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Research Article

Research on Logistics Capability of the Supply Chain in Food Production Enterprise Based on AHP and Fuzzy Entropy

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Abstract: As the third profit source, logistics plays an extremely important role to reduce costs, improve efficiency and enhance the enterprise market competitiveness. This study describes the logistics capability of the supply chain in food production enterprise. The logistics capability is summarized as the ability to control the logistics cost, the ability of logistics service, the ability of logistics elements and the ability of logistics organization and management. Through the analysis of logistics capability of the supply chain in food production enterprise, this study establishes an evaluation system of logistics capability of the supply chain from the above four aspects. The Analytic Hierarchy Process (AHP) is used to determine weights of the subspace dimension indicators and the membership function in fuzzy theory is used to determine the indicators of the level of the matrix. Combined with the theory of entropy, integrated weight of logistics capability of the supply chain of the matrix can be determined and quantified indicators will be achieved as an evaluation criterion. Finally, the indicator system and evaluation method are integrated to analyze the logistics capabilities of the supply chain in food production enterprise via a case study, which proves to be valid.

Keywords: Analytic Hierarchy Process (AHP), fuzzy entropy, logistics capability

INTRODUCTION

With the rapid development of economic globalization and technology advance, the enterprises have to face the global competition and the challenge, to shorten the delivery time, improve quality, improve the service and meet the personalized needs. At present, it becomes more and more difficult that the enterprises only rely on the ability to create ways to obtain the sustainable competitive advantage. Based on this, the enterprises began to turn their attention to the logistics field, which is called "the third profit source" of the enterprises.

In the past decades, some experts and scholars at home and abroad had made a lot of research on the logistics capability of the supply chain. Daugherty and Pittman (1995) studied the supply chain from the speed of product distribution, information exchange and flexibility. Logistics capability of the supply chain should include the customer's response speed, customer service level, delivery on time and delay or shortage of the advance notice (Daugherty *et al*., 1998). Morash *et al*. (1996) made a study on strategic logistics capabilities for competitive advantage and firm success. Logistics capability of the supply chain should include processing ability and the value-added capacity and the relationship between them was analyzed (Sameer, 2008). Huang (2008) put forward some problem-solving measures to improve the logistics capability of supply chain. Shang *et al*. (2009) summarized the logistics capability from four aspects and evaluated the logistics capability of a case based on the fuzzy evaluation method.

On the whole, most of experts and scholars performed some empirical studies on logistics capabilities of supply chain by means of some evaluation methods, including the Analytic Hierarchy Process (AHP), fuzzy evaluation and entropy theory and so on**.** At the same time, every evaluation method has its advantages and disadvantages. This study tries to make good use of their benefits and establish logistics capability of supply chain evaluation system in food production enterprise through model calculation of AHP and fuzzy entropy from four aspects, including the ability to control the logistics cost, the ability of logistics service, the ability of logistics elements and the ability of logistics organization and management.

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Table 1: The evaluation indicator system of supply chain logistics capabilities

First-level indicators	Second-level indicators	Connotation of indicators
Ability to control the logistics cost (A_1)	Ability to control the supply logistics cost (A_{11})	It mainly refers to forecast cost of logistics, projected cost of logistics and preparation cost of logistics.
	Ability to control the production logistics cost (A_{12})	It mainly refers to a variety of productive logistics cost, including loading and unloading, transportation, processing, storage and transportation, etc
	Ability to control the sales logistics cost (A_{13})	It mainly refers to the sales service cost of the logistics, including the storage, packaging, service fees, etc.
	Ability to control the return logistics cost (A_{14})	It mainly refers to the logistics cost for the return and exchange.
	Ability to control the abandoned logistics cost (A_{15})	It mainly refers to the logistics cost produced by waste, substandard products.
Ability of logistics service (A_2)	Time efficiency elements (A_{21})	It mainly refers to order processing speed, delivery accuracy and flexibility
	Information elements(A_{22})	It mainly refers to informatization level, complete information and visibility
	Customer element (A_{23})	It mainly refers to the goods availability, complaint handling, personalized response
Ability of logistics elements(A_3)	Logistics equipment (A_{31})	The machinery and equipment needed for various logistics activities and logistics operations
	Logistics facilities area (A_{32})	The facilities area needed for various logistics activities and logistics operations
	Logistics capital (A_{33})	The capital needed for various logistics activities and logistics operations
Ability of logistics organization and management (A_4)	Management ability (A_{41})	Management ability of logistics administrators
	Operation ability (A_{42})	Operation ability of logistics activity operators
	Technical level (A_{43})	Technical level of logistics technical personnel

TO CONSTRUCT THE EVALUATION SYSTEM OF LOGISTICS CAPABILITY OF THE SUPPLY CHAIN

Different industries have different priorities about the evaluation indicator of logistics capability of the supply chain. Based on the results of previous research, according to the comparison and summary, an evaluation indicator system of supply chain logistics capabilities can be established from four aspects (Table 1).

TO DETERMINE WEIGHTS AMONG THE SECOND-LEVEL INDICATORS BY MEANS OF AHP

Analytic Hierarchy Process (AHP) is a functional decision process proposed and gradually improved by the American mathematician Saaty T. L. in the 1970's (Saaty, 1990). It is appropriate to use the AHP method to determine weights among the second-level indicators and weighted calculation. Finally, this study uses the AHP method to establish a model, whose main steps are as follows (Duan *et al*., 2011):

To establish the hierarchical structure model: According to the Table 1 and the theory of AHP, the hierarchical structure model can be easily established.

To construct the judgment matrices of each level: Assuming the vector $C=(C_1,C_2,...,Cm_1)$, $S=(S_1,S_2,...,Sm_2)$, $E=(E_1,E_2,...,Em_3)$ and O = (O_1, O_2, ..., Om_4) represent respectively the vector which is composed of each first-level indicator and represent respectively the number of the second-level indicators responding to their own first-level indicator. Then the following data matrix will be obtained (Chen and Li, 2011):

$$(C_{ij})=\begin{pmatrix} C_{11} & \dots & C_{15} \\ \vdots & \ddots & \vdots \\ C_{m1} & \cdots & C_{m5} \end{pmatrix} \quad (S_{ij})=\begin{pmatrix} S_{11} & \dots & S_{13} \\ \vdots & \ddots & \vdots \\ S_{m1} & \cdots & S_{m3} \end{pmatrix}$$

$$(E_{ij})=\begin{pmatrix} E_{11} & \dots & E_{13} \\ \vdots & \ddots & \vdots \\ E_{m1} & \cdots & E_{m3} \end{pmatrix} \quad (O_{ij})=\begin{pmatrix} O_{11} & \dots & O_{13} \\ \vdots & \ddots & \vdots \\ O_{m1} & \cdots & O_{m3} \end{pmatrix}$$

where,

$$m_1=5, m_2=3, m_3=3, m_4=3$$

To perform hierarchical single sorting and consistency check: By means of the Matlab software, the hierarchical single sorting can be easily solved. Then the consistency check will be made, whose equation is as follows:

$$CI=\frac{(\lambda_{\max}-n)}{(n-1)} \tag{1}$$

$$CR=\frac{CI}{RI} \tag{2}$$

where,

- $\lambda_{\max}$ = The maximum eigenvalue
- n = The rank of judgment matrix
- CI = Consistency of judgment matrix deviation
- CR = Random consistence rate
- RI = The average random consistency of different rank judgment matrix, whose values can be selected from Table 2.

To adjust the judgment matrix and hierarchical ranking model: If necessary, the judgment matrix and hierarchical ranking model may be corrected and adjusted. If $CR<0.1$, the results of hierarchical sorting

Table 2: The indicator of average random consistency

n	3	4	5	6	7	8	9	10	11	12
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49	1.52	1.54

will satisfy the requirement for consistency, otherwise the judgment matrix will need to be adjusted.

TO ESTABLLISH EVALUATION SYSTEM OF SUPPLY CHAIN LOGISTICS ABILITY BASED ON THE FUZZY ENTROPY MODEL

To determine the evaluation set: In the model of rough sets and fuzzy entropy, the evaluation set of the logistics capability of the supply chain is C = (C_1, C_2, C_3, C_4, C_5), C_k (k = 1, 2, 3, 4, 5) represents, respectively five grades, which include the higher, high, general, low and lower. And the above five grades are given the assignment A= {90, 80, 70, 60, 30}.

To construct the membership degree matrix: If any element x in the domain is corresponding to a number of $A(x)$, $A(x)$ is the fuzzy set in the domain. When element x has a change in the domain, $A(x)$ can be considered as the membership function. If $A(x)$ is closer to 1, it denotes that membership degree of x to $A(x)$ is higher; at the same time, $A(x)$ is closer to 0; it denotes that membership degree of x to $A(x)$ is lower (Yu *et al*., 2010).

Then membership functions are used to establish the membership of indicators on levels. It is calculated as follows:

- **To calculate the membership and make normalized processing:** Supposing the number of each level indicator of logistics capability of the supply chain is n, the logistics capability of the index i is x_i and the corresponding membership $\mu(x_i)$ can be calculated by the Eq. (3):

$$\mu(x_i) = 1 - e^{-\frac{1}{x_i}(x_i - a)^2} \quad (3)$$

where,

$i = 1, 2, 3, 4;$
a = 1, 3/4, 1/2, 1/4, 0

And subspace dimension indexes of supply chain logistics capabilities are either positive or negative, either high or low; the indicators will be converted into the same trend changes via the following Eq. (4):

$$\mu(x_{ij}) = \frac{\mu(x'_{ij}) - \mu(x'_{i\min})}{\mu(x'_{j\max}) - \mu(x'_{i\min})} \quad (4)$$

where,
$\mu(x'_{j\max})$ = The maximum of membership degree matrix
$\mu(x'_{i\min})$ = The minimum of membership degree matrix

- **To calculate the evaluation matrix of fuzzy membership degree:**

$$T = \begin{bmatrix} \mu_{i11} & \mu_{i12} & \cdots & \mu_{i1n} \\ \mu_{i21} & \mu_{i22} & \cdots & \mu_{i2n} \\ \vdots & \vdots & \vdots & \vdots \\ \mu_{im1} & \mu_{in2} & \cdots & \mu_{imn} \end{bmatrix}_{m\times n}$$

where,
i = NO. of first-level indicators ($i = 1, 2, 3, 4$)
m = The indicator number of subspace dimension in the four aspects
n = The number of the evaluation grade (n = 5)
μ_{ijn} = The membership degree of the *j* to the grade of n responding to the aspect *i*

To determine the entropy values and weight of evaluation index:

- **To calculate the weighted coefficient of subspace dimension and make normalization:**

$$T_i = W_i \times A_i \quad (5)$$

where,
j = 1, 2, 3, 4
W_i = The weight of the indicator
A_i = The membership of subspace dimension index

- **To determine the entropy values of the first-indicator (Shi *et al*., 2009):**

$$H(x_j) = -k\sum_{i=1}^{n} z_{ij} \log z_{ij} \quad (6)$$

where,
j = 1, 2, 3, 4
k = The adjustment coefficient ($k = 1/\log n$)
n = The number of evaluation grade ($n = 5$)
z_{ij} = The element of a normalized matrix

- **To convert the entropy values into the weight values:**

$$d_j = \frac{1 - H(x_j)}{m - \sum_{j=1}^{m} H(x_j)} \tag{7}$$

where,
j = 1, 2, …, m

$$0 \le d_j \le 1, \sum_{j=1}^{m} d_j = 1$$

- **To calculate the value of supply chain logistics capabilities:**

$$F = d_j \times A^T \tag{8}$$

CASE STUDY

In this study, the logistics capability of supply chain of a food production enterprise in 2011 is evaluated by the models of AHP and fuzzy entropy.

To determine weights among the second-level indicators by means of AHP: According to the expert scoring and results of the questionnaires, the hierarchical analysis matrix will be built so as to determine the internal weights of evaluation index level. The maximum eigenvalue of all judgment matrices of every level is as follows and all the results of hierarchical sorting satisfy the requirement for consistency check.

- The calculation of the judgment matrix U_1 (Table 3):
- The calculation of the judgment matrix U_2 (Table 4):
- The calculation of the judgment matrix U_3 (Table 5):
- The calculation of the judgment matrix U_4 (Table 6):

To calculate the membership of indicators: According to the Eq. (3) and (4), the membership of indicators can be calculated, which can be shown in Table 7:

According to the Eq. (5), weighted coefficient of subspace dimension can be obtained:

$$T_1 = W_1 \times (A_{11} \quad A_{12} \quad A_{13} \quad A_{14} \quad A_{15}) =$$
(0.4506, 0.3327, 0.1679, 0.0469, 0.0021)

$$T_2 = W_2 \times (A_{21} \quad A_{22} \quad A_{23}) =$$
(0.5923, 0.2314, 0.1320, 0.0364, 0.0084)

$$T_3 = W_3 \times (A_{31} \; A_{32} \; A_{33})$$
(0.5692, 0.2573, 0.1544, 0.0179, 0.0010)

Table 3: The judgment matrix U_1 and its interior weights w_1

U_1	u_{11}	u_{12}	u_{13}	u_{14}	u_{15}	w_1
u_{11}	1	1/3	1/3	3	3	0.1629
u_{12}	3	1	1	4	4	0.3455
u_{13}	3	1	1	4	4	0.3455
u_{14}	1/3	1/4	1/4	1	1	0.0731
u_{15}	1/3	1/4	1/4	1	1	0.0731

Remarks: $\lambda_{max} = 5.1065$, $CI = 0.0266$, $CR = 0.0238 < 0.10$

Table 4: The judgment matrix U_2 and its interior weights w_2

U_2	u_{21}	u_{22}	u_{23}	w_2
u_{21}	1	2	3	0.5396
u_{22}	1/2	1	2	0.2970
u_{23}	1/3	1/2	1	0.1634

Remarks: λ_{max} = 3.0092, CI = 0.0046, CR = 0.0079< 0.10

Table 5: The judgment matrix U_3 and its interior weights w_3

U_3	u_{31}	u_{32}	u_{33}	w_3
u_{31}	1	3	5	0.6370
u_{32}	1/3	1	3	0.2583
u_{33}	1/5	1/3	1	0.1047

Remarks: λ_{max} = 3.0385, CI = 0.0193, CR = 0.0332 < 0.10

Table 6: The judgment matrix U_4 and its interior weights w_4

U_4	u_{41}	u_{42}	u_{43}	w_4
u_{41}	1	1/3	1/4	0.1172
u_{42}	3	1	1/3	0.2684
u_{43}	4	3	1	0.6144

Remarks: λ_{max} = 3.0735, CI = 0.0368, CR = 0.0634< 0.10

Table 7: The membership of indicators based on fuzzy entropy

Indicator	Higher	High	General	Low	Lower
A_{11}	0.459	0.317	0.156	0.061	0.007
A_{12}	0.430	0.297	0.213	0.059	0.001
A_{13}	0.448	0.368	0.163	0.020	0.001
A_{14}	0.597	0.315	0.051	0.034	0.003
A_{15}	0.394	0.387	0.121	0.098	0.001
A_{21}	0.714	0.162	0.121	0.003	0.001
A_{22}	0.410	0.357	0.120	0.098	0.015
A_{23}	0.522	0.232	0.190	0.035	0.021
A_{31}	0.630	0.210	0.148	0.011	0.001
A_{32}	0.477	0.359	0.141	0.021	0.001
A_{33}	0.427	0.294	0.226	0.052	0.001
A_{41}	0.418	0.361	0.123	0.077	0.021
A_{42}	0.661	0.291	0.027	0.020	0.001
A_{43}	0.374	0.307	0.269	0.035	0.015

$$T_4 = W_4 \times (A_{41} \quad A_{42} \quad A_{43})$$
= (0.4562, 0.3090, 0.1869, 0.0359, 0.0119)

According to the Eq. (6), the entropy values of the first-indicator can be obtained:

$$H = (H_1 \quad H_2 \quad H_3 \quad H_4) = (0.7340, 0.6691, 0.6446, 0.7497)$$

According to the Eq. (7), weight values can be obtained:

$$d = (d_1 \quad d_2 \quad d_3 \quad d_4) = (0.2212, 0.2752, 0.2955, 0.2081)$$

According to the Eq. (8), value of supply chain logistics capabilities can be obtained:

$$F = d \times A^T = d \times (90 \;\; 80 \;\; 70 \;\; 60)^T = 75.0950$$

The evaluation of calculation results: By the above calculation, the conclusion can be drawn that the capability of the enterprise in food production enterprise is at the secondary level and the capability of four aspects is in general, which is consistent with the actual situation.

CONCLUSION

In this study, an evaluation system of supply chain logistics capabilities is established from four aspects. A model of AHP and fuzzy entropy is used to analyze the logistics capabilities supply chain in food production enterprise. And the result of an empirical analysis proved to be valid.

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