

Research Article

Research on the Degree of Ecological Supply Chain Management Practice among Chinese Manufacturing Enterprises

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Based on the existing literature, this paper proposes two assumptions and designs a set of ecological supply chain performance evaluation indicators system. Because these indicators are interdependence for each other, this paper selects the analytic network process and builds the ANP network model to evaluate the degree of ecological supply chain management practice among Chinese manufacturing enterprises. The evaluation results show that there is different level indeed about the ecological supply chain management level; the better the ecological supply chain management practice degree is, the more quickly the ecological supply chain management performance levels increase.

1. Introduction

Resource and environment problems have been the enormous challenges for human society. Currently, resource depletion, environment degradation, and ecological imbalance and other problems are posing a serious threat to humans' survival and development. As environment problem is becoming more prominent, ecological research has been put on the agenda. In this context, enterprises must go through an ecological revolution, and those enterprises that take full account of the environment interest can maintain and improve competitiveness. Because the competition among enterprises has evolved into the competition between supply chains, only the supply chain that takes into account the environment interests, in the pursuit of economic interests at the same time, can obtain and maintain a competitive advantage.

Measurement to the degree of the ecological supply chain management practice is achieved by comparing the performance level of ecological supply chain management practice in this paper. This paper assumes that the enterprises implementing ecological supply chain management can be divided into three types: leading enterprise, start-up enterprise, and backward enterprise. There is a set of evaluation indicators system in this paper. Using the analytic network

process, this paper constructs a model of ANP and uses the Super Decisions 1.6.0 software to calculate the weight of indicators. The study result proves the correct of the prior assumptions. This study can provide a reference for manufacturing enterprises to evaluate the degree of ecological supply chain management practice. Therefore, there is some practical significance of this study.

2. Literature Review and Hypothesis

2.1. Literature Review. Carter et al. [1, 2] thought the broad sustainability should include the improvement of economic, social, and environmental performance from a broad point of view, and the literatures related to sustainability are increasing in recent years. Linton [3] and Preuss [4] thought that the core of the sustainability research was the level of environmental performance, while the focus of environmental management was reflected in the level of the supply chain management. Seuring [5] gave a definition about the environmental supply chain management in 2004. He thought green supply chain management was the integrated management of logistics and information flow, and it could meet customers' demand for green products and green services. Vachon [6] proposed that supply chain could maintain internal health

TABLE 1: The appraisal indicators system of ecological supply chain management performance.

Target layer	Level indicators	Secondary indicators	Object
Ecological supply chain management performance evaluation	Economic performance (ENP)	X ₁ Reduction of air emissions	(1) Leading enterprise (A ₁) (2) Start-up enterprise (A ₂) (3) Backward enterprise (A ₃)
		X ₂ Reduction of effluent waste	
		X ₃ Reduction of solid wastes	
		X ₄ Decrease in consumption for hazardous/harmful/toxic materials	
		X ₅ Decrease in frequency for environmental accidents	
		X ₆ Improvement in an enterprise's environmental situation	
	Operational performance (OPP)	X ₇ Increase in the amount of goods delivered on time	
		X ₈ Decrease in inventory levels	
		X ₉ Decrease in scrap rate	
		X ₁₀ Increase in product quality	
		X ₁₁ Increase in product line	
		X ₁₂ Improved capacity utilization	
	Economic performance (ECP)	X ₁₃ Decrease in cost of materials purchasing	
		X ₁₄ Decrease in cost for energy consumption	
		X ₁₅ Decrease in fee for waste treatment	
		X ₁₆ Decrease in fee for waste discharge	
		X ₁₇ Decrease in fine for environmental accidents	
		X ₁₈ Average return on investment over the past three years	
	Operational performance (ORP)	X ₁₉ Average profit over the past three years	
		X ₂₀ Profit growth over the past three years	
		X ₂₁ Average return on sales over the past three years	
		X ₂₂ Average market share growth over the past three years	
		X ₂₃ Average sales volume growth over the past three years	
		X ₂₄ Average sales (in dollars) growth over the past three years	

TABLE 2: The unweighted supermatrix of ecological supply chain management performance evaluation.

	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	X ₈
A ₁	0.0280	0.0253	0.0249	0.0225	0.0258	0.0349	0.2319	0.1238
A ₂	0.0107	0.0143	0.0132	0.0124	0.0135	0.0200	0.1160	0.0697
A ₃	0.0041	0.0032	0.0047	0.0034	0.0035	0.0076	0.0387	0.0157
	X ₉	X ₁₀	X ₁₁	X ₁₂	X ₁₃	X ₁₄	X ₁₅	X ₁₆
A ₁	0.1229	0.12167	0.09663	0.08770	0.06365	0.08845	0.06431	0.07209
A ₂	0.0677	0.06464	0.04589	0.05020	0.03382	0.05063	0.03539	0.02876
A ₃	0.0186	0.02290	0.01453	0.01915	0.01198	0.01932	0.00974	0.00860
	X ₁₇	X ₁₈	X ₁₉	X ₂₀	X ₂₁	X ₂₂	X ₂₃	X ₂₄
A ₁	0.06365	0.03280	0.03277	0.03209	0.03381	0.03334	0.03220	0.03251
A ₂	0.03382	0.01963	0.01741	0.01877	0.01690	0.01878	0.01610	0.01927
A ₃	0.01198	0.00392	0.00617	0.00549	0.00564	0.00423	0.00805	0.00457

and sustainability based on the external environment information and their own regulatory function. The enterprises in the supply chain realized that customers increasingly inclined to products and services which did no harm to the environment, so more and more enterprises supported the implementation of the green supply chain management. Sen [7], Barratt and Oke [8], and Handfield et al. [9] thought that implementing environmental sustainability and green supply chain management timely could make the enterprises in the supply chain gain a competitive advantage. Jorgensen

and Wilcoxon [10] did quantitative analysis about pollution cost control of goods and services in the US economy. Jaffe et al. [11] asserted that there is little evidence to prove that the environmental regulation did harm to the competitive. Therefore, we needed more empirical research to prove environmentally sustainable regulation had an important impact on the competitiveness of enterprises. Zhu et al. [12], Vachon and Klassen [13], and Wee and Quazi [14] had done some preliminary study about the indicators and the evaluation scale of environmental sustainability.

TABLE 3: The weighted supermatrix of ecological supply chain management performance evaluation.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
A_1	0.02804	0.02534	0.02490	0.02250	0.02581	0.03493	0.23190	0.12380
A_2	0.01070	0.01427	0.01323	0.01238	0.01349	0.01999	0.11595	0.06971
A_3	0.00408	0.00321	0.00469	0.00341	0.00353	0.00763	0.03865	0.01570
	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
A_1	0.12294	0.12167	0.09663	0.08770	0.06365	0.08845	0.06431	0.07209
A_2	0.06766	0.06464	0.04589	0.05020	0.03382	0.05063	0.03539	0.02876
A_3	0.01862	0.02290	0.01453	0.01915	0.01198	0.01932	0.00974	0.00860
	X_{17}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}	X_{23}	X_{24}
A_1	0.06365	0.03280	0.03277	0.03209	0.03381	0.03334	0.03220	0.03251
A_2	0.03382	0.01963	0.01741	0.01877	0.01690	0.01878	0.01610	0.01927
A_3	0.01198	0.00392	0.00617	0.00549	0.00564	0.00423	0.00805	0.00457

2.2. Research Methods. In order to study the level of ecological supply chain management implementation among Chinese manufacturing enterprises, the paper designs a questionnaire, which can assess the performance level of the ecological supply chain management implementation.

In this paper, the research process consists of four steps. (1) Problem description, the potential performance improvement brought by ecological supply chain management is studied based on relevant literature and proposes the hypothesis; (2) questionnaire development, firstly, the questions in the questionnaire are designed, and then consulting from the academic and business experts to modify and improve the questionnaire, finally the questions are obtained; (3) data collection and analysis, inviting relevant experts to score the questions in the questionnaire and using the Super Decisions software to analyze the reliability and consistency of the data; those data which cannot pass the consistency test need rescoring and then continue to analyze the reliability and consistency of the data, until passing the test; (4) evaluation results, using Super Decisions software to evaluate the level of ecological supply chain management implementation and then obtaining the level of performance improvement.

In order to research the change of enterprises performance level after implementing the ecological supply chain management, 24 questions are designed in this paper, which are environmental performance, operational performance, economic performance, and organizational performance. There are five degrees for the answers to these questions: (1) does not reflect the ecological degree, (2) less reflects the ecological degree, (3) in part reflects the ecological degree, (4) clearly reflects the ecological degree, and (5) very clearly reflects the ecological degree.

In order to focus the research objective and avoid error as much as possible, we invited experts from four typical industries: thermal power plants, chemical/petrochemical industry, electrical/electronics industry, and the automotive industry. We first revised and improved the questionnaire in the seminar held in Harbin University of Science and Technology. According to the opinions from 10 professors and 20 experts from four typical industries, the questionnaire was to be modified slightly. Finally, 900 questionnaires were

sent, and 117 available questionnaires were recovered, including thermal power plant (35, 30%), chemical/petrochemical enterprises (38, 32%), electrical/electronic enterprises, (15, 13%), and auto companies (29, 25%).

2.3. Hypothesis. There are two hypotheses in this paper:

Hypotheses 1. There is different level about the ecological supply chain management practice level. The enterprises practicing ecological supply chain management can be divided into three categories: leading enterprise, start-up enterprise, and backward enterprise. Leading enterprise does best in ecological supply chain management practices, start-up enterprise follows the leading enterprise, and the backward enterprise does worst.

Hypotheses 2. The better the ecological supply chain management practice degree, the more quickly the ecological supply chain management performance levels increase.

3. Model Based on ANP and Calculation

Ecological supply chain performance evaluation is a multi-objective decision problem about the limited program. Because the evaluation indicators are not entirely dependent, and there are many independent and influence relations between the indicators, the choice of the evaluation method will affect the results of the evaluation to a large extent. This paper chooses the analytic network process and the decisions 1.6.0 software to finish the evaluation. The implementation steps are as follows.

3.1. Design of the Indicators System. The choice of indicators will have a direct impact on the results of the evaluation. Zhu Qinghua, Geng Yong, Kenneth Green, Pamela Zebst, Jeremy Meacham, and Vikram Bhaduria did some study about the indicators of the green supply chain management practices performance appraisal. Zhu and Geng [15] analyzed the green supply chain practice performance evaluation indicators system based on the factor analysis method and extracted three evaluation factors which were environmental

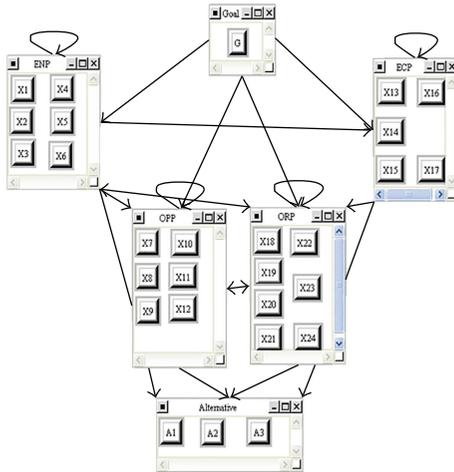


FIGURE 1: The ANP network model.

performance, operational performance, and economic performance. Green et al. [16] supplement their research and increased another factor, organizational performance. At this point, the evaluation of green supply chain management practice performance can be made from four factors: environmental performance, operational performance, economic performance, and organizational performance. On the basis of these scholars, this paper builds up ecological supply chain management performance appraisal indicator system, which is as shown in Table 1.

Using the indicator system and the Super Decisions software, this paper proposes the ecological supply chain management performance appraisal model, which is as shown in Figure 1. There are feedback and dependency relationship in the ANP model, so it can describe the most realistic decision-making problem. The model is universal and has a certain representation for the ecological supply chain performance evaluation among enterprises. The interaction of the factors in the network diagram is represented by arrows, and the direction of an arrow indicates the dominant role of an element (elements set) to another element (element set).

3.2. Construct of Judgment Matrix. Construct of Judgment Matrix. The process of establishing judgment matrix is comparing every two decision-making elements in the elements sets and then using the Eigen values to show the impact between the elements.

The process uses the scaling method of 1–9 and its inverse created by Saaty. This paper must build a lot of judgment matrix and take one of judgment matrix for example, which is as shown in Figure 2. The value of CR is 0.075 by Super Decisions software, less than 0.1, and it passes the consistency test. The establishment and test of the other matrix are similar to this. During the process of the consistency checking, if the CR value is greater than 0.1, then we believe there are obvious mistakes about the values. And those matrixes which do not pass the consistency test require the rescoring from the experts. And then the value of CR must be tested until they pass the consistency test.

	X1	X2	X3	X4	X5	X6
1. X1	1	>=9.5	9	8	7	6
2. X1		1	8	7	6	5
3. X1			1	8	7	6
4. X1				1	8	7
5. X1					1	8
6. X2						1
7. X2						
8. X2						
9. X2						
10. X3						

FIGURE 2: Comparisons wrt “G” node in “ENP” cluster.

3.3. Calculation Process and Results

- (1) Calculation of the unweighted supermatrix: in this model, there is only one objective criterion in the control layer. After all matrixes are built and pass the consistency test, we can use the software to compute the unweighted supermatrix, and the result is as shown in Table 2.
- (2) Calculation of the weighted super-matrix: the partial weight value of each sub-criterion is multiplied by the weight of the corresponding standard, so we can obtain a weighted supermatrix, and the result is as shown in Table 3.
- (3) Calculation of the limit super-matrix: by normalization the weighted super matrix, we can obtain the limit super matrix. Because the relationship are dependent and the feedback between elements, the normalization process is an iterative and gradually stabilization process. The result of the weight super-matrix is as shown in Table 4.
- (4) The rank of the three types of enterprise: we get the results of the three types of enterprise’ final performance appraisal. The result is as shown in Table 5. The leading enterprise’s score is the highest, the start-up enterprise follows The leading enterprise, and the backward enterprise is the lowest.

4. Conclusions

This paper uses the analytic network process and the Super Decision 1.6.0 software to construct ANP network model of ecological supply chain management. The model can evaluate the level of the ecological supply chain performance management among Chinese manufacturing enterprises. The result proves the accuracy of the initial hypothesis and the conclusions are as follows: there is different level indeed about the ecological supply chain management level; the better the ecological supply chain management practice degree, the more quickly the ecological supply chain management performance levels increase.

TABLE 4: The weight supermatrix of ecological supply chain management performance evaluation.

	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	X ₈
A ₁	0.04660	0.04660	0.04660	0.04660	0.04660	0.04660	0.04660	0.04660
A ₂	0.02498	0.02498	0.02498	0.02498	0.02498	0.02498	0.02498	0.02498
A ₃	0.00791	0.00791	0.00791	0.00791	0.00791	0.00791	0.00791	0.00791
	X ₉	X ₁₀	X ₁₁	X ₁₂	X ₁₃	X ₁₄	X ₁₅	X ₁₆
A ₁	0.04660	0.04660	0.04660	0.04660	0.04660	0.04660	0.04660	0.04660
A ₂	0.02498	0.02498	0.02498	0.02498	0.02498	0.02498	0.02498	0.02498
A ₃	0.00791	0.00791	0.00791	0.00791	0.00791	0.00791	0.00791	0.00791
	X ₁₇	X ₁₈	X ₁₉	X ₂₀	X ₂₁	X ₂₂	X ₂₃	X ₂₄
A ₁	0.04660	0.04660	0.04660	0.04660	0.04660	0.04660	0.04660	0.04660
A ₂	0.02498	0.02498	0.02498	0.02498	0.02498	0.02498	0.02498	0.02498
A ₃	0.00791	0.00791	0.00791	0.00791	0.00791	0.00791	0.00791	0.00791

TABLE 5: The rank of the three types of enterprise.

Object	Unweighted result	Weighted	Weight supermatrix result	Ranking
Leading enterprise (A ₁)	1.000000	0.586213	0.046600	1
Start-up enterprise (A ₂)	0.536040	0.314233	0.024980	2
Backward enterprise (A ₃)	0.169826	0.099554	0.007914	3

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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