m} \tag{7}$$

x_{ij} is expert j's score on i^{th} breakdown, $i=1,2,\ldots,n; j=1,2,\ldots,m$.

Greater $\boldsymbol{S_i}$ means greater dispersion of scores from judges and the more unreasonable scores which need correcting.

3.4 HOW TO SOLVE THE PROBLEM OF DETERMINING THE SCALE OF SCORES FOR COMMERCIAL BIDS.

The concept of comprehensive evaluation index Z_i, namely cost performance should be introduced to integrate price and performance instead of merely making decisions based on price. By comprehensive consideration of quality and value of engineering materials, it tactfully avoids determining scores for commercial bids merely relying on price. The greater Z_i is, the better the cost performance is.

$$\text{Comprehensive evaluation index}\ (Z_i)=\frac{\text{Comprehensive function appraisal coefficient}\ (F_i)}{\text{Cost coefficient}\ (C_i)} \tag{8}$$

$$Fi = \sum_{i=1}^{n} \bar{x}_i * f_i \quad (9)$$

$$C_i = \frac{c_i}{\sum_{i=1}^{n} c_i * 100\%} \quad (10)$$

4 Project case

A university library project was going to purchase illuminating system. It employed opening tendering and the judge panel contained seven people. After preliminary review, five bidders were eligible, including unit A, B, C, D, and E. To apply the improved bid evaluation method, the process is as follows:

4.1 DETERMINE THE CONTENT OF EACH SUB-ITEM OF EVALUATION STANDARDS

Units that were called for tenders organized a group of people who were specialized in lights performance and announcements through Delphi; the detailed process is presented in Figure 1. After asking experts for advice on the content of scoring rubrics of bidding documents, we then collated, summarized, and analysed the advice and gave feedbacks to experts anonymously for advice again. Concentration of advice and feedback was redone until the consensus was achieved. More details are exhibited in Figure 2.

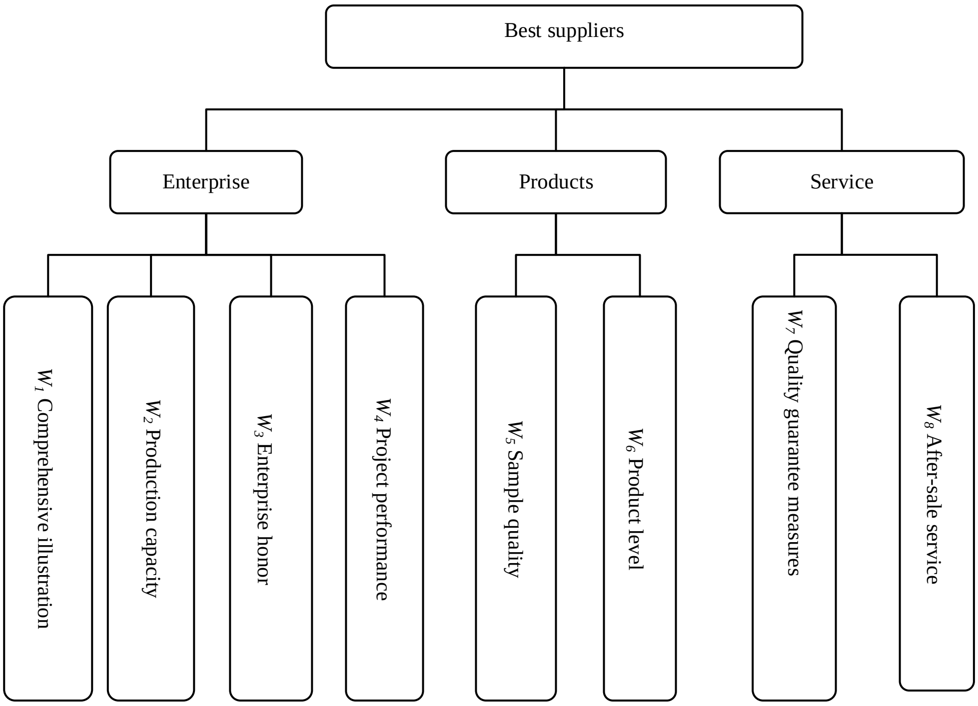

FIGURE 2 the Hierarchical Chart of Every Sub-item in Scoring Rubrics

4.2 DETERMINE SUB-WEIGHT

Make pairwise comparisons in scoring rubrics according to formula (2) and then calculate each sub-weight based on formula (3) and (4), which is illustrated in chart 2.

TABLE 2 List of Binary Comparison Matrix of Each Sub-item and its Weight

	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	$\sum_{j=1}^{8} e_{ij}$	ω_i
W_1	2	1	1	1	1	0	1	1	8	0.063
W_2	3	2	3	2	1	1	2	2	16	0.125
W_3	3	1	2	1	1	1	1	0	11	0.086
W_4	3	2	3	2	1	1	2	2	16	0.125
W_5	3	3	3	3	2	1	3	3	21	0.164
W_6	4	3	3	3	3	2	3	3	24	0.187
W_7	3	2	3	2	1	1	2	3	17	0.133
W_8	3	2	3	2	1	1	1	2	15	0.117

4.3 EACH SUB-ITEM IS SCORED IN A CENTESIMAL SYSTEM.

After judging offered marks, the value of every sub-item of bidder $\boldsymbol{S_i}$, was below 3 except $\boldsymbol{S_4}$, which indicated that judges' understanding of W_4 had great differences. After communicating with judges, it has been found that judges had different understandings of W_4 Project Performance. Some judges believed that project performance should be the project performance of product manufacturers while some thought that it should refer to the project performance of bidding units. After consultation in the judge panel, it was reasonable to measure project performance by the project performance of bidding units. Judges rescored W_4 after they achieved the agreement. Then the value of $\boldsymbol{S_4}$ was also below 3.0, which indicated that there were small dispersions among scores given by judges and scores were relatively reasonable. Chart 3 exhibits the scores of all sub-items of bidding units.

TABLE 3 List of Scores of all Sub-items of Bidding Units

	$\overline{x}_1$	$\overline{x}_2$	$\overline{x}_3$	$\overline{x}_4$	$\overline{x}_5$	$\overline{x}_6$	$\overline{x}_7$	$\overline{x}_8$
A	85.2	80.8	81.8	81.2	82.7	90.1	93.0	95.1
B	81.7	91.8	85.6	83.7	82.9	90.2	89.6	90.3
C	89.0	88.2	89.7	82.8	86.1	93.0	87.9	92.5
D	80.9	87.7	81.5	85.2	87.8	87.6	90.2	89.5
E	87.1	89.0	82.3	87.0	81.2	89.3	88.7	91.0

4.4 DETERMINE FUNCTION COMPREHENSIVE APPRAISAL COEFFICIENT Fi ACCORDING TO FORMULA (9) AND DATA IN CHART 2 AND 3. CHART 4 SHOWS THE FUNCTION COMPREHENSIVE APPRAISAL COEFFICIENT FOR EACH UNIT.

TABLE 4 List of the Function Comprehensive Appraisal Coefficient for each bidding unit

	$\overline{x}_1 * \omega_1$	$\overline{x}_2 * \omega_2$	$\overline{x}_3 * \omega_3$	$\overline{x}_4 * \omega_4$	$\overline{x}_5 * \omega_5$	$\overline{x}_6 * \omega_6$	$\overline{x}_7 * \omega_7$	$\overline{x}_8 * \omega_8$	Fi
A	5.37	10.10	7.03	10.15	13.56	16.85	12.37	11.13	86.6
B	5.14	11.48	7.36	10.46	13.59	16.87	11.92	10.57	87.4
C	5.61	11.03	7.71	10.35	14.12	17.39	11.69	10.82	88.7
D	5.10	10.96	7.01	10.65	14.40	16.38	11.99	10.47	86.9
E	5.49	11.13	7.08	10.88	13.32	16.70	11.79	10.65	87.0

4.5CALCULATE COST COEFFICIENT C_I AND COMPREHENSIVE EVALUATION INDEX Z_I BASED ON FORMULA (8) AND (10) AND CHART 4.

TABLE 5 List of Comprehensive Evaluation Index for Each Bidding Unit

	c_i	C_i *100%	F_i	$Z_i = F_i / C_i$	Rankings
A	85.5	19.39	86.6	4.47	**1**
B	90.0	20.40	87.4	4.28	**5**
C	88.6	20.08	88.7	4.42	**2**
D	89.3	20.24	86.9	4.29	**4**
E	87.8	19.90	87.0	4.37	**3**

Based on this, the top three bidding units in accordance with the rank order were: unit A, unit C and Unit E. The tender leading group chose A as the successful bidder.

5 Conclusions

When the content of scoring rubrics in bidding document is being determined, improved method is used to build scoring rubrics comprehensively, truly, and objectively with pointed references so as to not only give full play to the wisdom of experts but also not blindly follow authority and synthesize different opinions to the greatest extent and obtain more reasonable outcomes.

Bidding procurement model is built according to AHP, which is clear, understandable and easy to apply. Especially when determining sub-weight in scoring rubrics of bidding documents, we should mainly apply quantitative analysis supplemented by qualitative analysis to objectively determine the sub-weight.

We can take the reasonable combination of performance and cost as basis and highlight cost performance to try to improve materials' value to the greatest extent, which helps select cost-efficient products. Meanwhile, making decisions based on data can reduce subjective randomness, conflicts, and arguments.

We adopt improved bid evaluation method to evaluate bid, which conforms to the principles of fairness, justice, and reasonableness and gives prominence to key points and is systematic and comprehensive. Later, it is proved by project case that bidding units perform well in every aspect and win approval of all parties. It is proved by facts that this method is a successful improvement on materials bidding mode.

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