Study on the Selection of Equipment Suppliers for Wind Power Generation EPC Project

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Abstract: In the EPC project, the purchase cost of equipments accounted for about 60% of the total project cost, thus, the selection of equipment suppliers has an important influence on the EPC project. This paper, took EPC project for the phase I engineering of Guizhou Huaxi Yunding wind power plant as research background, constructed the evaluation index system for the selection of equipment suppliers for wind power generation EPC project from multiple perspectives, and introduced matter-element extension evaluation model to evaluate the selection of equipment suppliers for this project from the qualitative and quantitative point of view. The result is consistent with the actual situation, which verifies the validity and operability of this method.

1. Introduction

The EPC (Engineering Procurement Construction）mode adopts the design-procurement-construction one-stop management, and compared with the traditional construction mode, it has the advantages of investment saving, optimized management, full-process control, etc., thus, it is more and more widely applied in the international and domestic engineering projects [1].The procurement management plays an important role as a connecting link between the preceding and the following in the EPC mode. The selection of suppliers is an important part of procurement management, if the ideal supplier can be selected as a strategic partner, the construction time and cost of the project can be effectively controlled. The study on the selection of suppliers an important theoretical significance and practical value for improving the procurement management level of the EPC project [2].

In recent years, the research results on the selection of suppliers are fruitful. Wang Tong [3] constructed an evaluation index system for construction material suppliers based on the theory of balance score card when selecting material suppliers. Combining with the natures of the green building supply chains, Ruan Lianfa, Chen Jialing [4] put forward the VIKOR method based on the fuzzy theory to select the green building suppliers. There are many methods for supplier selection decision, but most of them are highly subjective. The paper constructed the evaluation index system for the selection of equipment suppliers for the wind power generation EPC project on the basis of equipment level, R&D ability, Enterprise's own ability, cooperation ability and service ability, introduced the improved matter-element extension evaluation model, and conducted an evaluation on the selection of the equipment suppliers for the phase I engineering of Guizhou Huaxi Yunding wind

power plant.

2. Construction of Evaluation Index System

2.1. Principle of Evaluation Index Selection
The scientific, reasonable, fair and comprehensive index system is the premise for selection of supplier evaluation index, thus, certain principles must be followed when choosing the index: ① scientific principle c, the scientific index means the evaluation index selected must have scientific definition and concept, i.e., the selected index must have a clear, confirmative and scientific meaning; ② Principle of reasonableness, the set and selection of the evaluation index should take into account the correlation n between the index and evaluation; ③ Comprehensive principle, the comprehensive index means the information reflected by the indexes shall be comprehensive,, but an index that can only reflect one aspect of the characteristics of the project should not be selected; ④ Operability principle, the index must be able to be evaluated and is easy to be evaluated, i.e., the index has the advantages of convenient comparability.

2.2. Evaluation Index System
Based on the study of the other scholars [5]-[8], the evaluation index system for selecting equipment suppliers of the wind power generation EPC project was confirmed as follows Figure1 1.

2.3. Classification of Evaluation Indexes
Combined with the actual condition of the case, the evaluation indexes of equipment suppliers were classified into four grades which are Excellent,, Good, Medium and Bad by using the expert scoring method, and respectively indicated by grade I, grade II, grade III and grade IV (see table 1). There are 21 evaluation indexes in table 1, including 9 quantitative indexes and 12 qualitative indexes.

3. Matter-Element Extension Evaluation Model
The matter-element extension evaluation model was derived from the matter-element extension analysis theory proposed by Cai Wen who is a famous Chinese professor. It is mainly used for solving the incompatibility between the functional target of the matter and the environment condition. The detailed steps for constructing the evaluation model of selecting equipment suppliers on the matter-element extension analysis method are as follows [9]:

3.1. Definition of Matter-Element
Based on the concept of the extension theory，matter N and its characteristic values C and V together form the matter-element matrix R, which is recorded as $R = (N, C, V)$. If N has n characteristics values $C_1, C_2, \cdots, C_n$, the magnitudes corresponding to each characteristics value are $V_1, V_2, \cdots, V_n$, and then the matter-element matrix can be expressed as:

$$R = (N, C, V) = \begin{bmatrix} N & C_1 & V_1 \\ & C_2 & V_2 \\ & \vdots & \vdots \\ & C_n & V_n \end{bmatrix} = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{bmatrix} \qquad （1）$$

3.2. Confirmation of the Matrixes of Classical Field Matter-element, Segment Field Matter-element and Matter-element to be evaluated
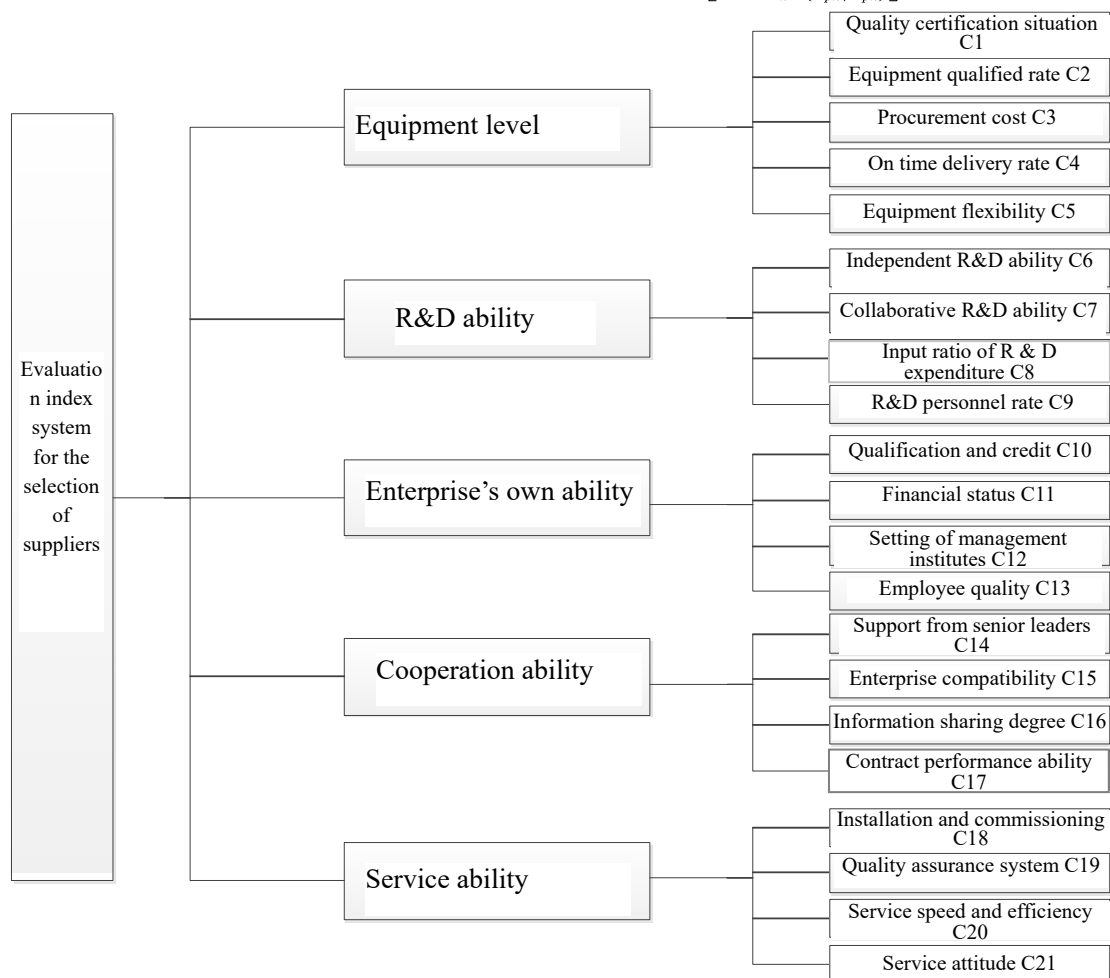The classical field matter-element matrix R_N is expressed as：

$$R_N = (N_i, C_n, V_n) = \begin{bmatrix} N_i & C_1 & (a_{i1}, b_{i1}) \\ & C_2 & (a_{i2}, b_{i2}) \\ & \vdots & \vdots \\ & C_n & (a_{in}, b_{in}) \end{bmatrix} \qquad (2)$$

Wherein: N_i is the i evaluation grades of the matter to be evaluated; $C_1, C_2, \cdots C_n$ are evaluation indexes; (a_{in}, b_{in}) is the value range of the evaluation C_n to the ith evaluation grade, i.e., the classical field.

The segment field matter-element matrix R_P is expressed as:

$$R_p = (N_p, C_p, V_p) = \begin{bmatrix} N_p & C_1 & (a_{p1}, b_{p1}) \\ & C_2 & (a_{p2}, b_{p2}) \\ & \vdots & \vdots \\ & C_n & (a_{pn}, b_{pn}) \end{bmatrix} \qquad (3)$$

Figure 1 Evaluation index system

Table 1 Classification of evaluation indexes

Principle level	Evaluation index	Grade of evaluation indexes				Remark
		Grade I	Grade II	Grade III	Grade IV	
	C1	97~100	94~97	91~94	88~91	Quantitative
Equipment level	C2	98~100	96~98	94~96	92~94	Quantitative
	C3	300~325	325~350	350~375	375~400	Quantitative

	C4	95～100	90～95	85～90	80～85	Quantitative
	C5	95～100	90～95	85～90	80～85	Qualitative
R&D ability	C6	90～100	80～90	70～80	60～70	Quantitative
	C7	90～100	80～90	70～80	60～70	Qualitative
	C8	9～10	8～9	7～8	6～7	Quantitative
	C9	4～5	3～4	2～3	1～2	Quantitative
Enterprise's own ability	C10	95～100	90～95	85～90	80～85	Qualitative
	C11	95～100	90～95	85～90	80～85	Qualitative
	C12	90～100	80～90	70～80	60～70	Qualitative
	C13	90～100	80～90	70～80	60～70	Qualitative
Cooperation ability	C14	95～100	90～95	85～90	80～85	Qualitative
	C15	90～100	80～90	70～80	60～70	Qualitative
	C16	95～100	90～95	85～90	80～85	Qualitative
	C17	98～100	96～98	94～96	92～94	Quantitative
Service ability	C18	90～100	80～90	70～80	60～70	Qualitative
	C19	98～100	96～98	94～96	92～94	Qualitative
	C20	90～100	80～90	70～80	60～70	Quantitative
	C21	90～100	80～90	70～80	60～70	Qualitative

Wherein, N_p is the staff of the grades of the matter to be evaluated, $C_1, C_2, \cdots C_n$ means the evaluation indexes corresponding to all evaluation grades, and (a_{pn}, b_{pn}) means the segment field of the nth index C_n, i.e., the detailed value range of the characteristic C_n.

The matrix of matter-element to be evaluated R_O is expressed as:

$$R_o = (N_o, C_o, V_o) = \begin{bmatrix} N_o & C_1 & (a_{o1}, b_{o1}) \\ & C_2 & (a_{o2}, b_{o2}) \\ & \vdots & \vdots \\ & C_n & (a_{on}, b_{on}) \end{bmatrix} \qquad (4)$$

Wherein: N_o is the field to be evaluated, $C_1, C_2, \cdots C_n$ is the n evaluation indexes of the field to be evaluated, and $V_{o1}, V_{o2}, \cdots, V_{on}$ are the actual values of the n evaluation indexes of the matter-element to be evaluated.

3.3 Calculation of Distance

In literature [10], the concept of distance in the real variable function is widely defined as the concept of D of which the calculation formula is as follows:

$$\begin{cases} d(v_i, V_{ij}) = |v_i - (a_{ij} + b_{ij})/2| - (b_{ij} - a_{ij})/2 \\ d(v_i, V_{ip}) = |v_i - (a_{ip} + b_{ip})/2| - (b_{ip} - a_{ip})/2 \end{cases} \qquad (5)$$

$$V_{ij} = |b_{ij} - a_{ij}| \qquad (6)$$

Wherein, $i = 1, 2, \cdots, n; j = 1, 2, \cdots, m$. v_i represents the magnitude range of the classical field of matter-elements, $d(v_i, V_{ij})$ is the distance between point v_i and the finite interval V_{ij} of the corresponding characteristic vector.

3.4. Correlation Function of Evaluation Indexes

The correlation function expands the qualitative description that things have "a certain property of A" into the quantitative description of the degree that things have "a property of A", and expresses the degree when the value of the matter-element conforms to the value range of the corresponding grade.

The correlation function is defined as:

$$K_j(v_i) = \begin{cases} -\dfrac{d(v_i, V_{ij})}{|V_{ij}|} & v_i \in V_{ij} \\ \dfrac{d(v_i, V_{ij})}{d(v_i, V_{ip}) - d(v_i, V_{ij})} & v_i \notin V_{ij} \end{cases} \qquad (7)$$

Wherein, $K_j(v_i)$ is the correlation of the ith index corresponding to the matter-element of grade j.

3.5 Calculation of Correlation

$$K_j(P) = \sum_{i=1}^{n} w_i K_j(v_i) \qquad (8)$$

Wherein, $K_j(P)$ is the correlation of the matter-element P (which is to be evaluated) about the evaluation grade j; $K_j(v_i)$ is the correlation of the ith index to grade j; w_i is the weight of the ith index. The paper uses the entropy method for calculation. If $K_j = \max\{K_j(P)\}$, the matter-element P which is to be evaluated belongs to grade j.

3.6. Improvement of Model
When the matter-element extension model is directly used, the meaningless of the correlation function may occur, the reason is that the actual value of the evaluation index exceeds the range of the segment field. Thus, the matter-element extension evaluation model shall be improved.

(1).The magnitude of the original classical field was normalized. Both ends of the magnitude of the classical field were divided at the same time by the value b_{np} at the right end of the segment field V_p, and then a new classical matter-element matrix $R_N{}'$ was obtained.

$$R_N{}' = \begin{bmatrix} N_i & C_1 & (a_{i1}/b_{i1}, b_{i1}/b_{1p}) \\ & C_2 & (a_{i2}/b_{i2}, b_{i2}/b_{2p}) \\ & \vdots & \vdots \\ & C_n & (a_{in}/b_{np}, b_{in}/b_{np}) \end{bmatrix} \qquad (9)$$

(2).In the same way, the magnitude of the original matrix of matter-element to be evaluated was normalized. Both ends of the magnitude of the original matrix of matter-element to be evaluated were divided at the same time by the value b_{np} at the right end of the segment field V_p, and then a new matrix of matter-element to be evaluated $R_o{}'$ was obtained.

$$R_o{}' = \begin{bmatrix} N_o & C_1 & V_1/b_{1p} \\ & C_2 & V_2/b_{2p} \\ & \vdots & \vdots \\ & C_n & V_n/b_{np} \end{bmatrix} \qquad (10)$$

(3). To the new matter-element to be evaluated, the distance D_{ij} of the new magnitude range of the classical field was calculated as follows:

$$D_{ij} = |V_i - (a_{ij} + b_{ij})/2| - (b_{ij} - a_{ij})/2 \qquad (11)$$

(4). Calculated the correlation: substitute the correlation function $K_j(V_i)$ with the distance D_{ij}, and then the comprehensive correlation $K_j(P)$ was obtained as follows:

$$K_j(P) = 1 - \sum_{i=1}^{n} w D_{ij} \qquad (12)$$

(5). Confirmed the evaluation grade: if $K_j = \max\{K_j(P)\}$, the matter-element P to be evaluated belongs to grade j.

4. Case Analysis

The phase I engineering of Guizhou Huaxi Yunding wind power plant (hereinafter refer to as the first stage project of Yunding wind farm) is located in Gaopo Town, Huaxi District, Guiyang City, Guizhou Province. A 110kV step-up substation is newly built in the wind farm according to the scale of 100MW. The first and second stage projects of the Yunding wind farm shares the booster substation. The project uses the EPC mode and relates to many procurement items, mainly including wind turbines, box-type transformers, 110kV booster transformers, 110kV high-voltage apparatus, high and low voltage cables, comprehensive automation of 110kV substations, etc.

After preliminary screening, there were four potential suppliers which were respectively marked as supplier A, supplier B, supplier C and supplier D. The section uses the evaluation model based on matter-element extension for assessing equipment suppliers so as to choose the best partner from them. The relevant average data of all suppliers in the last three years are shown in table 2.

Table 2 Potential supplier data sheet

Grade I index	Grade II index	Supplier A	Supplier B	Supplier C	Supplier D
Equipment Level	Quality certification %)	85	92	83	88
	Equipment qualified rate (%)	96	95	95	95
	Procurement cost（10-thousand Yuan）	385	398	370	340
	Rate of delivery on time (%)	91	89	85	85
	Equipment flexibility（one hundred-mark system）	90	83	82	90
R&D Ability	Independent R&D ability (%)	65	73	70	72
	Coordinative R&D ability (one hundred-mark system)	70	75	80	75
	Investment rate of R&D capital(%)	8.32	9.86	8.2	8.2
	Rate of R&D personnel (%)	3.3	5	4	4
Enterprise's own ability	Qualification and credit(one hundred-mark system)	83	84	86	82
	Financial status (one hundred-mark system)	66	58	60	65
	Setting of management organization(one hundred-mark system)	70	78	82	75
	Employee quality (one hundred-mark system)	45.9	48.4	39.2	47.5
Cooperation ability	Support from senior leaders(one hundred-mark system)	64	60	75	84
	Enterprise compatibility(one hundred-mark system)	80	86	82	79
	Information sharing(one hundred-mark system)	85	90	86	92
	Contract performance ability (%)	88.2	92	81	83.2
Service ability	Installation and commissioning(one hundred-mark system)	83	78	78	81
	Quality assurance system(one hundred-mark system)	80	82	78	82
	Service speed and efficiency (%)	76	84	72	77
	Service attitude (one hundred-mark system）	80	83	78	76

4.1. Matrixes of the Classical Field, Segment Field and Matter-element to be Evaluated

Supplier A was taken as an example, the matrixes R' of classical field and segment field which were normalized were structured according to formulas (9) and (10) and table 1.

$$R' = \begin{bmatrix} N & C & N_1 & N_2 & N_3 & N_4 \\ & C_1 & (0.970, 1.000) & (0.940, 0.970) & (0.910, 0.940) & (0.880, 0.910) \\ & C_2 & (0.980, 1.000) & (0.960, 0.980) & (0.940, 0.960) & (0.920, 0.940) \\ & \vdots & \vdots & \vdots & \vdots & \vdots \\ & C_{21} & (0.900, 1.000) & (0.800, 0.900) & (0.700, 0.800) & (0.600, 0.700) \end{bmatrix}$$ The matrix

$R_p{}'$ of the segment field and the matrix $R_o{}'$ of the matter-element to be evaluated which are normalized were confirmed according to the magnitude range of the classification standards of table 2.

$$R_p{}' = \begin{bmatrix} N_p & C & V \\ & C_1 & (0.88, 1.00) \\ & C_2 & (0.92, 1.00) \\ & \vdots & \vdots \\ & C_{21} & (0.60, 1.00) \end{bmatrix} \qquad R_o{}' = \begin{bmatrix} N_o & C_1 & 0.850 \\ & C_2 & 0.960 \\ & \vdots & \vdots \\ & C_{21} & 0.800 \end{bmatrix}$$

4.2. Calculation of Correlation

The distances of the evaluation indexes for selecting equipment suppliers of Yunding wind power generation EPC project in Huaxi, Guizhou to grades I, II, III and IV were calculated out according to formula (11):

$$D_{ij} = \begin{bmatrix} 0.0857 & -0.0857 & 0.2000 & 0.4857 \\ 0.1500 & 0.0500 & -0.0500 & 0.0500 \\ 0.1428 & -0.1429 & 0.1429 & 0.4286 \\ \vdots & \vdots & \vdots & \vdots \\ 0.3333 & 0.0833 & -0.0833 & 0.0833 \\ 0.0200 & -0.0200 & 0.1800 & 0.3800 \end{bmatrix}$$

The entropy method was used for weight calculation, and formula (12) was combined. Then $K_I(P) = 0.894$, $K_{II}(P) = 0.943$, $K_{III}(P) = 0.722$ and $K_{IV}(P) = 0.794$ were calculated out.

4.3. Confirmation of Evaluation Grades

Indicated by $K_j = \max\{K_j(P)\} = 0.943$, the evaluation of equipment supplier A was grade II.

The comprehensive correlation values of suppliers B, C and D were calculated out through the same method, and not listed in the paper in detail. The evaluation of suppliers B, C and D were respectively grades I, III and III. Thus, according to the evaluation results, the equipment supplier B should be selected for the project. In the actual project, the equipment supplier B was selected as the equipment supplier partner, thus, the method is effective in actual application.

5. Conclusion

(1) The paper constructed the evaluation index system of selecting equipment suppliers for wind power generation EPC project from multiple perspectives, evaluated the selection of the equipment suppliers of the phase I engineering of Guizhou Huaxi Yunding wind power plant on the basis of the improved matter-element extension evaluation model, and perfected the theory of supplier selection.

(2) The matter-element extension evaluation model can evaluate the selection of the equipment suppliers from the qualitative and quantitative point of view, and the correlation function used in it can truly reflect the affiliation of the evaluation indexes, and then the evaluation results can better conform to the actual condition.

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