A Method to Evaluate the Hoisting Outsourcing Provider of Wind Turbines

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***Abstract*—Service outsourcing is an organizational model that can effectively maximize the efficiency of business activities by reducing the input of human and material resources. In wind power industry, many business activities can be outsourced, i.e., hoisting, transportation, commissioning, and maintenance. The selection and evaluation of outsourcing service providers is an important issue. This paper develops a method to evaluate the hoisting outsourcing provider of wind turbines. The logistic function is used to normalize the data other than the linear normalization method, which makes the results of evaluation more scientific, reasonable and robust. A practical case study is delivered to validate the developed method.**

Keywords- Analytic hierarchy process; index normalization; logistics function; wind power

Notations:

$\boldsymbol{\lambda}$: the eigenvector of a comparison matrix

$\boldsymbol{n}$: the order of a decision matrix

$\boldsymbol{w_i}$: the weight of each indicator

$\boldsymbol{v_i}$: the score of each indicator

$\boldsymbol{u}$: the comprehensive score of each provider

$\boldsymbol{X}$: initial data to be normalized

$\boldsymbol{X_{min}}$: the minimum value of the data to be noramalized

$\boldsymbol{X_{max}}$: the maximum value of the data to be noramalized

$\boldsymbol{X^*}$: the result that is normalized by linear method

$\boldsymbol{v(x)}$: the result normalized by Logistic value function.

$\boldsymbol{Z}$: change of the score

$\boldsymbol{\bar{Z}}$: the average rate of change of the score

$\boldsymbol{y}$: represents the score of the provider

$\boldsymbol{y_0}$: score of providers before the participation of a new index

$\boldsymbol{y_1}$: score of providers after the participation of a new index

I. INTRODUCTION

Wind power is the fastest growing renewable energy in the world nowadays. The installed capacity of wind power increases rapidly, and the average annual growth rate of newly installed capacity and total installed capacity are both around 28% [1]. According to Ref. [2], China's installed wind power capacity will reach 1,000 GW by 2050, meeting 17% of the electricity demand at that time.

Outsourcing is one of the driving forces that bring fundamental changes to enterprises in the past decades, and it is also the strategy that many world-class enterprises often adopt. Faced with the fierce competition in the market, outsourcing is gradually favored by the wind power industry equipment maintenance and management institutes [3-5]. Hoisting outsourcing is an effective approach to reduce high maintenance costs of wind turbines (WTs). Outsourcing decision has a significant impact on the availability of equipment and the success of the business. Consequently, it is significant to evaluate and select the suitable provider with proper indicators. Talluri et al. [6], Aissaoui et al. [7] and Chiang et al. [8] emphasized the strategic importance of evaluation for providers and the trade-off among cost, quality and delivery performance. In addition, Peidro and Vasant [9] attempted to take several constraints into consideration, e.g., the demand of buyers, as well as the capacity, quota flexibility, and allocated budget of providers.

There are many businesses involved in the equipment management process in the wind power industry. The businesses adopt process management and process evaluation other than quantitative measurements. Therefore, there are many indicators to evaluate, and subjective scoring and objective information should be considered. Some scholars have carried out evaluations on equipment hoisting outsourcing service providers, mainly focusing on: chivalrous maintenance [10], overall outsourcing of equipment maintenance [11-14], and application of single evaluation method in this field [15]. The provider evaluation solutions for equipment maintenance subcontracting in wind power industry have not been comprehensively sorted out.

The analytical hierarchy process (AHP) is the most common for selecting the best provider. It is an accurate scoring method

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that has been applied to provider selection [16]. Masella and Rangone [17] provided four types of provider selection systems by using AHP method. Kilincci and Onal [18] proposed a fuzzy AHP method to select the best provider for maximizing the customer satisfaction. Tam and Tummala [19] developed an AHP model for provider selection of a telecommunications company. An AHP model is suggested in ref. [20] to rank the performance of providers by calculating the weights of tangible and intangible criteria. Handfield et al. [21] proposed an AHP model to evaluate providers along environmental dimensions. However, linear normalization is the most popular method of normalized in AHP, which always leads to the data fluctuation by outliers.

This paper proposes a comprehensive solution to the equipment hoisting outsourcing in wind power industry, especially the subcontracting after the dismantling of maintenance business. Indicators used in hoisting outsourcing evaluation, the weights of these indicators, and the processing of evaluation data are also included in this paper. AHP is chosen to determine the weight of indicators. The logistics function that is resistant to extreme interference is utilized in this paper to handle normalization of evaluated values. Finally, a case study is carried out to verify the feasibility of the proposed method.

The remainder of this paper is organized as follows. In section 2, a method based on AHP to evaluate the hoisting outsourcing provider of wind turbines is developed. A practical case study is then proposed in Section 3. Finally, Section 4 concludes this work.

II. AN METHOD TO EVALUATE THE OUTSOURCING PROVIDER OF WIND TURBINES BASED ON AHP

The hoisting outsourcing of wind turbines is complicated, and requires the participation and cooperation of both the on-site personnel and the back-office personnel. Therefore, there are a lot of indicators for evaluating providers, and these indicators are often strongly related to each other. AHP can depose the multi-objective decision problem into multiple targets, and then the qualitative index fuzzy quantification method is used to calculate the weight of the index to the previous level, and finally synthesizing the score of a provider. Therefore, the method is applicable to the evaluation for providers of the wind turbine maintenance service.

2.1 Introduction of main indicators

There are many important indicators used in this paper to evaluate an outsourcing provider. Some of their implications are introduced in this section.

• Timeliness and reasonableness of quotation：The price for completing business can be given in time, and the price is reasonable during the market.

• The performance of recce assembling: A complete road survey report will be issued in time, and the rectification can be carried out according to the revised opinions.

• Timeliness of entering: Construction tools can enter the construction site within the required time.

• Contract execution and emergency handling: The ability to strictly enforce contractual requirements and proactively assist in work

• Continuous improvement： External parties can make active improvements or cooperate with the establishment of relevant mechanisms to ensure our needs

• The paper documents: Provide complete documentation within the required time

• Extensive resources: Ability to undertake multiple segment services

• Construction quality and safety: Recording number of poor quality safety records during construction

• Difficult project contracting: The ratio of difficult projects number undertaken by the outsourcing party to the total number of contracted businesses

• Proportion of business volume: The ratio of the outsourced business to the total annual business of the provider.

• Integrity of qualification: Qualification to meet site requirements.

• Compliance of hoisting vehicle: The model and quantity of cranes are provided as required and the working conditions can meet the requirements.

• Professionalism and timeliness: The ability of personnel command, technology and operation.

• Security: Field tools, safety protective equipment and personnel safety awareness

• degree of adaptability: A good attitude of personnel to Actively cooperate with project work.

2.2 The AHP method

Steps of AHP when applying to evaluate and choose a provider is listed as follows:

a) Establishing a hierarchical model: The selection objectives, consideration indicators (factors) and alternatives are divided into the highest, middle and lowest levels. The middle layer can pack multiple layers of indicators.

b) Constructing a judgment matrix: Multiple indicators of the same level are compared in pairs, and a judgment matrix is constructed. The commonly used judgment scale is 1 to 9.

c) Calculating the corresponding indicator weights: The eigenvalue method is used to calculate the weight value of the indicator at each level.

d) Consistency test: The comparison matrix is judged to ensure the satisfaction of mathematical logic by calculating the consistency index: $CI = \frac{\lambda - n}{n-1}$, where λ is the eigenvector and n is the order of the decision matrix.

e) Scores of each alternative under each indicator are calculated, summarized and sorted (the weighted sum model is generally used).

2.3 The Method of indicator Normalization

After determining the weight of an indicator, it is necessary to calculate the score of alternative schemes by this indicator. For indicators with quantitative data, it is necessary to normalize. There are usually two types of normalization methods, linear and nonlinear. The commonly used linear normalization method formula is as follows.

$$X^* = \frac{X - X_{min}}{X_{max} - X_{min}}. \quad 1$$

Here,X^* is the result that is normalized by linear method. X is the data to be normalized. It scales the original data equally to the interval of [0,1]. This method relies on historical data, and a new maximum value will greatly influence the result.

For the nonlinear value method, the most common one is the Logistic function. If the indicator x is the larger the better, the corresponding Logistic value function is defined as:

$$v(x) = 1/(1 + e^{-(x-\mu)/\sigma}). \quad 2$$

If the objective x is as small as possible, then the corresponding Logistic value function is given by:

$$v(x) = 1/(1 + e^{(x-\mu)/\sigma}), \quad 3$$

where μ and σ are the model parameters, which can be given based on historical data or industry standards. $v(x)$ is the normalization result of the logistic function.

2.4 Comparison of the normalization method

Indicator A is chosen as an example to show the effectiveness of the adopted normalization method. Assuming that the weight is 100%, the scores are calculated by linear and logistic normalization respectively as listed in TABLE I. Considering the development of outsourcing providers, the indicator data of the new provider may exceed (or be less than) the existing indicator. If a new provider A31 participates in the evaluation, the scores of other providers will change, and the rate of change is expressed by Z.

$$Z = \frac{|y_0 - y_1|}{y_0} \quad (4)$$

Here, y represents the score of the provider. y_0 is score of providers before the participation of provider A31. y_1 is score after considering index A31. Z indicates the average rate of change of the score. Then the relationship between Z and X is shown in the Figure 1. The abscissa is the ratio of the X to X_{max}. Where X is the score of A31 and X_{max} is the maximum value of other providers.

It is clearly shown in TABLE I and Figure 1 that, there is always an index score of 1 and 0 after the line is normalized. However, in practice, the provider who can participate in the evaluation rarely has a zero score. The two normalization methods have a small change in $\bar{Z}$ value when the new added data are within the range of 0-1 times of the maximum value, and the variation range is between -10% and 10%. If the new added data value is in the range of 1-2 times of the maximum value, the overall score of a provider will have a large change after linear normalization. The $\bar{Z}$ value range is between 10% and 50%. However, the score after normalization by the logistics function is still within 10%, indicating that the method has strong anti-interference ability for a larger new data value, and the evaluation result is more reliable. Moreover, if an indicator needs to establish a technical level of the industry standard, more historical data can be normalized by logistics function to determine the basic value of its technical level (generally 1/4, 1/2, 3/4 and the corresponding X are used as the upper and lower bounds of the technical level).

TABLE I. THE SCORES OF PROVIDERS

Provider	Scores	logistic normalization	linear normalization
A1	15.1001	0.1546	0
A2	23.0677	0.1745	0.0445
A3	23.1677	0.1747	0.0450
A4	27.6390	0.1867	0.0700
A5	38.3795	0.2182	0.1300
A6	40.9492	0.2262	0.1444
A7	41.9001	0.2293	0.1497
A8	62.5179	0.3019	0.2649
A9	89.4921	0.4138	0.4156
A10	90.2795	0.4172	0.4200
A11	94.4908	0.4359	0.4435
A12	96.4825	0.4449	0.4546
A13	102.652	0.4727	0.4891
A14	104.9464	0.4831	0.5019
A15	106.9498	0.4921	0.5131
A16	111.9906	0.5150	0.5413
A17	115.8108	0.5323	0.5626
A18	117.7209	0.5409	0.5733
A19	118.4749	0.5443	0.5775
A20	126.5330	0.5803	0.6225
A21	126.9906	0.5823	0.6251
A22	139.5063	0.6364	0.6950
A23	168.5800	0.7479	0.8575
A24	172.9454	0.7625	0.8819
A25	174.6406	0.7680	0.8913
A26	176.9819	0.7755	0.9044
A27	180.9246	0.7877	0.9264
A28	186.5649	0.8044	0.9579
A29	190.3744	0.8150	0.9792
A30	194.0828	0.8249	1

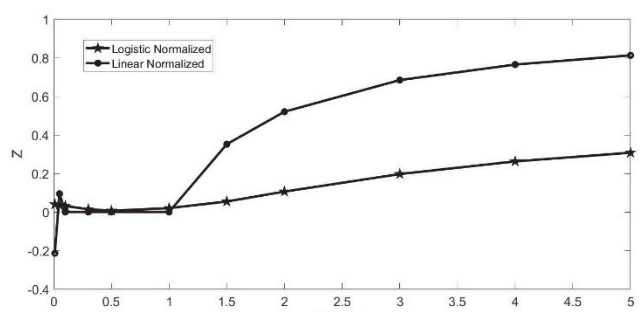

FIGURE 1. THE DIFFERENCE OF ORIGINALPROVIDER SCORE AFTER THE NEW PROVIDER ADDED

III. CASE STUDY

3.1 Background of the case

The case study in this section focuses on a wind turbine manufacturer who is to select outsourcing services for the hoisting business among 13 different providers. In order to achieve the hierarchical management and the benign competition, it is necessary to conduct a comprehensive evaluation of these providers. The evaluation indicators are composed of the office and the on-site information as shown in TABLE II. These indicators have such problems:

TABLE II. THE DEFINITION OF THE INDICATORS

Evaluator	score	indicator
On-site Evaluator	10	Timeliness and reasonableness of quotation
	5	The performance of recce assembling
	10	Timeliness of entering
	5	Contract execution and emergency handling
	10	Continuous improvement
	10	The paper documents
	10	Extensive resources
	10	Construction quality and safety
	10	Difficult project contracting
	10	Proportion of business volume
	10	Third party audit
	10	Integrity of recce
Office Evaluator	15	Timeliness of entering
	10	Integrity of qualification
	10	Completeness of personnel
	10	Compliance of hoisting vehicle
	15	Professionalism and timeliness
	20	Security
	10	Degree of adaptability

• Indicator redundancy: Some indicators appear in both on-site and office, which lead to a repeated evaluation.
• Unreasonable weight setting: The weight setting is only divided into 5 levels for 20 different indicators. The relative importance difference between many indicators is exactly the same.
• The correlation between indicators is strong
• The indicators are based on the selection of manufacturers, other than the decision objectives.

Therefore, it is necessary to rebuild the evaluation method of the hoisting service provider through the AHP method.

3.2 Evaluation method

According to the indicators shown in TABLE II, the comprehensive evaluation system for hoisting outsourcing service providers is constructed as shown in Figure 2. The system includes two aspects: on-site quality and contract implementation. The on-site quality includes 4 second indicators and 10 third indicators. The contract implementation includes 3 second indicators and 4 third indicators.

3.3 Relative weight of each indicator layer

According to the expert questionnaire, the nine-point scale and the normal weighting can be used to obtain the relative weight of each layer. Then, the weights of the upper-level indicators can be divided to obtain the lower-level index weights. The results are shown in TABLE III.

3.4 Normalization processing of indicators

For qualitative indicators, their evaluation scores are directly given by the relevant evaluators. Quantitative indicators can be normalized using the logistics function. The corresponding score can be obtained by multiplication of the value of $v(x)$ and the corresponding weight. In TABLE III, the quantitative indicators of total business volume, proportion of difficult items and resource extensiveness can be normalized. The results of total business volume is listed in TABLE IV.

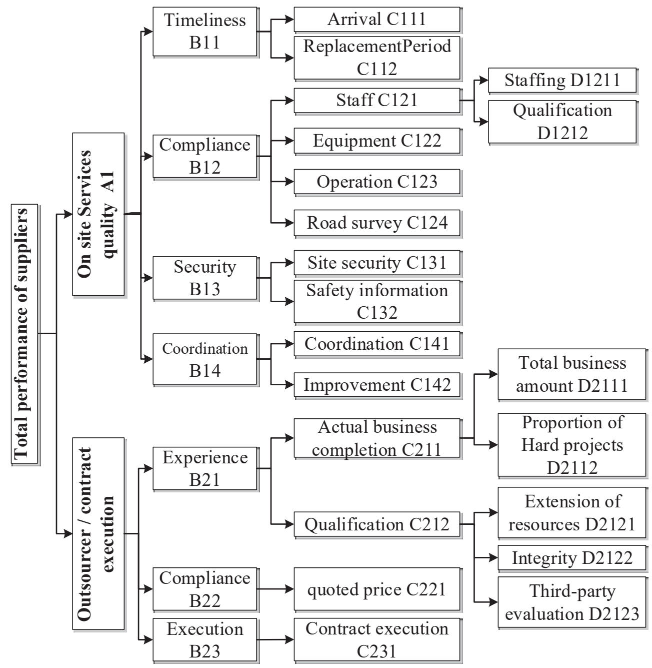

Figure 2. Relative weight of each indicator layer

TABLE III. RELATIVE WEIGHT OF INDICATORS

First indicator	Second indicator	Third indicator	Fourth indicator	Weight
Services quality of on site	Timeliness (11%)	Timeliness of Arrival		9%
		Timeliness of Replacement		2%
	Compliance (29%)	Staff	Staffing	2%
			Qualification	2%
		Equipment		8%
		Operation		6%
		Road survey		11%
	Security (22%)	Site security		10%
		Historical safety information		12%
	Coordination (7%)	Coordination on Site	Overall Coordination	5%
		improvement		2%
Outsourcer or contract execution	Experience (25%)	Actual business completion	Total business amount	8%
			Proportion of Hard projects	4%
		Qualification	Extension of resources	4%
			Integrity	7%
			Third-party evaluation	2%
	Compliance (3%)	quoted price	Timeliness and rationality	3%
			Bill document	

	Execution (3%)	Contract execution and incident handling		3%

TABLE IV. THE SCORE OF TOTAL BUSINESS AMOUNT

Provider	Number	$v(x)$	Score(8)
A1	82	0.93	7.46
A2	50	0.73	5.82
A3	45	0.67	5.39
A4	40	0.61	4.92
A5	33	0.53	4.21
A6	29	0.48	3.80
A7	28	0.46	3.70
A8	25	0.42	3.40
A9	21	0.38	3.00
A10	19	0.35	2.81
A11	14	0.30	2.36
A12	12	0.27	2.19
A13	4	0.20	1.60
parameter			
μ	30.9	σ	19.4

3.5 Indicator synthetic

As the outsourcing service needs to consider the compensatory nature, a weighted sum model is adopted for indicator synthesis, which is defined as

$$u = \sum_{i=1}^{n} w_i \, v_i, \; 0 \le w_i \le 1 \tag{5}$$

$$\sum_{i=1}^{n} w_i = 1 \tag{6}$$

The score of each indicator is multiplied by 100 (for the convenience of final evaluation) and then the final provider rating result is obtained, as listed in TABLE V.

TABLE V. RATING TABLE FOR PROVIDERS

ID	Vendor	Total Score	Rank	Original Score	Original Rank
1	A1	88.7	1	90.3	1
2	A2	84.5	2	87.2	2
3	A3	81.8	5	85.7	3
4	A4	77.9	8	85.2	4
5	A5	82.7	3	84.9	5
6	A6	82.2	4	83.4	6
7	A7	78.6	7	83.3	7
8	A8	79	6	83.1	8
9	A9	64.4	13	76.2	13
10	A10	77.8	9	82.2	9
11	A11	72.4	11	81.1	10
12	A12	75.2	10	80.5	11
13	A13	66.7	12	77.6	12
variation coefficient		8.81%		4.57%	
Variance		6.9		3.8	
Mean		77.8		83.1	

TABLE VI RATING STANDARD TABLE

	Standard		Level	Definition of levels
	Scores	Ranking and proportion		
1	[90,100]	Top 10%	S	Strategic and mature
2	[80,90]	Top 10% - 40%	A	Excellent and mature
3	[70,80]	Top 40% - 85%	B	Good and mature
4	[60,70]	Last 15%	C	Normal
5	<60	Last 5%	D	Normal

According to the scores in TABLE V, the corresponding rating standard table can be developed, as shown in

TABLE VI. It is effective to achieve the hierarchical management of providers for wind turbine manufactures.

The original evaluation method to generate first-level indicators is improved, and indicators become more distinguishable for evaluating providers. The management department of provider has applied the developed method in outsourcing provider selection. Annual performance, hierarchical management, and service performance is expected to be enhance by using the proposed method.

IV. CONCLUSION

In this paper, an evaluation method of wind turbine outsourcing service providers is proposed by the AHP, and the indicator weights are then determined. The logistic function is used to normalize the quantitative indicator evaluation data, and then the providers rating scheme is formed. The method is applied to actual business, and it proves that, the method for evaluating wind turbine outsourcing service providers are of great applicability and rationality. In addition, the proposed method provides a fair and scientific evaluation standard for the evaluation of outsourcing service providers in the wind power industry. In addition, the linear and nonlinear normalization methods are compared and analyzed. It is found that using the logistics function to normalize the indicator data has better robustness. Moreover, the method can provide data for the formulation of the industry standard technical level.

REFERENCES

[1] Global Wind Energy Council. Global wind 2007 report[R]. Belgium: Global Wind Energy Council, 2008.

[2] China Wind Power Development Roadmap 2050. Electrical World, vol. 6, pp. 50-50, 2012.

[3] Mcdougall P. Outsource more, spend less. Information Week, vol. 1072, pp. 24- 24, 2006.

[4] Mcdougall P . Customers rate their outsourcers. Information Week, v ol.1094, pp. 45- 45, 2006.

[5] Fan Tijun, Chen Rongqiu, Cui Nan. Analysis of Equipment Hoisting outsourcing Strategy. CMS, vol. 11, pp. 47-53, 2003.

[6] Talluri, S. and R. Narasimhan, Vendor evaluation with performance variability: A max–min approach. European Journal of Operational Research, vol. 146, pp. 543-552, 2003.

[7] Aissaoui, N., M. Haouari and E. Hassini, Supplier selection and order lot sizing modeling: A review. Computers & Operations Research, vol. 34, pp. 3516-3540, 2007.

[8] Chiang, C. and M. Shu. Supplier evaluation with quality-based fuzzy data. 2009: IEEE.

[9] Díaz-Madroñero, M., D. Peidro and P. Vasant, Vendor selection problem by using an interactive fuzzy multi-objective approach with modified S-curve membership functions. Computers & Mathematics with Applications, vol. 60, pp. 1038-1048, 2010.

[10] Murthy D N P , Karim M R , Ahmadi A . Data management in hoisting outsourcing. Reliability Engineering & System Safety, vol. 142, pp. 100-110, 2015.

[11] Pascual R , Santelices G , Liao H , et al. Channel coordination on fixed-term hoisting outsourcing contracts. A I I E Transactions, vol. 48, pp. 10, 2016.

[12] Hamidi M , Liao H . Hoisting outsourcing contracts based on bargaining theory. 2017.

[13] Wu S. Assessing maintenance contracts when preventive maintenance is outsourced. Reliability Engineering & System Safety, vol. 98, pp. 66-72, 2012.

[14] Krancher O , Dibbern J . Knowledge in Software-Hoisting outsourcing Projects: Beyond Integration of Business and Technical Knowledge. Hawaii International Conference on System Sciences. IEEE Computer Society, 2015.

[15] Long Yimin, Cui Nan. Fuzzy Comprehensive Evaluation Method for Performance Evaluation of Equipment Hoisting outsourcing Service Providers. Logistics Technology, vol. 26, pp. 6, 2007.

[16] Aissaoui, N., M. Haouari and E. Hassini, Supplier selection and order lot sizing modeling: A review. Computers & Operations Research, vol. 34, pp. 3516-3540, 2007.

[17] Masella, C. and A. Rangone, A contingent approach to the design of vendor selection systems for different types of co-operative customer/supplier relationships. International Journal of Operations & Production Management, vol. 20, pp. 70-84, 2000.

[18] Kilincci, O. and S.A. Onal, Fuzzy AHP approach for supplier selection in a washing machine company. Expert Systems with Applications, vol. 38, pp. 9656-9664, 2011.

[19] Tam, M. and V. Tummala, An application of the AHP in vendor selection of a telecommunications system. Omega-international Journal of Management Science, vol. 29, pp. 171-182, 2001.

[20] Lee, E.K., S. Ha and S.K. Kim, Supplier selection and management system considering relationships in supply chain management. IEEE Transactions on Engineering Management, vol. 48, pp. 307-318, 2001.

[21] Handfield, R., et al., Applying environmental criteria to supplier assessment: A study in the application of the Analytical Hierarchy Process. European Journal of Operational Research, vol. 141, pp. 70-87, 2002.