Study on Performance Evaluation on Supply Chain System of Manufacturing Enterprises Based on AHP-DEA Model

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Abstract. A typical manufacturing enterprise supply chain system is a complex system, which is composed of interconnected subsystems. The efficiency of resource allocation, operation characteristics and coordination degree of between subsystems in different subsystems has a great impact on the overall performance of supply chain system. Based on the establishment of performance evaluation index system of the supply chain system of manufacturing enterprises, it uses AHP-DEA comprehensive evaluation model to evaluate its performance. This model is different from the previous AHP and DEA combination model in: the former is realizing the combination of subjective and objective, while the latter is not reflecting the preference of decision makers. This paper verifies the rationality and validity of the method by examples, makes the decision-making process is more reasonable and tight.

1. Introduction

In the increasingly fierce market competition environment, the competition between manufacturing enterprises have gradually evolved competition between supply chains which formed by customers, suppliers, research centers, manufacturers, distributors and service providers and other partners. Therefore, the importance of supply chain management in the development of manufacturing enterprises gradually emerges. As an integral part of supply chain management, supply chain performance evaluation is the basic aspects of supply chain management, but also a prerequisite to achieve supply chain optimization. Therefore, how scientific, objective and comprehensive analyses and evaluates the supply chain operational performance has become a very important issue. The supply chain performance evaluation model, evaluation indicators and evaluation methods are the core issues of the supply chain performance evaluation [1-3].

Manufacturing enterprise supply chain system is a complex system which contains a series of subsystems; each subsystem interacts, and has an important impact on the overall performance of manufacturing enterprises supply chain systems. Based on depth analyzing the inherent operation mechanism of the manufacturing enterprise supply chain system, this paper decomposes the overall supply chain system into a set of core subsystems, and then builds AHP-DEA comprehensive evaluation model to evaluate and compare, In order to provide reference for the research on the performance evaluation of manufacturing enterprises supply chain system.

2. Construction of index system of manufacturing enterprises supply chain system performance evaluation

In the process of operation of supply chain system, a variety of resources is consumed, but also produces a variety of values. Therefore, the performance evaluation of manufacturing enterprise supply chain system is essentially a conversion efficiency issue between multiple inputs and multiple outputs. Typical manufacturing enterprise supply chain system is a complex systems composed by a plurality of interconnected subsystems, resource allocation efficiency, operational

characteristics and synergy degree of different subsystems have a great impact on the overall performance of the supply chain system.

2.1 Analysis of the supply chain system

Manufacturing enterprise supply chain system has a certain microstructure, clarifies its functional structure within the system is key aspects to grasp the system characteristics, evaluates the overall system performance. Based the angle of processes and value increase, this article divides the manufacturing enterprise supply chain system into raw material supply subsystem, manufacturing subsystem, sales subsystems [4]. It shows in Figure 1.

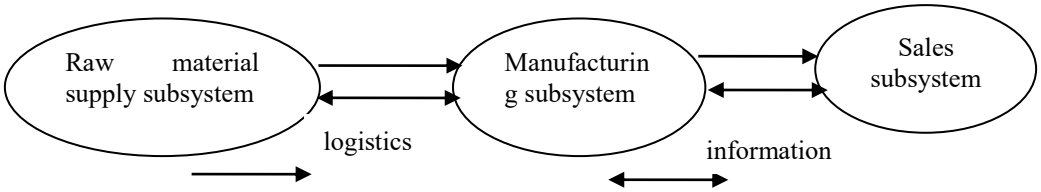

Figure 1. The basic structure of manufacturing enterprises supply chain system

Raw material supply subsystem (RMSS) is the starting of a manufacturing enterprise supply chain systems. In a customer-oriented supply chain system, in order to be able to respond quickly to the needs of customers, when a customer orders, companies must begin to organize production, so raw material procurement has become a key link in the production. At the lowest cost, the fastest speed to provide high quality raw materials is main objective for raw material supply subsystem.

Manufacturing subsystem (MS) is the core aspect of supply chain management; it has an important impact on the performance of supply chain systems. The main objective of manufacturing subsystem lies in the shortest possible time, at the lowest cost to produce functional, high-quality products to meet customer requirements.

Sales subsystem (SS) includes the distribution and retail sales. Distribution connects manufacturers and consumers, while a retail sale puts goods to the ultimate consumer. Sales subsystem aims: meet customer demand as a precondition to achieve minimizing the cost to provide customers with products and services. Customers as a supply chain terminals and the recipient of products, customer satisfaction directly affects the sales, revenues and profits of enterprise in the supply chain. The product quality and stock rate are the most important factor affecting customer satisfaction.

Raw material supply subsystem and manufacturing subsystem mainly connected by raw materials, manufacturing subsystem and sales subsystem mainly connected through production. Each subsystems of manufacturing enterprise supply chain system interact, interdependent, and each is production system with multi-input and multi-output. Therefore, the overall performance of manufacturing enterprise supply subjects to the performance of each subsystem and subsystems relations.

2.2 Evaluation index system

Manufacturing enterprise supply chain system performance evaluation is a very complex issue, not only to use scientific and effective evaluation methods, but also in a practical evaluation index system as an evaluation basis. Based on established goals of manufacturing enterprise supply chain system performance evaluation and determine principles of evaluation index, building a hierarchical structure of index system, including the target layer, guidelines and index three levels. In reference to a number of related documents [4-5], finalizes index system of manufacturing enterprise supply chain system performance evaluation, as shown in Table 1.

Table 1. Index system of manufacturing enterprise supply chain system performance evaluation.

Target layer	Guidelines layer		Index layer
Manufacturing enterprise supply chain system performance evaluation	Raw material supply subsystem	Input	Procurement costs (X_{11})
			Number of staff and workers in purchasing (X_{12})
		Output	Value of the raw materials (Y_{11})
			On time delivery rate (Y_{12})
	Manufacturing subsystem	Input	Raw material input (X_{21})
			Production cost (X_{22})
			number of production workers (X_{23})
		Output	Product yield (Y_{21})
			Qualified rate of products (Y_{22})
	Sales subsystem	Input	Cost of sales (X_{31})
			Yield (X_{32})
			Sales personnel (X_{33})
		Output	Sales (Y_{31})
			Customer satisfaction (Y_{32})
			Sales profit ratio (Y_{33})

Since each manufacturing enterprise supply chain subsystems are a multiple inputs and outputs production system with specific operational objectives. Therefore, classifying the input and output index of each subsystem to make base for later identification, as shown in Table 1.

3. The establishment of AHP-DEA evaluation model

3.1. Analytic hierarchy process

Analytic Hierarchy Process (AHP) is an American Saaty first proposed, it is the semi-qualitative and semi-quantitative problem into an effective method for quantitative calculations [6]. The basic idea is to divide the elements of decision problems in accordance with the domination relation form a hierarchy, with a certain scale of the subjective judgment of experts to quantitatively, constructs the judgment matrix, calculating the weight coefficient of each index and on this basis, the specific steps are as follows:

3.1.1. Constructing judgment matrix

Judgment matrix formulating the relative importance comparison for factors of a upper level and the level factors. In order to determine the quantitative decision, can generally uses in [0,1,2] 3 standard degree method, 1.1-1.9 scale, 1-9 scale method, this paper adopts 1-9 scale method.

3.1.2. Calculating the weight of every index value

The calculation of the maximum characteristic value and eigenvectors of judgment matrix, general can be taken root method, eigenvalue method and least square method, this paper adopts the square root method to calculate.

a. Determining the calculation of each row of the matrix element M_j

$$M_j = \prod_{k=1}^{n} r_{jk}, \; j = 1, 2, ..., n \tag{1}$$

b. Calculation of n root M_j

$$\overline{w}_j = \sqrt[n]{M_j} \tag{2}$$

c. To normalize $\overline{W} = \left[\overline{w}_1, \overline{w}_2, ..., \overline{w}_n\right]^T$

$$w_j = \frac{\overline{w}_j}{\sum_{j=1}^{n} \overline{w}_j} \tag{3}$$

The $\overline{W} = \left[\overline{w}_1, \overline{w}_2, ..., \overline{w}_n\right]^T$ is the feature vector, that is the value of the weight of each index.

3.1.3. Test of consistency judgment matrix

Calculating the largest eigenvalue $\lambda_{\max}$ of judgment matrix

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(Aw)_i}{nw_i} \tag{4}$$

Calculate the consistency index CI

$$CI = \frac{\lambda \max - n}{n-1} \tag{5}$$

Calculate the random consistency ratio CR

$$CR = \frac{CI}{RI} \tag{6}$$

In the formula, RI is the mean random consistency index, for 1-9 judgment matrix, the value can be found in Table 2. When CR <0.1, namely that the judgment matrix has satisfactory consistency. Otherwise you need to determine the matrix to be adjusted.

Table 2. Mean random consistency index RI.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.48

3.2 Data envelopment analysis

Data envelopment analysis (DEA) is known by Saaty A.Chames and W.W.Copper and other scholars on the basis of "efficiency" concept, it is a system analysis method of relative effective evaluation for the same type of unit according to the multi-input and multi-output indicators [7]. This paper evaluates the manufacturing enterprises supply chain system performance is based on the CCR model.

3.3 Comprehensive evaluation model of AHP-DEA

This paper use the method combining analytic hierarchy process and data envelopment analysis method[10-12], but the traditional AHP and DEA combined model is only using DEA to construct the judgment matrix and does not reflect the decision maker preferences problem in nature. This paper combines the subjectivity of AHP and objectivity of DEA, considering the preference of decision maker and advantages to the objective data of DEA, puts forward the evaluation model of AHP-DEA combined with the actual of manufacturing enterprise supply chain system of performance evaluation, specific evaluation operation steps are as follows:

Step 1: Using AHP calculate weights ω_1, ω_2, ω_3 which raw material supply subsystem, manufacturing subsystem, sales subsystem relative to the total manufacturing enterprise supply chain systems target.

Step 2: Each manufacturing enterprise supply chain system is a production system with multi-input and multi-output, are shown in Table 1. Uses CCR model of DEA methods to calculate the efficiency values θ_{ij} (θ_{ij} denotes the i subsystem operation performance value of the j manufacturing enterprise supply chain system).

Step 3: uses the calculated weight ω_1, ω_2, ω_3 by step 1 and θ_{ij} calculated in step 2 to calculate the overall efficiency values:

$$\theta_j = \sum_{i=1}^{3} \theta_{ij}\omega_i, j = 1, 2, ..., n \tag{7}$$

Among them, n is the number of the manufacturing enterprise supply chain systems. It can obtain the quality order of each manufacturing enterprise supply chain system's performance by comparing θ_j.

Manufacturing enterprise supply chain system overall performance depends not only on the performance of various subsystems, but also on the relative importance of each subsystem; The relative importance of 3 supply chain subsystem is essentially a decision-making preferences,

depending on the decision-makers experience; in orders to reflect the preference of decision makers for each subsystem and makes evaluation results more fully rational, uses AHP method to determine the criterion level weight. On this basis, uses DEA method to evaluate the 3 core subsystems of supply chain system, the reason is that: the evaluation results by DEA method entirely depends on objective indicators data, that is, the performance entirely depends on the actual production. Supply chain system performance level is entirely determined by the objective reality, which determines the need for a completely objective method to measure and evaluate, DEA method fits this requirement. After considering the advantages of AHP and DEA method, establishes AHP-DEA comprehensive evaluation model on the basis of subjective and objective integrated.

4. Example analyses

This paper selects 10 manufacturing enterprise supply chain system to be evaluated, uses capital letters A-J to indicate, the initial data of input and output of 10 manufacturing enterprise supply chain systems shown in Table 3.

Table 3. Initial data.

	RMSS				MS					SS					
	X_{11}	X_{11}	Y_{11}	Y_{12}	X_{21}	X_{22}	X_{23}	Y_{21}	Y_{22}	X_{31}	X_{32}	X_{33}	Y_{31}	Y_{32}	Y_{33}
A	2078	26	2598	89	2598	288	218	312	99	312	203	156	302	5.3	99
B	1244	21	2765	93.8	2765	396	229	285	88	285	289	164	201	3.9	94
C	3174	26	3968	91	3968	296	172	256	92	256	236	123	156	4.03	95
D	2314	18	3856	95.3	3856	278	203	206	94.6	206	215	145	145	4.36	96
E	1185	20	2154	98	2154	326	207	362	98.9	362	198	148	350	5.66	99
F	1534	11	1918	94	1918	203	187	289	96	289	271	134	214	4.56	97
G	2112	15	2610	92.6	2610	245	140	146	95.6	146	256	100	78	3.96	95
H	1786	14	3247	97	3247	278	173	342	97.8	342	180	124	326	4.97	98
I	2648	23	3310	92.6	3310	300	176	245	93.7	245	245	126	145	4.56	96
J	1584	26	2214	98	2214	256	489	101	97	101	124	78	78	3.98	95

Step 1: Troughs expert scoring method, uses Sadi scale to constructs judgment matrix of 3 criteria layer for raw material supply subsystem, manufacturing subsystem, sales subsystem, applies eigenvector method to calculate weight and test conformance of judgment matrix, the calculation process and results are shown in Table 4.

Table 4. The hierarchical analysis results of criterion layer.

Judgment matrix	RMSS	MS	SS	Weights
RMSS	1	1/5	1/2	0.228
MS	5	1	3	0.474
SS	2	1/3	1	0.298

Step 2: Respectively uses DEA method to calculate raw material supply subsystem, manufacturing subsystem, sales subsystem performance of 10 supply chain system to be evaluated, obtains the relative efficiency value of supply chain systems, calculation results shown in Table 5.

Table 5. Analytic result.

	A	B	C	D	E	F	G	H	I	J
RMSS	0.642	1.000	0.682	0.924	1.000	1.000	0.823	1.000	0.674	0.764
MS	0.871	0.743	0.887	0.796	0.917	1.000	1.000	1.000	0.869	0.875
SS	1.000	0.758	0.747	0.796	1.000	0.804	0.780	1.000	0.761	1.000
$\theta_j = \sum_{i=1}^{3} \theta_{ij}\omega_i$	0.857	0.806	0.798	0.825	0.961	0.942	0.894	1.000	0.792	0.887
Ranking	6	8	9	7	2	3	4	1	10	5

Step 3: Combing the efficiency evaluation results obtained in step 2 and weight obtained in step 1 of the 3 subsystems, it calculates the final evaluation results, as shown in Table 5.

By the final result, the ranking of performance for 10 to be evaluated manufacturing enterprise supply chain systems is: H, E, F, G, J, A, D, B, C, I, the performance of supply chain system H is

the best, I is the worst. Furthermore, through table 5, we can find which subsystem's DEA evaluation results of each supply chain system is poor, and improve, which provides a clear direction for improve the relevant unit or department.

5. Conclusions

Supply chain system is a complex systems composed by a plurality of subsystem interconnected; the supply, operational characteristics and synergy degree of different subsystems have a great impact on the overall performance of the supply chain system. Based on establishing evaluation index system of manufacturing enterprise supply chain system performance, it constructs AHP-DEA evaluation model: firstly, uses AHP to calculate weights of the criteria layer (supply chain subsystems), then uses DEA to determine the relative efficiency of each subsystem; Finally, calculates overall efficiency values of each manufacturing enterprise supply chain system to be evaluated and sorts them. The model method fully considered the advantages of AHP and DEA method; it achieves a combination of subjective and objective, but also meets the actual of supply chain system, the evaluation results are more comprehensive. This paper verifies the rationality and effectiveness of the method by example verification, which making the decision-making process more rational and rigorous.

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