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Research on Performance Evaluation of Aquatic Products Cold Chain Transportation based on AHP and Entropy Weight Method

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Abstract

The complexity of aquatic products cold chain transportation puts forward higher requirements for its performance evaluation index design and evaluation method selection. Because the transportation process involves multiple stakeholders, it is necessary to balance the demands of all parties in the performance evaluation index design, and balance the systematicness of cold chain transportation and the subjectivity of performance evaluation in the evaluation methods design. According to the characteristics of aquatic products cold chain transportation, the evaluation indexes are designed from four dimensions including consumers, supply chain, aquatic products and transportation enterprises. The analytic hierarchy process (AHP) and entropy weight method are used to evaluate the performance of aquatic products cold chain transportation, systematicness and subjectivity of evaluation are well balanced in this research, and an example is given for empirical analysis. This paper provides a reference for the performance evaluation of aquatic products cold chain transportation.

Keywords

Aquatic Products; Cold Chain Transportation; Performance Evaluation.

1. Introduction

Compared with ordinary agricultural products transportation, aquatic products cold chain transportation has higher operating costs, higher quality requirements and greater market demand. Performance evaluation of aquatic products cold chain transportation plays a prominent role in aquatic products cold chain transportation management, which has been studied by some scholars.

Fengquan Huang (2016) discussed the cold chain performance evaluation system of most ordinary foods and found that most performance evaluation systems could not measure integrated cold chain logistics. Therefore, he built a set of integrated cold chain system framework on this basis. Jing Li (2015) established key indexes from both supply chain and consumers, and combined AHP method and efficacy coefficient method for evaluation. Chowetal (2016) analyzed the advantages and disadvantages of all aspects of the cold chain and considered the factors that should be paid attention to in performance evaluation. Bradley (2016) constructed an appropriate performance evaluation system for cold chain logistics and discussed three aspects in the process of performance evaluation research, namely, the enterprise's own advantages and disadvantages, customer response and external environmental impact. Donald J Bowersox (2017) chose to analyze the enterprise's operation from the internal and external environment when evaluating the enterprise's cold chain performance, that is, the enterprise should not only pay attention to the aquatic product market, but also pay attention to its own problems, such as whether the cold chain facilities and equipment owned by the enterprise are perfect, whether the cost of cold chain transportation is high or not. The existing research is not comprehensive enough in the design of key evaluation indexes, cannot cover the main cold chain business processes, tends to use a certain

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method in the selection of evaluation methods, and cannot coordinate the shortcomings of specific evaluation methods. Therefore, this paper adjusts the design of evaluation indexes and the selection of evaluation methods, and comprehensively uses analytic hierarchy process and entropy weight method. Analytic hierarchy process is systematic. It evaluates the assessment elements of different dimensions and levels. It is concise and practical. Entropy weight method can avoid the subjectivity when giving weight. The combination of the two methods can better balance the subjectivity and systematicness of evaluation and improve the evaluation effect.

2. Content of Performance Evaluation Index System of Aquatic Products Cold Chain Transportation

Table 1. Performance evaluation index system of aquatic products cold chain transportation

	level Ⅰ index	level Ⅱ index	level Ⅲ index
Performance evaluation system of aquatic products cold chain transportation	Customer value evaluation B_1	Order fulfillment evaluation C_1	Punctual transportation and distribution rate D_1
			Quantity accuracy D_2
			Fresh rate of aquatic products D_3
		Customer service level evaluation C_2	Customer satisfaction rate D_4
			Handling rate of customer comments D_5
			Customer churn rate D_6
	Supply chain value evaluation B_2	Technology collaboration C_3	Technical compatibility D_7
		Information collaboration C_4	Information transmission and sharing D_8
		Process collaboration C_5	Smoothness of process connection D_9
			Cohesion D_{10}
	Aquatic product evaluation B_3	time C_6	Transportation time D_{11}
		temperature C_7	Temperature compliance rate D_{12}
		quality C_8	Test qualification rate D_{13}
	Evaluation for cold chain transportation enterprises B_4	cost C_9	Unit transportation cost D_{14}
			Equipment depreciation cost D_{15}
			Transportation flexibility cost D_{16}
		asset management C_{10}	Vehicle serviceability rate D_{17}
			Average vehicle load rate D_{18}

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The performance evaluation index system of aquatic products cold chain transportation is designed including six criteria: purposefulness, systematicness, criticality, ease of operation, balance between dynamics and stability, and the combination of quantitative and qualitative.

In this paper, the performance evaluation is carried out from four dimensions: consumers, supply chain, aquatic products and transportation enterprises. On this basis, the performance evaluation index model is established, and the corresponding level I and level Ⅱ indexes are given. There are 32 indexes in this paper, including 4 level Ⅰ indexes, 10 level Ⅱ indexes and 18 level Ⅲ indexes. The indexes of the first two levels, i.e., level I and level Ⅱ indexes, cannot be measured directly, but can be measured by the indexes of the next level. As shown in Table 1.

3. Performance Evaluation Method of Aquatic Products Cold Chain Transportation

The setting of index weight in the cold chain evaluation system is directly related to the performance evaluation results of the index. This paper comprehensively applies the analytic hierarchy process and entropy weight method to allocate the weight of each index. Analytic hierarchy process is a mature method to determine the index weight, which is widely used in evaluation research, For example, Xiaomin Cai (2020) uses analytic hierarchy process and ideal point approximation method to analyze the vehicle safety driving evaluation model. This paper uses entropy weight method to assign the performance evaluation index of aquatic products cold chain transportation.

3.1. Weight Calculation Process of Analytic Hierarchy Process

Assume that n experts are invited to score the indexes and specify the criticality of the indexes. In this paper, AHP method is used to analyze the set of level Ⅲ indexes $C_1=(D_1,D_2,D_3,D_4)$ to specify the weight of the upper level indexes. The process includes the following aspects:

(1) Build judgment matrix. Use D_{ij} to indicate the importance of index D_i to index D_j, D_{ii} =1, $D_{ij}=\frac{1}{d_{ji}}$, $D_{ij}=\frac{d_{ik}}{d_{jk}}$, By means of the evaluation results of experts, an index judgment matrix is created.

(2) Calculate the target weight. The performance evaluation index system in this paper sets up three levels of indexes, and takes the judgment matrix as an example to illustrate the determination steps of weight.

Firstly, multiply the elements of various indexes of $X=\left(x_{ij}\right)_{(4\times4)}$:

$$X_{\mathrm{i}}=\prod_{j=1}^{4}x_{ij}\left(i,j=1,2,3,4\right) \tag{1}$$

Secondly, calculate the expected value of X_{i}:

$$\overline{X_i}=\sqrt[4]{\overline{X_i}}\left(i=1,2,3,4\right) \tag{2}$$

Finally, process the data obtained from $\overline{X_i}$ to obtain the score of each index element, that is, the calculation formula of the weight of each index element of the level Ⅲ index set $C_1=\left(D_1,D_2,D_3,D_4\right)$ can be obtained as follows:

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$$b_i' = \frac{\overline{X_i}}{\sum_{i=1}^{4} \overline{X_i}} \tag{3}$$

3.2. The Process of Calculating Weight by Entropy Weight Method

When evaluating the performance of aquatic products cold chain transportation, evaluators need to consider that any index has its value and give different weights to each index by calculating the corresponding index score. For example, there are level II evaluation index C_1, the next level index level, there are four level III indexes D_1, D_2, D_3, D_4. It is assumed that n experts participate in the questionnaire survey.

On the basis of set $C_1 = (D_1, D_2, D_3, D_4)$, entropy weight method is used to deeply analyze the upper-level indexes and give weight to C_1, the specific contents are as follows:

Firstly, the judgment matrix is constructed. The scoring range is divided into five grades, namely very poor, poor, average, good and very good.

Secondly, the matrix is transformed into standard form. The level III index set C_1 from n experts is standardized into matrix $\overline{C_{c1}}$, and $\overline{\alpha_{ik}}$ represents the standardization result of judgment matrix:

$$\overline{\alpha_{ik}} = \frac{\alpha_{ik}}{\sum_{k=1}^{5} \alpha_{ik}} \tag{4}$$

in the above formula, $i = 1,2,3,4$, $k = 1,2,3,4,5$, so C_{C1} is:

$$C_{C1} = \begin{pmatrix} \overline{a_{11}} & \overline{a_{12}} & \overline{a_{13}} & \overline{a_{14}} & \overline{a_{15}} \\ \overline{a_{21}} & \overline{a_{22}} & \overline{a_{23}} & \overline{a_{24}} & \overline{a_{25}} \\ \overline{a_{31}} & \overline{a_{32}} & \overline{a_{33}} & \overline{a_{34}} & \overline{a_{35}} \\ \overline{a_{41}} & \overline{a_{42}} & \overline{a_{43}} & \overline{a_{44}} & \overline{a_{45}} \end{pmatrix}$$

Thirdly, the results can be obtained. Set level III evaluation index set $C_1 = (D_1, D_2, D_3, D_4)$, and the entropy of each index is expressed by R_i:

$$R_i = -\frac{1}{\ln n} \sum_{k=1}^{n} \overline{\alpha_{ik}} . \ln \overline{\alpha_{ik}} \tag{5}$$

in the above formula, $i = 1,2,3,4$, $k = 1,2,3,4,5$.

Finally, the entropy weight is calculated. Based on set $C_1 = (D_1, D_2, D_3, D_4)$, entropy weight can be expressed by γ_i:

$$\gamma_i = (1 - R_i) / \sum_{i=1}^{4} (1 - R_i) \tag{6}$$

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in the above formula, $i=1,2,3,4$. The corresponding entropy weight is γ_1, γ_2, γ_3, γ_4.

3.3. Comprehensive Weight Calculation

In this paper, AHP method and entropy weight method are reasonably applied to solve the comprehensive weight. AHP method obtains the weight as $d_i^{'}$ ($i=1,2,3,4$),entropy weight method obtains the weight γ_i ($i=1,2,3,4$), Then the comprehensive weight ω_i is calculated on the basis of the two weights, The calculation formula is as follows:

$$\omega_i = \frac{d_i^{'}\gamma_i}{\sum_{i=1}^{4} d_i^{'}\gamma_i} \tag{7}$$

4. Empirical Analysis

This paper takes Anhui Fuhuang Sanzhen Food Group Co., Ltd. as an example. The company is mainly engaging in the farming, production and foreign trade of aquatic products. The total number of aquatic products reaches 20000 tons every year. The company has a large number of refrigerators, freezers, various transportation vehicles, high-end analytical instruments and other equipment, and has strong cold chain operation capacity of aquatic products. Now we evaluate and analyze its cold chain transportation performance.

4.1. Setting of Evaluation Index Weight

4.1.1. Applying Analytic Hierarchy Process to Set Weight

Through interviews with relevant experts and managers, the author obtains the statistical data of cold chain transportation performance evaluation. Based on the performance evaluation index system mentioned above, the judgment matrix obtained is processed again.

Judgment matrix of $B_1 - B_4$ relative to target A is as follows:

$$B=\begin{pmatrix} 1 & 2 & 1 & 2 \\ 1/2 & 1 & 1/2 & 1 \\ 1 & 2 & 1 & 2 \\ 1/2 & 1 & 1/2 & 1 \end{pmatrix}, \text{ Similarly, } B_1=\begin{pmatrix} 1 & 2 \\ 1/2 & 1 \end{pmatrix}, B_2=\begin{pmatrix} 1 & 1/2 & 1 \\ 2 & 1 & 2 \\ 1 & 1/2 & 1 \end{pmatrix},$$

$$B_3=\begin{pmatrix} 1 & 1/2 & 1/2 \\ 2 & 1 & 1 \\ 2 & 1 & 1 \end{pmatrix}, B_4=\begin{pmatrix} 1 & 2 \\ 1/2 & 1 \end{pmatrix}, C_1=\begin{pmatrix} 1 & 2 & 1 \\ 1/2 & 1 & 1/2 \\ 1 & 2 & 1 \end{pmatrix}, C_2=\begin{pmatrix} 1 & 2 & 1 \\ 1/2 & 1 & 1/2 \\ 1 & 2 & 1 \end{pmatrix},$$

$$\ldots C_9=\begin{pmatrix} 1 & 1 & 2 \\ 1 & 1 & 2 \\ 1/2 & 1/2 & 1 \end{pmatrix}, C_{10}=\begin{pmatrix} 1 & 2 \\ 1/2 & 1 \end{pmatrix}.$$

Use the formula mentioned above to calculate all judgment matrices and weight of the indexes. Firstly, the judgment matrix X_i is calculated, X_1=2, X_2=0. 25, X_3=2 can be obtained from equation (1), $\overline{X_1}$=1. 2599, $\overline{X_2}$=0. 6299, $\overline{X_3}$=1. 2599 can be obtained from equation (2), it can be

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obtained from equation (3) that the weight vector of C_1 is $C_1'=(0.4, 0.2, 0.4)$, CR=0.00<0.1. As above, the weights of performance evaluation indexes at other levels can be obtained, as shown in Table 2.

Table 2. Index weight set by AHP method

Level Ⅰ index	Weight	CR	level Ⅱ index	Weight	CR	level Ⅲ index	Weight	CR
B_1	0.3333	0.01<0.1	C_1	0.6667	0.00<0.1	D_1	0.4	0.00<0.1
						D_2	0.2	
						D_3	0.4	
			C_2	0.3333		D_4	0.4	0.00<0.1
						D_5	0.2	
						D_6	0.4	
B_2	0.1667		C_3	0.25	0.00<0.1	D_7	1	0.00<0.1
			C_4	0.5		D_8	1	0.00<0.1
			C_5	0.25		D_9	0.6667	0.01<0.1
						D_{10}	0.3333	
B_3	0.3333		C_6	0.2	0.00<0.1	D_{11}	1	0.01<0.1
			C_7	0.4		D_{12}	1	0.01<0.1
			C_8	0.4		D_{13}	1	0.01<0.1
B_4	0.1667		C_9	0.6667	0.00<0.1	D_{14}	0.4	0.01<0.1
						D_{15}	0.4	
						D_{16}	0.2	
			C_{10}	0.3333		D_{17}	0.6667	0.01<0.1
						D_{18}	0.3333	

4.1.2. Applying Entropy Weight Method to Set Weight

According to the statistical information obtained from the questionnaire survey of several respondents, the judgment matrix of level Ⅲ index $D_1 \sim D_3$ to level Ⅱ index C_1 is obtained. After standardizing formula (4), a judgment matrix is created as follows:

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$$\overline{C_{C1}} = \begin{pmatrix} 1 & 0 & 1 & 0 & 1/2 \\ 1 & 1 & 0 & 1 & 1/2 \\ 0 & 1 & 1/3 & 1 & 1/2 \end{pmatrix}$$

According to formulas (5) ~ (6), calculate all the above judgment matrices to obtain the weight of each index.

Taking the judgment matrix of C_1 as an example, the calculation process is as follows:

According to formula (5), the index entropy of set C_1 is R_1 =0. 95, R_2 = 0. 87, R_3 = 0.84, according to formula (6), the entropy weight is γ_1= 0. 4, γ_2 =0. 33, γ_3 =0. 27, That is, similarly, the entropy weight of other indexes can be obtained, as shown in Table 3.

Table 3. Index weight set by entropy weight method

Level Ⅰ index	Weight	level Ⅱ index	Weight	level Ⅲ index	Weight
B_1	0.22	C_1	0.5	D_1	0.4
				D_2	0.33
				D_3	0.27
		C_2	0.5	D_4	0.41
				D_5	0.33
				D_6	0.26
B_2	0.27	C_3	0.39	D_7	1
		C_4	0.22	D_8	1
		C_5	0.39	D_9	0.5
				D_{10}	0.5
B_3	0.22	C_6	0.39	D_{11}	1
		C_7	0.22	D_{12}	1
		C_8	0.39	D_{13}	1
B_4	0.29	C_9	0.67	D_{14}	0.44
				D_{15}	0.23
				D_{16}	0.33
		C_{10}	0.33	D_{17}	0.5
				D_{18}	0.5

4.1.3. Comprehensive Weight

According to the above formula (7), the comprehensive weight is calculated as follows:

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Table 4. Comprehensive weight

Level Ⅰ index	Weight	level Ⅱ index	Weight	level Ⅲ index	Weight
B_1	0.3055	C_1	0.6667	D_1	0.4790
				D_2	0.1976
				D_3	0.3234
		C_2	0.3333	D_4	0.4910
				D_5	0.1976
				D_6	0.3114
B_2	0.1875	C_3	0.3196	D_7	1
		C_4	0.3606	D_8	1
		C_5	0.3196	D_9	0.6667
				D_{10}	0.3333
B_3	0.3055	C_6	0.2422	D_{11}	1
		C_7	0.2732	D_{12}	1
		C_8	0.4845	D_{13}	1
B_4	0.2014	C_9	0.8024	D_{14}	0.5605
				D_{15}	0.2930
				D_{16}	0.1465
		C_{10}	0.1976	D_{17}	0.6667
				D_{18}	0.3333

4.2. Quantification of Evaluation Index

Through the on-site investigation of the company's cold storage and means of transport and communication with employees at different levels of the enterprise, the required data are obtained. Relevant experts analyze and process the obtained data, and give reasonable weight to each index.

4.2.1. Index Score Calculation

(1) Quantitative indexes score

After inviting relevant experts for scoring and discussion, ask them to provide the score range, i.e. the highest value and the lowest value. After adding the actual value of Anhui Fuhuang Sanzhen food group, the following table is finally listed.

(2) Qualitative indexes score

The non-quantitative indexes described in the performance evaluation index system created in this paper have cohesion tightness and information sharing degree, so the corresponding scoring standards must be set. Through field market research, the author consults with the managers of the enterprise, and makes a thorough investigation on the above two kinds of indexes. The final results are shown in the table below.

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Table 5. Scores of quantitative performance indexes

Name of evaluation index	Satisfaction degree	Inadmissibility degree	Real weight	Final score
On time delivery rate	100%	80%	90.25%	80.50
Delivery accuracy	100%	80%	89.25%	78.50
Fresh rate of aquatic products	100%	80%	95%	90.00
Customer complaint rate	0%	10%	5.50%	78.00
Product flexibility	100%	0	100%	92.00
Punctual shipment	8	48	12	78.00
Quantity flexibility	100%	80%	95%	92.00
Transportation cost	1%	0	0.80%	96.00
Information transmission accuracy	70%	50%	60%	80.00
Timeliness of information transmission	70%	30%	50%	80.00
Loss rate of aquatic products	0	5%	1.4%	88.80
Temperature compliance rate	100%	60%	80%	86.00

Table 6. Scores of qualitative performance indicators

	Very good (90—100)	Good (80—90)	Average, (70—80)	Poor (60—70)	Very poor (<60)	Score
Cohesion tightness	3	2	3	2	0	81
Information sharing degree	1	4	3	1	1	78

4.2.2. Comprehensive Performance Evaluation and Analysis

The performance evaluation of aquatic products cold chain logistics is overall and comprehensive, so it must be scored comprehensively to ensure that the data results are comprehensive and objective. The data in this study comes from the scores of relevant experts and managers and field research, to determine the corresponding weight. The calculation results are shown in the table below.

Multiply the comprehensive weight of the level Ⅲ indexes and their corresponding indexes scores and then sum to obtain the performance of each level II index, and then obtain the performance of the level I index.

Table 7. Level II evaluation index scores

Index	Order fulfillment	Customer service	Technology collaboration	Information collaboration	Process collaboration
Achievements	83.08	89.63	85.00	78.00	85.87
Index	Time	Temperature	Quality	Cost	Asset management
Achievements	88.50	76.50	81.00	94.24	85.00

Table 8. Level I evaluation index scores

Index	Customer value	Supply chain value	Aquatic product	Cold chain transportation enterprise
Performance	85.26	82.74	81.58	92.41

In conclusion, the performance of cold chain transportation of aquatic products is,

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$$0.3055\times85.26+0.1875\times82.74+0.3055\times81.58+0.2014\times92.41=85.04.$$

After the performance evaluation of aquatic products cold chain transportation, we get the corresponding evaluation result, that is, the evaluation score of the target company. However, we are not sure whether the score is good or bad. Therefore, we also need to delimit the rating range for the enterprise performance evaluation score, including five levels: very good, good, average, poor and very poor, as shown in the table below:

Table 9. Rating table

Score range	90-100	80-90	70-80	60-70	<60
Rating	Very good	Good	Average	Poor	Very poor

According to the rating table, the performance score of the target enterprise Anhui Fuhuang Sanzhen food group is at a good level, with a score of 85.04, and the overall situation is good.

5. Conclusions and Recommendations

According to the evaluation rating table, the performance score of Anhui Fuhuang Sanzhen Food Group Co., Ltd. is at a good level. From the perspective of level Ⅲ index, the performance of customer satisfaction index is very good, while the performance of order fulfillment index, on-time delivery and distribution rate index, logistics operation efficiency index and unit transportation cost index are good, So that the overall indicators can be improved. At the same time, we can see that the performance scores of information sharing rate index and temperature compliance rate index are not high, which has dragged down the overall performance in some aspects. In terms of level Ⅱ index, the level of customer satisfaction is high, the degree of supply chain coordination is also good, and the performance score of corresponding indicators is also prominent.

Combined with this study, the following suggestions are put forward to improve the performance of cold chain transportation enterprises:

(1) Focus on the data search of all links of the cold chain. Only when the data provided are accurate, the whole aquatic product cold chain logistics performance evaluation can achieve the evaluation purpose, actively apply information technology to monitor the subtle problems existing in the cold chain process and solve them in time.

(2) Continuous improvement. Through the evaluation of the cold chain logistics of aquatic products of Anhui Fuhuang Sanzhen Food Group Co., Ltd., this paper finds the advantages and disadvantages of the enterprise in its own business process. Enterprise managers should pay more attention to the causes behind the evaluation results, present performance improvement suggestions according to the evaluation score, so as to continuously improve the performance of the enterprise.

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