Research on Evaluation of Supply Chain Competitiveness Based on Entropy Weight TOPSIS Model

Xia Wang*, Shenhui Wu, Xianjun Guan
School of Economics and Management
Tongji University, Shanghai, China
***EMAIL: david887766@163.com**

Abstract: This article evaluates the complex problem of supply chain competitiveness by a model of multi-index evaluation in order to avoid the uncertainty and randomness of subjective judgment. Considering the shortcoming of the traditional method that index weight is determined by subjective judgment, a new approach to determine index weight by combining subjective judgment and objective information is proposed. In the new approach, the evaluation indexes of supply chain competitiveness are established first and the objective weight about index is determined based on the Entropy theory. And the synthetic weight about index is obtained by integrating the determined objective weight and the subjective weight that is presented by the decision-maker. With the synthetic weight, the supply chain competitiveness is evaluated according to the basic principle of TOPSIS. The model is applied to assess supply chain competitiveness and obtained rather satisfied result.

Keywords: supply chain competitiveness; Entropy weight TOPSIS model; synthetic weight; evaluation

I. General Information

The fierce market competition and fast changing market demands makes enterprises to face the pressures of continuously shortened delivery time, improving quality, reducing costs and improving service, which forces suppliers, manufacturers, distributors and retailers to cooperate with each other. Supply chain management as a competitive advantage in gaining access to an effective mode of cooperation has become a hot spot to research and practice in both academic and business areas. Supply chain competitiveness is a kind of abilities that the core enterprise implemented supply chain management, integrates the organizational structure and business processes of its partners, like suppliers, distributors and retailers, obtaining competitive advantages through more quickly effective reaction compared with competitors to customers' changing needs. It is of great practical significance and importance to establish a supply chain competitiveness evaluation index system for evaluating and improving the supply chain competitiveness of enterprises.

The commonly used quantitative methods of evaluation for supply chain competitiveness are grey comprehensive judgment method, DEA (Data Envelopment Analysis) method, comprehensive evaluation method, and fuzzy evaluation model method. However, calculation of these methods is either complex or the determination of weights is subjective. That's to say it needs to determine the weights of different types of indexes, which is inconvenient for application. This article establishes the evaluation indexes of supply chain competitiveness first and uses a multi-index model based on the theory of Entropy to evaluate it. The model can not only evaluate many indexes comprehensively, but also make good use of the inherent information of the object evaluated and count the evaluation weight value and the subjective judgment weight value of experts by Entropy, then combine the two comprehensive weight values and apply them to TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), at last acquire a latest ideal solution. It is practical, furthermore, more scientific.

II. Design Evaluation Index System

Identifying the Criteria and Sub-criteria

Through a comprehensive research, this paper selects 22 evaluation indicators, which are shown in Table I. These indicators are now considered as the relevant criteria and sub-criteria which are used to formulate an evaluation index system of supply chain competitiveness.

Table 1 The evaluation index system

Goal	Criteria	Sub-criteria
Supply chain competitiveness	Suppliers (B1)	The lead time to deliver goods (C1)
		Order fulfill rate (C2)
		Weight of Key enterprise's business in supplier's (C3)
		level of information communication (C4)
	Key Enterprises (B2)	Labor production rate (C5)
		ROI (C6)
		Market share (C7)
		Profit increase rate (C8)
		ROS (C9)
		Inventory turnover rate (C10)
		Production eligibility rate (C11)
		Rejected and returned material ratio (C12)
		Unit production cost (C13)
		Unit stock cost (C14)
		Production flexibility (C15)

	Distributors & Retailers (B3)	Weight of Key enterprise's business in distributor's（C16）
		Service level (C17)
		Distribute network number (C18)
		On time delivery rate (C19)
		level of information communication (C20)
	Customers (B4)	Customer satisfaction (C21)
		Customer purchase ability (C22)

Establishing the Evaluation Index System of Supply Chain Competitiveness

In this phase, an evaluation index system can be formulated based on the analytic hierarchy process model consisting of the goal, criteria and sub-criteria. The goal, which is placed on the first level, is to evaluate supply chain competitiveness. The second level of the hierarchy occupied the criteria to achieve the goal. There are four criteria related to the destination, namely suppliers, key enterprises, distributors and retails, customers, which are determined according to different stages of supply chain. The third level consists of the 22 sub-criteria, which is grouped with respect to the three criteria occupying the second level. The evaluation index system show in Table 1 can assess the supply chain competitiveness by the rating scheme and determine the priority weights to find the best-performed supply chain.

Quantize Evaluation Indexes of Supply Chain Competitiveness

Different indexes will have different quantized methods, which are shown in Table 2.

Table 2 Different quantized methods for different indexes

Goal	Criteria	Sub-criteria	Calculation formula or source
Supply chain competitiveness	Suppliers (B1)	The lead time to deliver goods (C1)	Statistics data
		Order fulfill rate (C2)	in-time fulfill orders/all the orders in key enterprise
		Weight of Key enterprise's business in supplier's (C3)	purchase amount/sales amount of suppliers
		level of information communication (C4)	By the way of questionnaire(score from 10 to 1 where 10 means best)
	Key enterprises（B2）	Labor production rate (C5)	All the production value/ average NO. of workers (value unit: million RMB)
		ROI (C6)	All profit value / all investment value
		Market share (C7)	Sales quantity/ sales quantity of related products
		Profit increase rate (C8)	(Profit of this period-profit of last period)/ profit of last period
		ROS (C9)	All profit value / all sales value
		Inventory turnover rate (C10)	All stock in warehouse/average stock
		Production eligibility rate (C11)	Eligibility products/ all products
		Rejected and returned material ratio (C12)	Rejected and returned products/ all products
		Unit production cost (C13)	Statistics data (unit: RMB)
		Unit stock cost (C14)	Statistics data (unit: RMB)
		Production flexibility (C15)	By the way of questionnaire(score from 10 to 1 where 10 means best)
	Distributors & Retailers (B3)	Weight of Key enterprise's business in distributor's (C16)	sales amount/sales amount of distributors
		Service level (C17)	By the way of questionnaire(score from 10 to 1 where 10 means best)
		Distribute network number (C18)	Statistics data
		On time delivery rate (C19)	On time delivery orders/ all orders
		level of information communication (C20)	By the way of questionnaire(score from 10 to 1 where 10 means best)
	Customers (B4)	Customer satisfaction (C21)	By the way of questionnaire(score from 10 to 1 where 10 means best)
		Customer purchase ability (C22)	Statistics data (value unit: million RMB)

Ⅲ. An Entropy Weight TOPSIS Model for Supply Chain Competitiveness

Determination of the objective weights based on the Entropy theory

The concept of Entropy originates from thermodynamics and it is used to measure the uncertainty of a system. A system is perhaps in different kinds of conditions. The probability of each state is P_i (i=1, 2,⋯, m), and then the Entropy of the system is:

$$E = -k\sum_{i=1}^{m} P_i \ln P_i \quad (0 \le P_i \le 1; \sum_{i=1}^{m} P_i = 1) \tag{1}$$

When $P_i = 1/m$, i =1, 2, ⋯, m, namely the probabilities are equal, Entropy is maximum, i.e. $E_{max} = \ln(m)$. Multi-index evaluation is to use n indexes $F_1, F_2, \cdots, F_n$ to evaluate the superiority of m alternatives $M_1, M_2, \cdots, M_m$. Let M_{ij} represents the value of the alternative M_i ($1 \le i \le m$) with respect to the index F_j ($1 \le j \le n$). Thus, there is a decision making matrix as following.

$$(M_{ij})_{m*n} = \begin{bmatrix} M_{11} & M_{21} & \cdots & M_{m1} \\ M_{12} & M_{22} & \cdots & M_{m2} \\ & \cdots & \cdots & \\ M_{1n} & M_{2n} & \cdots & M_{mn} \end{bmatrix} \tag{2}$$

For different indexes and alternatives, the type of the index and measurement of the index value are not necessarily the same. Therefore, it is necessary for us to normalize the decision matrix before analysis. The normalized decision matrix $(P_{ij})_{m*n}$ can be obtained by the following method.

$$\begin{cases} P_{ij} = M_{ij} \Big/ \max\limits_{1\le i\le m} M_{ij} \\ P_{ij} = \min\limits_{1\le i\le m} M_{ij} \Big/ M_{ij} \end{cases} \tag{3}$$

Then, the normalized decision matrix $(P_{ij})_{m*n}$ is obtained from the original matrix $(M_{ij})_{m*n}$ which is shown as follows.

$$(P_{ij})_{m*n} = \begin{bmatrix} P_{11} & P_{21} & \cdots & P_{m1} \\ P_{12} & P_{22} & \cdots & P_{m2} \\ & \cdots & \cdots & \\ P_{1n} & P_{2n} & \cdots & P_{mn} \end{bmatrix} \tag{4}$$

We can measure the degree of the uncertainty about the relative importance of the jth index to m alternatives by following entropy:

$$e_j = -k\sum_{i=1}^{m} p_{ij} \ln p_{ij} \tag{5}$$

in which k= 1/ln$n$ >0, $0 \leqslant e_j \leqslant 1$.

In addition, the difference coefficient g_j=1-e_j of jth index can be calculated. For determined j, the smaller the difference g_j of M_{ij} is, the bigger e_j is. We can judge from the character of Entropy that smaller the e_j is, the relative importance of index j is greater. So the weight of every index can be defined as follows:

$$W_j = g_j / \sum_{j=1}^{n} g_j \tag{6}$$

It is obviously that the weight W_j satisfies $0 \le W_j \le 1$, $\sum_{j=1}^{n} W_j = 1$. The determination of W_j depends on the inherent information among indexes in the alternative. That's why we call it objective weight. The same evaluation index j to different alternatives maybe has different objective weight W_j. But, in the practice of evaluation to the supply chain competitiveness, the evaluator always obtains more or less subjective information, such as level of information communication, customer satisfaction etc. To reflect subjective judgment and objective information comprehensively, we can combine subjective weight with objective one and get a comprehensive weight. In order to image the importance of the evaluation indexes in full scale and considering the experience judgment of experts, we combine the subjective weights $W_{s1}, W_{s2}, \cdots, W_{sn}$ of each index given by the experts with the objective weight, and then ascertain the weight of each index, which is shown in equation (7).

$$W_j = \frac{W_{sj}W_{oj}}{\sum_{j=1}^{n}(W_{sj}W_{oj})} \tag{7}$$

Then the Entropy weight matrix is also determined in equation (8).

$$W' = \begin{bmatrix} W'_1 & 0 & \cdots & 0 \\ 0 & W'_2 & \cdots & 0 \\ & \cdots & \cdots & \\ 0 & 0 & \cdots & W'_n \end{bmatrix} \tag{8}$$

To Choose the Best Alternative by Using TOPSIS

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is an effective ranking method for multi-index decision making. Its basic approach is to find an alternative which is closest to the ideal solution and farthest to the negative-ideal solution in a multi-dimensional computing space. This multi-dimensional computing space is specified by a set of evaluation criteria as dimensions. The ideal solution represents a virtual alternative with a set of possibly best synthetic scores in terms of each criterion, while the negative ideal solution is a virtual alternative with a set of worst scores. Physically, they are two points in the computing space with extreme values as dimensions.

The basis of the theory of TOPSIS lies in analyzing the reliability of data resource. Being applied in the evaluation to the supply chain competitiveness, it aims to find a comparing standard value in the indexes which are used to evaluate the competitiveness of different supply chain, the ideal solution and negative ideal solution (the best and the worst index value of supply chains with same index), and compares some index value of one supply chain with the efficient index of the standard value. The smaller the disparity with the standard value is, the stronger the capability is. The method considers the close degree that each index value of each alternative to the ideal solution and negative ideal solution comprehensively. The closer it is, the stronger the supply chain competitiveness is.

First, establish the weighted normalize matrix is by multiplying the normalized decision matrix and the Entropy weight matrix.

$$V=\begin{bmatrix} V_{11} & V_{21} & \cdots & V_{m1} \\ V_{12} & V_{22} & \cdots & V_{m2} \\ & \cdots & \cdots & \\ V_{1n} & V_{2n} & \cdots & V_{mn} \end{bmatrix} \quad (9)$$

Second, ascertain the ideal solution and negative-ideal solution.

$$V^{+}=\left\{(\max_{1\le j\le m} V_{ij} \mid j\in J_1),(\min_{1\le j\le m} V_{ij} \mid j\in J_2) \middle| i=1,2,\cdots,\ m\right\} \quad (10)$$

$$V^{-}=\left\{(\min_{1\le j\le m} V_{ij} \mid j\in J_1),(\max_{1\le j\le m} V_{ij} \mid j\in J_2) \middle| i=1,2,\cdots,\ m\right\} \quad (11)$$

Third, calculate the distance. The distances of evaluation objects to the ideal solution and negative-ideal solution are shown as follows.

$$d_i^{+}=\sqrt{\sum_{j=1}^{n}(V_{ij}-V_j^{+})^2} \quad (i=1,2,\cdots,m) \quad (12)$$

$$d_i^{-}=\sqrt{\sum_{j=1}^{n}(V_{ij}-V_j^{-})^2} \quad (i=1,2,\cdots,m) \quad (13)$$

Finally, ascertain the relative approach degree. The relative approach degree of evaluation object to the ideal solution is demonstrated in equation (14).

$$C_i=d_i^{-}/(d_i^{+}+d_i^{-}) \quad (i=1,2,\cdots,m) \quad (14)$$

The bigger C_i is, the higher competitiveness of its corresponding supply chain *i* is, and vice versa.

Ⅴ. A Case Study

Relative indexes data for competitiveness of five different supply chains in chemical industry S1, S2, S3, S4, and S5 are as follows, as it shows in Table 3. We use multi-index model to evaluate it.

We can calculate the evaluation weight value from (1) to (6) and get the subjective judgment weight value from the experts. After normalizing, the result $W_{s,}$ is show in Table 4. Then, according to equation (7) we can get the synthetic weight $W_{j,}$ which is shown in Table 5.

Then the distances each alternative of each supply chain to the positive ideal solution, the negative ideal solution and approach degree can be got respectively from (8) to (14). The distance and relative approach degree can be seen in Table 6.

So, we can know that the order of supply chain competitiveness of five cities is S4, S_2, S_3, S_1 and S_5, according to the value of C. The result coincides with the fact.

Table 3 Relative indexes data for five different supply chains

Goal	Criteria	Sub-criteria	S_1	S_2	S_3	S_4	S_5
Supply chain competitiveness	Suppliers (B1)	The lead time to deliver goods (C1)	15	20	7	8	4
		Order fulfill rate (C2)	90.65%	96.96%	98.37%	90.31%	96.50%
		Weight of Key enterprise's business in supplier's (C3)	60.28%	45.29%	86.26%	89.05%	93.07%
		level of information communication (C4)	8	9	7	6	4
	Key Enterprises （B2)	Labor production rate (C5)	0.564	0.973	0.617	0.728	0.419
		ROI (C6)	1.8	2.4	1.7	1.9	1.2
		Market share (C7)	35.18%	40.87%	38.03%	38.85%	32.09%
		Profit increase rate (C8)	8.25%	3.98%	6.38%	7.26%	5.73%
		ROS (C9)	10.20%	17.43%	14.48%	13.95	15.62%
		Inventory turnover rate (C10)	2.4	3.2	2.8	4.2	3.1
		Production eligibility rate (C11)	95.42%	97.41%	89.97%	98.37%	94.15%
		Rejected and returned material ratio (C12)	3.66%	4.57%	2.89%	3.62%	4.18%
		Unit production cost (C13)	178.93	254.87	265.19	116.49	218.81
		Unit stock cost (C14)	14.76	26.7	12.7	17.8	18.95

		Production flexibility (C15)	8	5	7	6	6
	Distributors & Retailers (B3)	Weight of Key enterprise's business in distributor's (C16)	78.98%	67.32%	58.21%	74.21%	83.79%
		Service level (C17)	7	5	6	8	7
		Distribute network number (C18)	89	217	54	93	68
		On time delivery rate (C19)	95.38%	97.98%	92.73%	91.45%	90.98%
		level of information communication (C20)	6	9	7	8	7
	Customers (B4)	Customer satisfaction (C21)	8	9	7	7	6
		Customer purchase ability (C22)	0.35	0.54	1.42	0.76	0.96

Table 4 Experts' weight W_s,

Goal	Criteria	Sub-criteria	Experts' weight W_s,
Supply chain competitiveness	Suppliers (B1)	The lead time to deliver goods (C1)	0.0382
		Order fulfill rate (C2)	0.0573
		Weight of Key enterprise's business in supplier's (C3)	0.0446
		level of information communication (C4)	0.0510
	Key enterprises （B2)	Labor production rate (C5)	0.0255
		ROI (C6)	0.0446
		Market share (C7)	0.0510
		Profit increase rate (C8)	0.0382
		ROS (C9)	0.0446
		Inventory turnover rate (C10)	0.0446
		Production eligibility rate (C11)	0.0318
		Rejected and returned material ratio (C12)	0.0318
		Unit production cost (C13)	0.0446
		Unit stock cost (C14)	0.0318
		Production flexibility (C15)	0.0446
	Distributors & retailers (B3)	Weight of Key enterprise's business in distributor's (C16)	0.0510
		Service level (C17)	0.0637
		Distribute network number (C18)	0.0446
		On time delivery rate (C19)	0.0573
		level of information communication (C20)	0.0510
	Customers (B4)	Customer satisfaction (C21)	0.0637
		Customer purchase ability (C22)	0.0446

Table 5 synthetic weight W_j

Goal	Criteria	Sub-criteria	synthetic weight W_j
Supply chain competitiveness	Suppliers (B1)	The lead time to deliver goods (C1)	0.0291
		Order fulfill rate (C2)	0.0724
		Weight of Key enterprise's business in supplier's (C3)	0.0455
		level of information communication (C4)	0.0479
	Key enterprises （B2)	Labor production rate (C5)	0.0211
		ROI (C6)	0.0407
		Market share (C7)	0.0589
		Profit increase rate (C8)	0.0361
		ROS (C9)	0.0563
		Inventory turnover rate (C10)	0.0401
		Production eligibility rate (C11)	0.0405
		Rejected and returned material ratio (C12)	0.0302

		Unit production cost (C13)	0.0341
		Unit stock cost (C14)	0.0291
		Production flexibility (C15)	0.0436
	Distributors & retailers (B3)	Weight of Key enterprise's business in distributor's (C16)	0.0554
		Service level (C17)	0.0650
		Distribute network number (C18)	0.0320
		On time delivery rate (C19)	0.0718
		level of information communication (C20)	0.0515
	Customers (B4)	Customer satisfaction (C21)	0.0644
		Customer purchase ability (C22)	0.0345

Table 6 Evaluation results

Supply chain	Positive distance value	Negative distance value	Approach degree	Ranking
S_1	0.0781	0.0022	0.373	4
S_2	0.0822	0.0029	0.397	2
S_3	0.0757	0.0024	0.393	3
S_4	0.0418	0.0060	0.650	1
S_5	0.0812	0.0021	0.360	5

Ⅵ. Conclusion

This article comprehensively considers the mutual relations among the indexes of evaluation to supply chain competitiveness and puts forward a method of multi-index decision. The method evaluates supply chain competitiveness based on the Entropy-Weight and the TOPSIS. The new method makes full use of the inherent information of alternative. Moreover, the author calculates the evaluation weight value and the subjective judgment weight value of experts by Entropy and combines the two a comprehensive value, at last evaluates by the method of the law of approaching ideal point. It's advantage lie in that there are no special request for the samples and it is more scientific and standard, even more simple and easy to operate after solving the problem of the calculation software, supply chains with correct data sample can use it.

The research of this article is hoped to be useful in the area of supply chain competitiveness evaluation, meanwhile, can help relative enterprises to find their weakness and improve their performance.

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Background of Authors

Xia Wang received her PhD degree in Architecture from Tongji University in 1997. Now she is the Professor of Tongji University, tutor of PhD. Her recent research interests include logistics and supply chain management,and management science & engineering. Her research results had published in some international journals and core magazines in China and international conference.

Shenhui Wu received his Bachelor degree in Management from Zhejiang Gongshang University in 2004. He is now a master candidate in SEM, Tongji University. His recent research interests include supply chain management and logistics management. Six of his academic papers have been published in renowned academic magazines and conference. three of which are indexed by EI and ISTP.