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Original Research Article

Power Grid Equipment Supplier Selection Based on Cloud Model and Hesitant Linguistic Information

Yunna Wu[1], Kaifeng Chen[1,*], Yi Zhang[2]
[1]School of Economics and Management, North China Electric Power University, Beijing, China
[2]Inner Mongolia EHV Power Supply Bureau, China

***Corresponding author**
Kaifeng Chen
Email: ckfhdchina@126.com

Abstract: Power grid equipment is the guarantee of the safe and stable operation of power grids, selecting rational power grid equipment suppliers is the focus of power grid enterprise. In order to select the equipment supplier for grid enterprises more objectively and comprehensively, this paper proposes a power grid equipment supplier selection method based on cloud model and hesitant linguistic information, considering the compensation effect among indicators. First, this paper builds an evaluation index system of the equipment supplier selection. Next, using the hesitant linguistic information with credibility to describe the indicators information, and carrying on the transformation by using cloud model, the results of the supplier evaluation indicators can be gained. Finally, through the compensation effect among the indicators, the evaluation results are aggregated. The proposed method can improve scientifically the power grid equipment supplier selection evaluation system, and make the power grid enterprises choose a more reasonable selection of equipment suppliers.
Keywords: Power grid enterprise; hesitant linguistic information; credibility; cloud model; compensation effect.

INTRODUCTION

With the increasing demand for electricity and power supply reliability, the stability of power grid operation has become first subject to electric power enterprises. Actually, the power grid equipment is the most direct factors affecting the normal operation of power grid. Therefore, for power grid enterprise long-term safe operation and good development, it is critical to evaluate and select the power grid equipment suppliers scientifically and rationally.

Currently, some research on supplier selection methods can be found, such as Ref [1] proposed an integrated framework based on analytic hierarchy process (AHP) and technique for order preference by similarity to an ideal solution (TOPSIS) for selecting the suitable supplier. Besides, some MCDM methods used for supplier selection can be listed as follows: analytic network process (ANP) [2,3], preference ranking organization method for enrichment evaluations (PROMETHEE) [4] and elimination et choice translating reality (ELECTRE) [5] and other hybrid methods integrating fuzzy set theory [6, 7], etc. To a certain extent, the above researches solved the equipment supplier selection evaluation decision problem. However, two problems are still unsolved. (1) Information loss. The quantitative description of evaluation information not only is not conducive to understand, but also reduce reliability without considering the randomness. Besides, decision makers with different expertise, practical experience and backgrounds express their preference information with different reliability coefficients, which failed to be paid attention. (2) Compensation effect. The above researches assumed that the indicators can be fully compensated. However, the fact is not the case, such as the quality of equipment cannot be compensated since equipment quality is the foundation of the power grid reliability and stability. Of course, such indicator as after-sales service can compensate equipment cost.

Therefore, the cloud model is introduced to describe the information uncertainty, which can give consideration to both fuzziness and randomness to reduce information loss. Among the uncertainties involved in natural language, randomness and fuzziness are the two most important aspects. Meanwhile, the compensation effect is further analyzed and the decision-making information of suppliers will be aggregated accordingly. Both efforts contribute to a better decision-making.

The remainder of the paper is structured as follows. Section 2 proposed a supplier selection methods based on cloud model and hesitant linguistic information. Section 3 analyzes the detailed sub-criteria of criteria considered for supplier selection. In Section 4, a case study from China is evaluated. Subsequently, final conclusion is provided in Section 5.

POWER GRID EQUIPMENT SUPPLIER SELECTION MODEL

Cloud model and hesitant fuzzy linguistic information with credibility

Definition 1 [8]. Suppose U is a quantitative domain expressed by precise values, and C is a qualitative concept on the domain. If the quantitative value is a random instantiation to C, whose membership for C is a random number with stable tendency.

Definition 2 [8]. Let U be the universe of discourse and T a qualitative concept in U. If $x\left(x \in U\right)$ is a random instantiation of concept T, which satisfies $En' \sim N\left(En, He^2\right)$, $x \sim N\left(Ex, En'^2\right)$ and the certainty degree of x belonging to concept T satisfies

$$\mu = e^{-\frac{\left(x-Ex\right)^2}{2\left(En'\right)^2}}$$

Then the distribution of x in the universe U is called a normal cloud. The cloud model can effectively integrate the randomness and fuzziness of concepts and describe the overall quantitative property of a concept by three numerical characteristics, namely, Expectation$\left(Ex\right)$, Entropy$\left(En\right)$, and Hyper entropy$\left(He\right)$. Here, Ex is the mathematical expectation of the cloud drops belonging to a concept in the universe and is the most representative and typical sample of the qualitative concept; En represents the fuzziness measurement of a qualitative concept, which is determined by both the randomness and the fuzziness of the concept; He is the uncertain degree of entropy En, which reflects the dispersion of the cloud drops.

Definition 3 [9]. Let X be a reference set and $S = \left\{ s_\alpha \left| s_0 \le s_\alpha \le s_g, \alpha \in \left[0, g\right] \right. \right\}$ be a linguistic term set. A HFLS on X is in terms of a function E that when applied to X returns a subset of S. And the HFLS can be represented as the following mathematical symbol:

$$E = \left\{ < x, h_E(x) > \left| x \in X \right. \right\}$$

Definition 4 [9]. Orderly linguistic scale $S = \left\{ s_1, s_2, \cdots, s_g \right\}$ is the set of g orderly linguistic items, iff $a < b$, $s_a < s_b$, $a, b \in \left\{1, 2, \cdots, g\right\}$.

In this paper, a 5-scale linguistic term is used, namely $S = \left\{ s_{-1}: \text{very poor}, s_{-2}: \text{poor}, s_0: \text{medium}, s_1: \text{good}, s_2: \text{very good} \right\}$

Definition 5. Hesitant fuzzy linguistic information with credibility is $H(x) = \left\{ < l_1, s_1 >, < l_2, s_2 >, \cdots, < l_n, s_n > \right\}$.

where l_n denotes the credibility of the *nth* linguistic information, namely s_n. When $l_1 = l_2 =, \cdots, = l_n = 1$, hesitant fuzzy linguistic information with credibility degrades into hesitant linguistic information.

The proposed method

Step 1 Transfer linguistic information into cloud variables

Suppose $U^* = \left[0, 100\right]$, $He_0 = 0.1$, golden section method is used to transfer linguistic information into cloud variables.

(i) Calculate Ex.

$$Ex_0 = (X_{\min} + X_{\max})/2,\quad Ex_{(n-1)/2} = X_{\max},\quad Ex_{-(n-1)/2} = X_{\min},$$

$$Ex_i = Ex_0 + 0.382i(\frac{X_{\max} + X_{\min}}{2}) \Big/ \frac{(n-3)}{2},$$

$$Ex_{-i} = Ex_0 - 0.382i(\frac{X_{\max} + X_{\min}}{2}) \Big/ \frac{(n-3)}{2},\ (1 \le i \le \frac{n-3}{2}).$$

(ii) Calculate En.

$$En_{-1} = En_1 = \frac{0.382 \times (X_{\max} - X_{\min})}{6},\quad En_0 = 0.618 En_{+1},\quad En_{-i} = En_i = \frac{En_{i-1}}{0.618},\ (2 \le i \le \frac{n-1}{2}).$$

(iii) Calculate He.

He_0 is given beforehand, and $He_{-i} = He_{+i} = He_{i-1}/0.618,\ 1 \le i \le (n-1)/2$.

In this paper, the corresponding cloud variables can be shown as follows:
$Y_{-2} = (0, 10.31, 0.26)$, $Y_{-1} = (30.9, 6.37, 0.16)$, $Y_0 = (50, 3.93, 0.1)$,
$Y_1 = (69.1, 6.37, 0.16)$, $Y_2 = (100, 10.31, 0.26)$

Step 2 Aggregate the cloud variables with credibility

For a hesitant fuzzy linguistic information with credibility of an indicator of an alternative $H(x) = \{<l_1, s_1>, <l_2, s_2>, \cdots, <l_n, s_n>\}$, according to the one-dimensional cloud generator algorithm [8], the cloud variables can be transformed into N cloud drops, namely (x_1, y_1), (x_2, y_2),..., (x_N, y_N). The cloud composed of N cloud drops is shorthand for A, and the estimated value is $\hat{s}(A)$ [10].

$$\hat{s}(A) = \frac{1}{n}\sum_{i=1}^{n} x_i y_i \tag{1}$$

When $H(x)$ is transferred into cloud variables, the estimated values are $\hat{s}_1(H)$, $\hat{s}_2(H)$,..., $\hat{s}_n(H)$ respectively, and they are aggregated to $Ag(H)$ by weighted average method

$$Ag(H) = \frac{1}{\sum_{i=1}^{n} l_i}(\sum_{i=1}^{n}(l_i * \hat{s}_i(H))) \tag{2}$$

Step 3 Rank the alternatives considering the compensation effect among indexes

This paper ranks the alternatives based on incomplete compensation principle, the score of a power grid equipment supplier is S_f

$$S_f = (\sum_i \omega_i * Ag(H_i)) \bullet (\sum_j \omega_j * Ag(H_j)) \bullet \cdots \bullet (\sum_k \omega_k * Ag(H_k)) \tag{3}$$

where $\omega_i, \omega_j, \cdots, \omega_k$ are the corresponding weights of indexes respectively.

INDEX SYSTEM FOR POWER GRID EQUIPMENT SUPPLIER SELECTION

For power grid enterprises, equipment quality (C1) is the decisive factors to select equipment suppliers. The characterization indexes of equipment quality includes five parts, namely equipment specification coincidence rate (C11), the qualification rate of type test report (C12), the responsivity of technical specifications (C13), equipment qualification rate (C14) and level of quality certification (C15). C11-C13 analyze the equipment quality from the perspective of conformity with the requirements of power grid enterprise. C14 shows the overall quality level of the equipment supplier. C15 reflects the long-term stability of the quality level of supplier equipment, which can be a valuable reference indicator.

$$C11 = \frac{The\ number\ of\ equipment\ conform\ to\ the\ biding\ specification}{The\ total\ number\ of\ equipment\ required} * 100\% ,$$

$$C12 = \frac{The\ number\ of\ qualified\ test\ reports}{The\ total\ number\ of\ test\ reports} * 100\% ,$$

$$C13 = \frac{The\ number\ of\ equipment\ conform\ to\ the\ technoligical\ specification}{The\ total\ number\ of\ equipment\ required} * 100\% ,$$

$$C14 = \frac{The\ number\ of\ qualified\ purchasing\ equipment}{The\ total\ number\ of\ purchasing\ equipment} * 100\%$$

Equipment cost (C2) is an important factor when selecting the best equipment suppliers. Actually, in the investment plan of the power grid company, equipment investment can account for at least 63.6% of the total investment. Grid equipment investment includes not only the initial purchase cost of power grid equipment, but also long-term operation & maintenance and fault recovery costs. Considering about product life cycle, the characterization indexes of equipment cost includes four aspects, namely equipment procurement cost (C21), running cost (C22), maintenance costs (C23) and fault repair costs (C24). Based on the above, it is very beneficial to select the supplier having a cost advantage for a long time.

Equipment supply ability (C3) reflects the supplier's delivery ability and production capacity, which directly affects long-term cooperation between the two sides and is a necessary reference factor for supplier selection. The characterization indexes of equipment supply ability mainly include three respects: on-time delivery (OTD) (C31), time flexibility (C32), quantity flexibility (C33). The higher OTD shows, the stronger the supplier's production capacity and supply ability are. C32 reflects the response speed to the changes in requirements of power grid enterprises. C33 shows the response capability for requirement change, for example, increasing the equipment supply.

$$C31 = \frac{Delivery\ times\ by\ the\ required\ date}{The\ total\ delivery\ times} * 100\%$$

Good after-sales service is also a basic requirement for the supplier. The characterization indexes of after-sales service (C4) are listed as follows: fulfillment rates of service commitment (C41), after-sales service response time (C42) and service attitude (C43). C41 reflects the quality of after-sales service. C42 shows the timeliness of solving after-sales problems. C43 is the direct result of supplier’s overall quality and strength.

In the process of supplier selection, decision makers should not only consider supplier’s present situation, but also supplier’s strategic prospects. Technology innovation ability (C5) is the key indicator to evaluate supplier’s strategy development potential. It contains four parts: scientific research funds investment proportion (C51), degree of automation (C52), new equipment development success rate (C53), educational level of technical person (C54). C51 can manifest the ability of strategic development planning and management. C53 is one of the important indicators to measure enterprise innovation ability and determines the strategic development level of the enterprise. Both indicators are the key technical indicators for measuring whether a long-term cooperation with the suppliers is possible. C52 reflect the supplier's ability to meet the technology demand of power grid enterprise. C54 directly reflects the enterprise existing technical support level.

Finance conditions will eventually reflect the supplier's production operations and the long-term development ability. Bad financial situation of suppliers may reduce greatly equipment production and supply due to a shortage of funds. Therefore, financial situation (C6) is one of the important indices to choose the optimal supplier. Three sub-indicators are considered in this paper, namely debt to assets ratio (C61), rate of return on common stockholders’ equity (ROE) (C62), quick ratio (QR) (C63). The three sub-indicators can reflect well the debt-paying and earning abilities.

$$C61 = \frac{Total\ liabilities}{Total\ assets} * 100\% ,$$

$$C62 = \frac{Net\ profit}{Average\ owner's\ equity} * 100\% ,$$

$$C63 = \frac{Current\ asset}{Current\ liabilities} * 100\%$$

Corporate reputation is an important index to measure whether an enterprise is worth cooperation when evaluating the suppliers. The characterization indexes of corporate reputation (C7) are rate of contract implementation (C71) and bank credit rating (C72).

$$C71 = \frac{The\ performance\ contract\ number}{The\ total\ contract\ number} * 100\%$$

Table 1: Index system for power grid equipment supplier selection

Indicator	Sub-indicator
Equipment quality	Equipment specification coincidence rate
	The qualification rate of type test report
	The responsivity of technical specifications
	Equipment qualification rate
	Level of quality certification
Equipment cost	Equipment procurement cost
	Running cost
	Maintenance costs
	Fault repair costs
Equipment supply ability	On-time delivery
	Time flexibility
	Quantity flexibility
After-sales service	Fulfillment rates of service commitment
	After-sales service response time
	Service attitude
Technology innovation ability	Scientific research funds investment proportion
	Degree of automation
	New equipment development success rate
	Educational level of technical person
Technology innovation ability	Scientific research funds investment proportion
	Degree of automation
	New equipment development success rate
	Educational level of technical person
Corporate reputation	Rate of contract implementation
	Bank credit rating

CASE STUDY

Decision problem analysis

"S" province in northwest China needs 110kV power transmission and transformation engineering equipment. The equipment can be divided into 12 categories (20 varieties). Through open tender, three suppliers are eligible to enter the bidding, namely supplier A, B, C respectively. The weight of indicators is $\omega = [0.3982, 0.1388, 0.0628, 0.1369, 0.1578, 0.0183, 0.0871]$. Then the decision makers, including three experts E_1, E_2, E_3, evaluate them. And the expert scoring results with the credibility are shown in table 2.

Table 2: Expert scoring results with the credibility

Sub-indicator	Weight	Supplier A	Supplier B	Supplier C
C11	0.1100	M(0.7), G(0.6)	VG	G(0.6), VG(0.8)
C12	0.0909	G	G(0.6), VG(0.4)	G(0.8), VG(0.3)
C13	0.0851	M(0.6), G(0.9)	VG	VG
C14	0.3639	G(0.4), VG(0.6)	G(0.5), VG(0.8)	VG
C15	0.3501	M(0.6), G(0.3)	G	G(0.5), VG(0.9)
C21	0.3537	P(0.6), G(0.8)	M(0.9), VG(0.6)	G
C22	0.1671	M(0.4), VG(0.8)	P(0.4), M(0.6)	P
C23	0.1189	P(0.6), M(0.4)	G(0.9), VG(0.6)	M(0.5), G(0.7), VG(0.8)
C24	0.3610	G	M(0.3), G(0.8)	G
C31	0.6306	G(0.6), VG(0.9)	G(0.8), VG(0.5)	M(0.4), G(0.7)
C32	0.2261	M	G(0.3), VG(0.7)	M(0.6), G(0.4)
C33	0.1417	M(0.5), G(0.8)	G	M(0.5), G(0.9)
C41	0.4427	G	M(0.7), G(0.3)	G(0.4), VG(0.6)
C42	0.4719	P	VG	M(0.8), VG(0.4)
C43	0.0855	G(0.8), VG(0.3)	G	P
C51	0.0805	G	G(0.7), VG(0.7)	M(0.3), G(0.6)
C52	0.4981	M(0.6),VG(0.4)	G	M(0.9), G(0.5)
C53	0.3834	M(0.8), G(0.2)	G(0.7), VG(0.9)	M
C54	0.0380	G(0.6), VG(0.7)	G(0.8), VG(0.5)	M
C61	0.2514	M	P(0.3), G(0.6)	P
C62	0.5683	G(0.4), VG(0.7)	G(0.4), VG(0.8)	G(0.9), VG(0.7)
C63	0.1749	M	M(0.8), G(0.4), VG(0.7)	G
C71	0.7256	G(0.7), VG(0.6)	VG	M(0.8), G(0.3)
C72	0.2744	M(0.4), G(0.8)	VG	M(0.6), G(0.8)

Based on equations (1) and (2), the information of all the sub-indicators can be aggregated. The corresponding aggregated results of supplier A, B and C are listed as follows:

A=[49.2050 43.8632 53.3314 36.5702 45.4277 54.3947 70.2513]

B=[58.9009 45.6597 57.5995 55.1176 54.7577 69.4408 71.1060]

C=[57.7019 44.9159 43.0409 51.6643 38.3842 67.2110 47.5752]

Next, the information of all the indicators can be aggregated according to equation (3) and compensation effect. This paper takes supplier A as an example, the corresponding aggregated result can be gained as following.

$$S_{fA}=(\omega(1)*A(1))\bullet(\omega(2)*A(2)+\omega(4)*A(4)+\omega(5)*A(5))\bullet(\omega(3)*A(3)+\omega(6)*A(6)+\omega(7)*A(7))$$

Finally, the equipment supplier evaluation results considering compensation effect are gained and shown in table 3.

Table 3: The equipment supplier evaluation results considering compensation effect

Supplier	Supplier A	Supplier B	Supplier C
Case 0: Partial Compensation (considering credibility)	3744.20 [2]	5854.10 [1]	3593.60 [3]
Case 1: complete compensation	48.3201 [3]	57.0596 [1]	50.4178 [2]
Case 2: partial compensation (without considering credibility)	5276.40 [3]	6254.60 [1]	5296.00 [2]

Seen from table3, in case 1, the alternatives ranking is B>C>A; in case 2 the ranking is B>A>C. Therefore, supplier B is optimal. The reason for the ranking changes between supplier A and C is that good financial condition can compensate for the disadvantages in the technical innovation ability of supplier C in case 1. However, in case 0, good financial condition cannot compensate for the disadvantages. Neglecting credibility in case 2may cause inaccurate results, though the results are in accordance with ones in case 0.

Sensitivity analysis

A good evaluation model should be strong in robustness. In order to evaluate the stability of the evaluation result, the sensitivity by switching any two weights of C1, C2, C3, C4, C5, C6 and C7 are conducted. Meanwhile, the correlation coefficients matrix between every two decision factors still remains the same. The whole results of sensitivity analysis are shown in table 4. From table 4, supplier B is always the best supplier. Based on the above analysis, decision makers can draw a conclusion that the evaluation model in this paper has a strong stability to choose the best one from multiple alternatives.

Table 4: The whole results of sensitivity analysis

No.	Weights	Ranking
1	[0.3982,0.1388 ,0.0628,0.1369,0.1578,0.0183,0.0871]	B>A>C
2	[0.1388 ,0.3982,0.0628,0.1369,0.1578,0.0183,0.0871]	B>A>C
3	[0.0628,0.1388 ,0.3982,0.1369,0.1578,0.0183,0.0871]	B>A>C
4	[0.1369,0.1388 ,0.0628,0.3982,0.1578,0.0183,0.0871]	B>C>A
5	[0.1578,0.1388 ,0.0628,0.1369,0.3982,0.0183,0.0871]	B>A>C
6	[0.0183,0.1388 ,0.0628,0.1369,0.1578,0.3982,0.0871]	B>C>A
7	[0.0871,0.1388 ,0.0628,0.1369,0.1578,0.0183,0.3982]	B>A>C
8	[0.3982,0.0628,0.1388,0.1369,0.1578,0.0183,0.0871]	B>A>C
9	[0.3982,0.1369,0.0628,0.1388 ,0.1578,0.0183,0.0871]	B>A>C
10	[0.3982,0.1578,0.0628,0.1369,0.1388 ,0.0183,0.0871]	B>A>C
11	[0.3982,0.0183,0.0628,0.1369,0.1578,0.1388 ,0.0871]	B>C>A
12	[0.3982, 0.0871,0.0628,0.1369,0.1578,0.0183,0.1388]	B>A>C
13	[0.3982,0.1388 ,0.1369,0.0628,0.1578,0.0183,0.0871]	B>A>C
14	[0.3982,0.1388 ,0.1578,0.1369,0.0628,0.0183,0.0871]	B>A>C
15	[0.3982,0.1388 ,0.0183,0.1369,0.1578,0.0628,0.0871]	B>C>A
16	[0.3982,0.1388 ,0.0871,0.1369,0.1578,0.0183,0.0628]	B>A>C
17	[0.3982,0.1388 ,0.0628,0.1578,0.1369,0.0183,0.0871]	B>A>C
18	[0.3982,0.1388 ,0.0628,0.0183,0.1578,0.1369,0.0871]	B>C>A
19	[0.3982,0.1388 ,0.0628,0.0871,0.1578,0.0183,0.1369]	B>A>C
20	[0.3982,0.1388 ,0.0628,0.1369,0.0183,0.1578,0.0871]	B>C>A
21	[0.3982,0.1388 ,0.0628,0.1369,0.0871,0.0183,0.1578]	B>A>C
22	[0.3982,0.1388 ,0.0628,0.1369,0.1578,0.0871,0.0183]	B>C>A

CONCLUSIONS

In the light of the characteristics of selecting equipment suppliers, this paper constructs the index system for power grid equipment supplier selection and proposes the cloud model and hesitant linguistic information-based equipment supplier selection method considering compensation effect. The method first uses hesitant linguistic information with credibility to describe the indicators information of all the alternatives, which not only can effectively solve information loss but also can reflect and take into account the experts' different opinions. Next, it uses cloud model to aggregate the hesitation linguistic information, which can give consideration both to fuzziness and randomness, and improve the decision accuracy. Finally, according to the compensation effect, the decision results can be gained, which can help power grid enterprise to select more scientific and reasonable equipment suppliers.

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