A performance evaluation model of green supply chain based on fuzzy analysis method of multi-attribute decision-making

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Abstract

This paper proposes a performance evaluation model of green supply chain based on fuzzy analysis method of multi-attribute decision-making. In this model, an evaluation index system is established with economic profit, environment protection, business process and customer service taken into consideration. Fuzzy analysis method of multi-attribute decision-making is introduced to get the fuzzy incidence degree of different performance evaluation indicators. Analysis of performance evaluation of green supply chain is based on the fuzzy incidence degree. Finally, the model and the algorithm are proved to be scientific and feasible through case study.

Keywords: green supply chain, performance evaluation, multi attribute decision making, fuzzy theory, model

1 Introduction

In recent years, with the degradation of environment, people are paying more and more attention to sustainable development. Green supply chain management is born under such circumstance. It is a modern management mode integrated with environment protection, aiming at reducing environment pollution and resources depletion while increasing the benefit of the whole supply chain [1-3]. Performance evaluation of green supply chain helps us to learn about the operation of the supply chain and understand how to improve it. It is significant to increase the competitiveness of products, protect the environment and reach for a sustainable development. Many researches both home and abroad have studies this issue [4-6].

Currently, analysis hierarchy process, grey incidence analysis method and fuzzy evaluation method are major ways to evaluate the performance of green supply chain. However, these methods are more often subjective using index evaluation matrix and indicator weight but overlook the incomparable nature of some indicators or the influence of membership on target evaluation grade [7-10]. Therefore, this paper constructs a performance evaluation index system based on improved fuzzy analysis method of multi-attribute decision-making. It sheds some lights on real practice.

2 The performance evaluation index system of green supply chain

2.1 PRINCIPLES FOR THE CONSTRUCTION OF THE INDEX SYSTEM

The evaluation index system should be objective, fair and accurate that can reflect the sustainable development capability of the enterprise in an all-round way. Therefore, there are some principles that must be followed in constructing the index system.

(a) Scientific principle: The evaluation index system should be scientific. Data source should be reliable, the indicators should be clear, the evaluation method should be convincing and the evaluation mode should be reasonable.

(b) General principle: The evaluation index system should involve with all features of the sustainable development capability of the enterprise and be able to analyse these features based on their structure, layer and interaction.

(c) Leading principle: Not all factors are significant to the sustainable development capability. Thus, some factors should be given priority with more weight.

(d) Operating principle: The evaluation index system should be practical in real use. Therefore, data should be acquired in a reliable way and those that cannot be available should be kept out of the index system.

(e) Simple principle: Simple and practical indicators are the ones that should be selected. They will reflect the operation state of the supply chain and serve to the calculation and analysis of the performance

2.2 CONSTRUCTING THE PERFORMANCE EVALUATION INDEX SYSTEM OF GREEN SUPPLY CHAIN

The evaluation index system will provide a measurement standard, restriction as well as incentives for green supply chain management. According to abovementioned principles, the evaluation index system falls into three layers: target layer, standard layer and indicator layer. Standard layer consists of economic profit, environment

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protection, business process, customer service and sustainable development and they evolve into 21 indicators. The structure of the evaluation index system is shown in Table 1.

TABLE 1 The structure of the evaluation index system of green supply chain

Target layer	Standard layer	Index layer	Class of indicator	Type of indicator
The evaluation index system of green supply chain	Economic profit	Manufacturing and sale rate of products	Quantitative	Positive
		Rate of return on net assets	Quantitative	Positive
		Profit growth rate	Quantitative	Positive
	Environment protection	Investment rate in environment protection	Quantitative	Positive
		Utilization rate of material and energy	Quantitative	Positive
		Return rate of material and energy	Quantitative	Positive
		Impact degree on environment	Qualitative	Adverse
		Energy consumption level	Qualitative	Adverse
	Business process	Production capability	Quantitative	Positive
		Operation efficiency	Qualitative	Positive
		Traffic rate	Quantitative	Positive
		Product quality	Quantitative	Positive
		Transport rate	Quantitative	Adverse
	Customer service	Safe delivery rate	Quantitative	Positive
		Customers satisfaction degree	Qualitative	Positive
		Green identity	Qualitative	Positive
		Market share	Quantitative	Positive
	Sustainable development	Accuracy of market prediction	Quantitative	Positive
		Investment rate in R&D	Quantitative	Positive
		Proportion of design staff	Quantitative	Positive
		Profit rate of new products	Quantitative	Positive

3 The performance evaluation model of green supply chain based on fuzzy analysis method of multi-attribute decision-making

3.1 STANDARDIZATION OF PERFORMANCE EVALUATION INDICATORS

According to Table 1, there are two classes of indicators, one is quantitative and the other is qualitative. Quantitative indicators are available through statistics and calculation analysis. Qualitative indicators need fuzzy description. Detailed descriptions for qualitative indicators are shown in Table 2.

According to Table 1, there are two types of indicators, one is positive indicator and the other is adverse indicator. As indicators have different value and scale, they need to be standardized to ensure the effectiveness and reliability of the performance evaluation.

TABLE 2 Fuzzy descriptions of qualitative indicators

Positive language grade	Negative language grade	Range of score
Very good	Very bad	90-100
Good	Bad	70-90
So-so	So-so	50-70
Poor	A little bad	0-50

If the performance evaluation indicator is a positive indicator, its value is $v_{ij}(\Omega)=\left[v_{ij}^1(\Omega),v_{ij}^2(\Omega)\right]$, and the value after standardization is $u_{ij}(\Omega)=\left[u_{ij}^1(\Omega),u_{ij}^2(\Omega)\right]$. There is:

$$u_{ij}(\Omega)=\left[u_{ij}^1(\Omega),u_{ij}^2(\Omega)\right]=\left(v_{ij}^1(\Omega)/\left(v_{ik}^2(\Omega)\,|\max_{1\le j\le m}\left(v_{ij}^2(\Omega)\right)\right),v_{ij}^2(\Omega)/\left(v_{ik}^2(\Omega)\,|\max_{1\le j\le m}\left(v_{ij}^2(\Omega)\right)\right)\right). \qquad (1)$$

If the performance evaluation indicator is an adverse indicator, its value is $v_{ij}(\Omega)=\left[v_{ij}^1(\Omega),v_{ij}^2(\Omega)\right]$, and the value after standardization is $u_{ij}(\Omega)=\left[u_{ij}^1(\Omega),u_{ij}^2(\Omega)\right]$. There is:

$$u_{ij}(\Omega)=\left[u_{ij}^1(\Omega),u_{ij}^2(\Omega)\right]=\left(\left(v_{ik}^1(\Omega)\,|\min_{1\le j\le m}\left(v_{ij}^1(\Omega)\right)\right)/v_{ij}^2(\Omega),\left(v_{ik}^1(\Omega)\,|\min_{1\le j\le m}\left(v_{ij}^1(\Omega)\right)\right)/v_{ij}^1(\Omega)\right). \qquad (2)$$

In the expression, $v_{ik}^2(\Omega)\,|\max_{1\le j\le m}\left(v_{ij}^2(\Omega)\right)$ refers to the maximum value of indicator j under scheme i. $v_{ik}^1(\Omega)\,|\min_{1\le j\le m}\left(v_{ij}^1(\Omega)\right)$ refers to the minimum value of indicator j under scheme i. After standardization, the value of indicator falls between [0, 1], which means all indicators have unified measurement standard. This will make the analysis more accurate and reliable.

3.2 FUZZY ANALYSIS METHOD OF GREEN SUPPLY CHAIN OF MULTI-ATTRIBUTE DECISION MAKING

After standardization, construct the positive ideal interval $\bar{u}_{0j}(\Omega)$ for indicators:

$$\bar{u}_{0j}(\Omega) = \left[\bar{u}^1_{0j}(\Omega), \bar{u}^2_{0j}(\Omega)\right] = \left[\max\left(u^1_{ij}(\Omega) \mid 1 \le i \le m\right), \max\left(u^2_{ij}(\Omega) \mid 1 \le i \le m\right)\right]. \tag{3}$$

The adverse ideal interval $\underline{u}_{0j}(\Omega)$ for the corresponding indicator is described as:

$$\underline{u}_{0j}(\Omega) = \left[\bar{u}^1_{0j}(\Omega), \bar{u}^2_{0j}(\Omega)\right] = \left[\min\left(u^1_{ij}(\Omega) \mid 1 \le i \le m\right), \min\left(u^2_{ij}(\Omega) \mid 1 \le i \le m\right)\right]. \tag{4}$$

Therefore, the positive ideal scheme S^+ of performance evaluation scheme for green supply chain is:

$$S^+ = \left\{\left[\bar{u}^1_{01}(\Omega), \bar{u}^2_{01}(\Omega)\right], \left[\bar{u}^1_{02}(\Omega), \bar{u}^2_{02}(\Omega)\right], ..., \left[\bar{u}^1_{0n}(\Omega), \bar{u}^2_{nj}(\Omega)\right]\right\}. \tag{5}$$

The adverse ideal scheme S^- of performance evaluation scheme for green supply chain is:

$$S^- = \left\{\left[\underline{u}^1_{01}(\Omega), \underline{u}^2_{01}(\Omega)\right], \left[\underline{u}^1_{02}(\Omega), \underline{u}^2_{02}(\Omega)\right], ..., \left[\underline{u}^1_{0n}(\Omega), \underline{u}^2_{0n}(\Omega)\right]\right\}. \tag{6}$$

Calculate the distance of fuzzy set by Hamming distance. Construct positive and adverse ideal interval scheme. Establish a fuzzy evaluation model of multi attribute based on fuzzy information. Suppose $\tilde{A}$ and $\tilde{B}$ are two fuzzy sets in the discourse domain Ω. Their membership functions are $\mu_{\tilde{A}}(x)$ and $\mu_{\tilde{B}}(x)$. The Hamming distance between fuzzy set $\tilde{A}$ and $\tilde{B}$ is:

$$d\left(\tilde{A}, \tilde{B}\right) = \int_\alpha^\beta \left|\mu_{\tilde{A}}(x) - \mu_{\tilde{B}}(x)\right| dx. \tag{7}$$

The positive ideal scheme S^+ is featured by membership function $\mu^{\vee}_{S^+}(u_j(\Omega))$:

$$\mu^{\vee}_{S^+}(u_{ij}(\Omega)) = \sup_{\substack{u = u_1 \vee u_2 \vee \cdots \vee u_m \\ (u_1, u_2, \cdots u_m) \in R^m}} \min\left\{\mu_{u_{1j}}(u_1), \mu_{u_{2j}}(u_2), ..., \mu_{u_{nj}}(u_n)\right\}. \tag{8}$$

The adverse ideal scheme S^- is featured by membership function $\mu^{\wedge}_{S^-}(u_j(\Omega))$:

$$\mu^{\wedge}_{S^-}(u_j(\Omega)) = \sup_{\substack{u = u_1 \wedge u_2 \wedge \cdots \wedge u_m \\ (u_1, u_2, \cdots u_m) \in R^m}} \min\left\{\mu_{u_{1j}}(u_1), \mu_{u_{2j}}(u_2), \cdots, \mu_{u_{nj}}(u_n)\right\}. \tag{9}$$

The difference between performance evaluation scheme i and positive ideal scheme S^+ about indicator j is:

$$D^+_i = \sqrt{\sum_{j=1}^n \left[w_{ij} \times \left(d\left(u^1_{ij}(\Omega), S^+_1\right) + d\left(u^2_{ij}(\Omega), S^+_2\right)\right)\right]^2}. \tag{10}$$

In the expression, S^+_1 and S^+_2 are left fuzzy maximum set and right fuzzy maximum set of positive ideal scheme S^+.

The difference between performance evaluation scheme i and positive ideal scheme S^- about indicator j is:

$$D^-_i = \sqrt{\sum_{j=1}^n \left[w_{ij} \times d\left(u^1_{ij}(\Omega), S^-_1\right) + d\left(u^2_{ij}(\Omega), S^-_2\right)\right]^2}. \tag{11}$$

In the expression, S^-_1 and S^-_2 are left fuzzy maximum set and right fuzzy maximum set of positive ideal scheme S^-.

So the calculation model μ_i for fuzzy incidence degree of performance evaluation scheme i is:

$$\mu_i = 1 / \left(1 + \left((1 - D^-_i) / (1 - D^+_i)\right)^2\right). \tag{12}$$

3.3 PERFORMANCE EVALUATION MODEL AND ALGORITHM OF GREEN SUPPLY CHAIN

According to close principle in fuzzy analysis of multi-attribute decision making [11-14], if there is:

$$\mu_0 = \max\left(\mu_i, \mu_i, ..., \mu_i\right) = \mu_s, 1 \le s \le m. \tag{13}$$

Then the scheme s has the optimal performance.

As is mentioned above, the algorithm of the performance evaluation model of enterprise green supply chain based on fuzzy analysis method of multi-attribute decision making is described as follows:

Step 1: Construct the performance evaluation index system of green supply chain after survey, statistics and consultation with experts;

Step 2: Under the index system, obtain indicator values of different performance evaluation scheme and standardize them based on Equations (1) and (2);

Step 3: Acquire positive ideal interval and adverse ideal interval according to performance evaluation indicators based on Equations (3) and (4);

Step 4: Acquire positive ideal scheme and adverse ideal scheme according to performance evaluation indicators based on Equations (5) and (6);

Step 5: Get the difference of the performance evaluation scheme from positive ideal scheme and that from adverse ideal scheme;

Step 6: Acquire fuzzy incidence degree of performance evaluation scheme based on Equation (12);

Step 7: Implement the optimal scheme of green supply chain according to fuzzy incidence degree based on Equation (13).

4 Case study and model test

This paper tests the model and algorithm by analysing the performance of green supply chain of three brand enterprises in a certain industry. After survey, data collection and consultation with experts, management team and relevant technicians, the performance evaluation indicators are available and shown in Table 3.

TABLE 3 Information of performance evaluation indicator of green supply chain

Standard layer	Weight	Indicator layer	Weight	Indicator information		
				Scheme 1	*Scheme 2*	*Scheme 3*
Economic profit	0.305	Manufacturing and sale rate of products	0.25	0.88-0.93	0.90-0.95	0.88-0.93
		Rate of return on net assets	0.25	0.35	0.35	0.30
		Profit growth rate	0.35	0.20	0.15	0.22
		Investment rate in environment protection	0.15	0.16	0.20	0.15
Environment protection	0.120	Utilization rate of material and energy	0.30	0.92-0.95	0.88-0.93	0.92-0.95
		Return rate of material and energy	0.25	0.18	0.26	0.23
		Impact degree on environment	0.20	50-60	60-70	50-60
		Energy consumption level	0.25	40-50	40-50	50-60
Business process	0.285	Production capability	0.25	95	92	85
		Operation efficiency	0.22	85	90	90
		Traffic rate	0.15	0.85-0.90	0.80-0.85	0.85-0.90
		Product quality	0.25	985	962	895
		Transport rate	0.13	24	48	24
Customer service	0.165	Safe delivery rate	0.20	0.95	0.90	0.90
		Customers satisfaction degree	0.25	85-90	80-85	85-90
		Green identity	0.20	80-85	80-85	85-90
		Market share	0.35	0.18	0.22	0.13
Sustainable development	0.125	Accuracy of market prediction	0.22	0.35-0.40	0.60-0.65	0.45-0.50
		Investment rate in R&D	0.21	0.35	0.25	0.25
		Proportion of design staff	0.19	0.55	0.45	0.55
		Profit rate of new products	0.38	0.36	0.23	0.30

According to Section 3.1, standardize indicators of different classes and types and get the standardized indicator values, as is shown in Table 4.

TABLE 4 Standardization of performance evaluation indicators of green supply chain

Indicator layer	Indicator information		
	Scheme 1	*Scheme 2*	*Scheme 3*
Manufacturing and sale rate of products	0.926-0.979	0.947-1.000	0.926-0.979
Rate of return on net assets	1.000	1.000	0.857
Profit growth rate	0.909	0.682	1.000
Investment rate in environment protection	0.800	1.000	0.750
Utilization rate of material and energy	0.968-0.95	0.926-0.979	0.968-1.000
Return rate of material and energy	0.692	1.000	0.885
Impact degree on environment	0.833-1.000	0.714-0.833	0.833-1.000
Energy consumption level	0.800-1.000	0.800-1.000	0.667-0.800
Production capability	1.000	0.968	0.924
Operation efficiency	0.944	1.000	1.000
Traffic rate	0.944-1.000	0.889-0.944	0.944-1.000
Product quality	1.000	0.977	0.909
Transport rate	1.000	0.500	1.000
Safe delivery rate	1.000	0.947	0.947
Customers satisfaction degree	0.944-1.000	0.889-0.944	0.944-1.000
Green identity	0.889-0.944	0.889-0.944	0.944-1.000
Market share	0.818	1.000	0.591
Accuracy of market prediction	0.538-0.615	0.923-1.000	0.692-0.769
Investment rate in R&D	1.000	0.714	0.714
Proportion of design staff	1.000	0.818	1.000
Profit rate of new products	1.000	0.639	0.833

According to Section 3.2, acquire the Hamming distance of performance evaluation indicators by constructing positive ideal interval and adverse ideal interval, as is shown in Table 5.

TABLE 5 Hamming distance of performance evaluation indicators of green supply chain

Indicator layer	Scheme 1		Scheme 2		Scheme 3	
	Positive	*Adverse*	*Positive*	*Adverse*	*Positive*	*Adverse*
Manufacturing and sale rate of products	0.021	0.000	0.000	0.021	0.021	0.000
Rate of return on net assets	0.000	0.143	0.000	0.143	0.143	0.000
Profit growth rate	0.091	0.227	0.318	0.000	0.000	0.318
Investment rate in environment protection	0.200	0.050	0.000	0.250	0.250	0.000
Utilization rate of material and energy	0.000	0.032	0.032	0.000	0.000	0.032
Return rate of material and energy	0.308	0.000	0.000	0.308	0.115	0.193
Impact degree on environment	0.000	0.143	0.143	0.000	0.000	0.143
Energy consumption level	0.000	0.167	0.000	0.167	0.167	0.000
Production capability	0.000	0.076	0.032	0.044	0.076	0.000
Operation efficiency	0.056	0.000	0.000	0.056	0.000	0.056
Traffic rate	0.000	0.056	0.056	0.000	0.000	0.056
Product quality	0.000	0.091	0.023	0.068	0.091	0.000
Transport rate	0.000	0.500	0.500	0.000	0.000	0.500
Safe delivery rate	0.000	0.053	0.053	0.000	0.053	0.000
Customers satisfaction degree	0.000	0.056	0.056	0.000	0.056	0.000
Green identity	0.056	0.000	0.056	0.000	0.000	0.056
Market share	0. 182	0.227	0.000	0.409	0.409	0.000
Accuracy of market prediction	0.385	0.000	0.000	0.385	0.231	0.154
Investment rate in R&D	0.000	0.286	0.286	0.000	0.286	0.000
Proportion of design staff	0.000	0.182	0.182	0.000	0.000	0.182
Profit rate of new products	0.000	0.361	0.361	0.000	0.167	0.194

Therefore, the differences of performance evaluation indicators from positive ideal scheme and those from adverse ideal scheme are shown in Table 6.

TABLE 6 Differences of performance evaluation indicators from positive ideal scheme and those from adverse ideal scheme

Difference	Scheme 1	Scheme 2	Scheme 3
Positive ideal scheme	0.053	0.092	0.099
Adverse ideal scheme	0.118	0.088	0.082

Thus, the fuzzy incidence degree of different performance evaluation schemes is. Therefore, enterprise 1 has the highest performance level of green supply chain.

5 Conclusions

This paper constructs a performance evaluation index system of enterprise green supply chain. Indicators of different classes and types are standardized according to their features and a performance evaluation model of fuzzy analysis method of multi attribute decision making is constructed. This provides a quantitative analysis method for performance evaluation of enterprise green supply chain management.

Fuzzy analysis method of multi attribute decision making is suitable for evaluating green supply chain in real situation. It is simple and clear. More importantly, it can realize the uncertain evaluation by qualitative description and evaluate the performance of green supply chain in a quantitative way. It serves as guidance to scientific management and decision making and helps to increase the competitiveness of the enterprise.

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