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The Application of Fuzzy Clustering Method in the Warehouse Performance Evaluation

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Abstract

The warehouse of a modern business enterprise has become the logistics center, which also forms the part of the high value-added process, which is seen as a key element in the successful business operations. Under the new economic situation, if companies pay attention to their economic benefits, it is necessary to strengthen the management of the warehouse. After hiring a third-party public warehouse in warehousing strategy, selecting the appropriate storage provider becomes crucial. This paper proposes the use of fuzzy clustering method, based on storage performance evaluation, and establishes a simple model to solve the problem of warehousing provider's choice. That is, first using fuzzy clustering method in optional storage provider for clustering, and then that is the further choice in a small range to simplify the complex issues.

Key words: Warehousing performance evaluation; Fuzzy clustering; Choosing

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INTRODUCTION

As the modern enterprise production and operation mode has changed revolutionarily and the competition of the external market environment intensifies, companies want to establish a competitive advantage based on the reliable and efficient logistics operation. Taking effective logistics operation mode can enhance the competitiveness of enterprises and improve the economic efficiency of enterprises. People also come to realize that to meet customer demand for business processes (including product storage, processing, circulation, distribution, etc.) is crucial for any business, and these aspects are the main content for warehouse management. Due to increasing competitive pressures of modern enterprise and globalization of economic activity, enterprise has to concentrate its limited resources to their core business and reducing costs and improving operational efficiency, and is concentrating to cultivate their own core competencies by outsource the non-core part to third-party logistics companies.

For regional logistics warehouse planning (such as the number, capacity and location, etc.), after the enterprises overall balance warehouse expenses, transportation costs and customer service levels and many other factors, they choose the warehouse logistics decision of hiring third-party logistics later. Then how to choose the right strategic partner among the many logistics providers is core content in the enterprise storage business outsourcing. The selected warehousing and logistics provider needs to achieve a series of objectives, which are lower warehousing storage costs, higher security of the goods, more smooth information and a certain ability to cooperate. After choosing the right logistics providers, enterprises will be able to establish their own competitive advantage and invincible in the market economy.

Based on the many factors that affect the merits of logistics enterprises, the paper establishes a warehousing performance evaluation system, and uses the fuzzy clustering method, first clustering the warehousing and logistics provider in a wide range, and then in a small area. Finally a choice is made according to the actual situation of their own. Till now about the literature, there are many indicators of warehousing performance evaluation design, but the indicator's design is too broad, and is lacking of practicality. The paper has improved this. Combined with the actual case, the paper further elaborates in practice how to choose logistics provider by building business models and using of evaluation methods

1. THE BUILDING OF A MATHEMATICAL MODEL OF FUZZY CLUSTERING ANALYSIS

In science and technology, economics and management, we classify something often according to certain criteria (the degree of similarity or affinity relationships). It uses fuzzy math as its theoretical basis. It is sometimes difficult to use "yes" or "no" as an answer, whether a thing belongs to a class, but can only make a "somewhat" judgment, and fuzzy clustering analysis is used to solve such problems (Xie, & Liu, 2005).

1.1 Creating the Original Data Matrix

Let $U=\{x_1,x_2,\cdots,x_n\}$ be a finite set for our considerations which is to be classified for n objects. Each object has m indicators to say its traits which are $x_i=(x_{i1},x_{i2},\cdots,x_{im}),i=1,2,\cdots,n$. These indicators should be considered in warehousing performance evaluation, and we select the content and the number of indicators according to their own requirements. So, we will get the original matrix $X=(x_{ij})_{n\times m}$.

1.2 Standardizing the Data Matrix

In practical problems, different data generally has different dimensions. In order to make that different dimension quantity can be compared, the data generally requires appropriate transformation. But, even so, data is not in the interval [0,1] necessarily. Therefore, standardization of data mentioned here, is that the data is compressed to the interval [0,1] according to the request of the matrix. We need to do the following transformation usually:

1.2.1 The Transforming of Translational Motion and Standard Deviation

$$x_{ik}{}' = \frac{x_{ik}-\overline{x_k}}{s_k}\left(i=1,2,\cdots,n;k=1,2,\cdots,m\right),$$

$$\overline{x_k}=\frac{1}{n}\sum_{i=1}^{n}x_{ik}\ ,\quad s_k=\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_{ik}-\overline{x_k}\right)^2} \tag{1}$$

After conversion, the mean of each variable is 0 and the standard deviation is 1, eliminating the effect of dimension. However, the results thus obtained are not necessarily in the interval [0,1].

1.2.2 The Transforming of Translational Motion and Range Deviation

$$x_{ik}{}'' = \frac{x_{ik}{}' - \min\limits_{1\le i\le n}\left\{x_{ik}{}'\right\}}{\max\limits_{1\le i\le n}\left\{x_{ik}{}'\right\}-\min\limits_{1\le i\le n}\left\{x_{ik}{}'\right\}}\left(k=1,2,\cdots,m\right) \tag{2}$$

It is obvious that $0\le x_{ik}{}''\le 1$, eliminating the effect of dimension.

1.3 Demarcating (Establishing a Fuzzy Similar Matrix)

We set $U=\{x_1,x_2,\cdots,x_n\}$, $x_i=(x_{i1},x_{i2},\cdots,x_{im})$, $i=1,2,\cdots,n$, and determine similarity coefficients according to the traditional clustering methods, then build fuzzy similar matrix, obtain the degree of similarity of x_i and x_j . A method to determine $r_{ij}=R(x_i,x_j)$ is mainly through traditional cluster analysis such as similarity coefficient method, distance method and so on. Which specific method is selected to choose for calculating r_{ij} according to the nature of the problems:

1.3.1 Angle Cosine Method

$$r_{ij}=\frac{\sum_{k=1}^{m}x_{ik}\cdot x_{jk}}{\sqrt{\sum_{k=1}^{m}x_{ik}{}^2}\cdot\sqrt{\sum_{k=1}^{m}x_{jk}{}^2}} \tag{3}$$

1.3.2 Maximum and Minimum Method

$$r_{ij}=\frac{\sum_{k=1}^{m}\left(x_{ik}\wedge x_{jk}\right)}{\sum_{k=1}^{m}\left(x_{ik}\vee x_{jk}\right)} \tag{4}$$

1.3.3 Absolute Value Reduction Method

$$r_{ij}=\begin{cases}1 & \text{when } i=j,\ i=1,2,\cdots,5\\ 1-c\sum_{k=1}^{5}\left|x_{ik}-x_{jk}\right| & \text{when } i\ne j,\ i=1,2,\cdots,5\end{cases} \tag{5}$$

C values between 0 and 1.

1.4 Clustering (Seeking Dynamic Clustering Diagram)

We obtain the fuzzy matrix, which is only a vague similarity matrix *R*, and not necessarily transitive, and not necessarily the fuzzy equivalent matrix according to the calibration. In order to be classified, we also need to transform R into R^* which is fuzzy equivalent matrix. Finding the transitive closure of matrix R , we can use the secondary method, and so $t(R)$ is the fuzzy equivalent matrix R^* which is asked for. It is namely $t(R)=R^*$. Ranging λ from big to small, we can form a dynamic cluster diagram.

2. THE APPLICATION OF FUZZY CLUSTERING METHOD IN WAREHOUSE PERFORMANCE EVALUATION

2.1 The Design Principles of Evaluation System

In the process of warehousing performance evaluation, evaluation index is not the more the better, but not the less the better. It will be repetitive when it is too many; it is lacking of adequate representation when it is too small. Therefore, when establishing evaluation system, we should follow some principles (Ge & Su, 2010).

First, the scientific principle. Scientific Principles are mainly in terms of the combination of theory and practice, as well as scientific methods used; Second, the operable principle. Indicator system needs some flexibility to reflect the inherent characteristics of logistics enterprises and the actual situation; Third, comparability principle. Evaluation index system should reflect all the individuality and common of warehousing and logistics companies ,and quantifiable indicators are used as soon as possible, while qualitative indicators will be given by using available expert or Delphi methods; Fourth, practical principle. It refers practicality, feasibility and operability; Fifth, scalability principle. Indicator system reflects not only the current ability of the service providers, but also needs to adapt to future developments. We can use selectively some of these indexes content under different circumstances of service providers .

2.2 The Establishment of Logistics Enterprise Performance Evaluation System

Storage performance evaluation system is a comprehensive reflection of the fruits of production and warehouse operation status, and is intuitive judgments whether good or bad. Indicators Species will be different according to warehouse location in the supply chain or nature of business. Based on the relevant literature results and the principles of indicators, the paper established a relatively perfect system of the warehouse performance evaluation (Jiang, Bai & Wu, 2010). It is shown in Table 1:

Table 1
Storage Performance Evaluation System

Destination layer	The first level indicators	The second level indicators
Storage Performance Evaluation Index System	The goods stored quantitative index	Cargo throughput plan period
		Used warehouse area
		Used area of yard
		Storage capacity per unit area
		Number of staff and workers
		Equipment quantity indicators
	The goods stored quality index	Consistent account cargo rate
		The consignee or consignor error rate
		The attrition rate of goods
		The average storage loss
		Average delivery time
		Acceptance rate of the goods in time
		Rate of equipment in good co-ndition equipment availability
	The goods stored efficiency index	Utilization rate of warehouse
		Rate of equipment utilization
		Labor productivity
		Capital usage efficiency
		The goods turnover speed indicator
	The goods stored economic index	The average storage costs
		Total profit
		Profit rate on funds
		Profit margin
		Per capita profit
		Profit of Keeping the goods per ton
	The goods stored safety index	All the size and number of the accident

3. CLUSTERING CASE

Based on the data from some commercial journals, library inventory information, seminars and professional advisory body, the paper selected five logistics companies x_1, x_2, x_3, x_4, x_5, whose evaluation performance are the different .Combined the principles of performance evaluation system and the weight derived from the experts, the original data of indicators can be obtained as follows. It is shown in Table 2:

Table 2
Indicators Data of Warehousing Logistics Enterprise Performance Evaluation

The second level indicators	Numerical order	The second level indicators	Weight	x_1	x_2	x_3	x_4	x_5
The goods stored quantitative index	1	Cargo throughput plan period%	0.1943	85	73	68	70	59
	2	Used warehouse area%	0.1351	92	95	86	80	79
	3	Used area of yard%	0.1712	76	72	85	60	72
	4	Storage capacity per unit area(m^3)	0.2052	169	183	89	85	98
	5	Number of staff and workers%	0.1892	79	84	65	75	67
	6	Equipment quantity indicators(unite)	0.1050	110	156	89	75	120
The goods stored quality index	7	Consistent account cargo rate%	0.1182	97	89	85	70	85
	8	The consignee or consignor error rate%	0.1863	95	90	79	86	70
	9	The attrition rate of goods%	0.1681	12	7	18	20	11
	10	The average storage loss(ten thousand)	0.1500	1	0.5	1.2	2	1.8
	11	Average delivery time(day)	0.1913	2	3	2.5	4	5
	12	Acceptance rate of the goods in time%	0.1667	87	79	80	81	78
	13	Rate of equipment in good condition equipment availability%	0.0194	78	87	75	78	80
The goods Stored efficiency index	14	Utilization rate of warehouse %	0.2308	86	84	75	70	90
	15	Rate of equipment utilization%	0.1765	87	92	85	80	88
	16	Labor productivity%	0.1709	87	82	76	90	78
	17	Capital usage efficiency%	0.1985	92	90	87	78	80
	18	The goods turnover speed indicator(day)	0.2233	3	5	2	6	5
The goods stored economic index	19	The average storage costs%	0.1364	69	73	60	59	40
	20	Total profit%	0.2727	40	38	25	30	20
	21	Profit rate on funds%	0.1485	18	28	25	19	30
	22	Profit margin%	0.1724	22	28	30	29	19
	23	Per capita profit(ten thousand)	0.1981	1	0.8	2.1	1	0.8
	24	Profit of keeping the goods per ton%	0.0719	38	45	67	50	49
The goods stored safety index	25	All the size and number of the accident%	1	8	10	9	10	5

According to the obtained original data, we select the providers among the above five logistics using fuzzy clustering evaluation method. Steps are as follows:

3.1 Measuring the First Level Indicators Magnitude of Warehousing Performance

We selected storage and logistics companies x_1 as representative and determine its weight and the indicators of satisfaction using expert scoring method. Collated data is shown in Table 3:

Table 3
The Univariate Evaluation Form of Enterprise Logistics Provider

The first level indicators	The second level indicators	Weight A_i	Judge set R_i				x_{1i}
			Quite satisfied	Satisfa-ction	Basic satisfa-ction	Dis -satisf-action	$A_i o R_i$
The goods stored quantitative index	Cargo throughput plan period	0.1943	0.27	0.15	0.16	0.42	{0.2052, 0.1800, 0.2052, 0.2052}
	Used warehouse area	0.1351	0.23	0.19	0.34	0.24	
	Used area of yard	0.1712	0.35	0.12	0.28	0.25	
	Storage capacity per unit area	0.2052	0.22	0.18	0.29	0.31	
	Number of staff and workers	0.1892	0.18	0.13	0.27	0.42	
	Equipment quantity indicators	0.1050	0.36	0.26	0.24	0.14	
The goods stored quality index	Consistent account cargo rate	0.1182	0.05	0.12	0.28	0.55	{0.1863, 0.1913, 0.1913, 0.1667}
	The consignee or consignor error rate	0.1863	0.35	0.52	0.11	0.02	
	The attrition rate of goods	0.1681	0.11	0.33	0.45	0.11	
	The average storage loss	0.1500	0.63	0.33	0.04	0	
	Average delivery time	0.1913	0.04	0.41	0.50	0.05	
	Acceptance rate of the goods in time	0.1667	0.01	0.12	0.55	0.32	
	Rate of equipment in good condition equipment availability	0.0194	0.05	0.35	0.52	0.08	

To be continued

Continued

The first level indicators	The second level indicators	Weight A_i	Judge set R_i				x_{1i}
			Quite satisfied	Satisfa-ction	Basic satisfa-ction	Dis -satisf-action	$A_i o R_i$
The goods stored efficiency index	Utilization rate of warehouse	0.2308	0.22	0.18	0.22	0.38	{0.2233, 0.1985, 0.2233, 0.2308}
	Rate of equipment utilization	0.1765	0.06	0.45	0.26	0.23	
	Labour productivity	0.1709	0.35	0.06	0.14	0.45	
	Capital usage efficiency	0.1985	0.33	0.28	0.17	0.22	
	The goods turnover speed indicator	0.2233	0.23	0.18	0.31	0.28	
The goods stored economic index	The average storage costs	0.1364	0.14	0.18	0.21	0.47	{0.2727, 0.2600, 0.1900, 0.2300}
	Total profit	0.2727	0.35	0.26	0.16	0.23	
	Profit rate on funds	0.1485	0.22	0.20	0.30	0.28	
	Profit margin	0.1724	0.22	0.20	0.25	0.33	
	Per capita profit	0.1981	0.19	0.43	0.19	0.19	
	Profit of Keeping the goods per ton	0.0719	0.25	0.51	0.10	0.14	
The goods stored safety index	All the size and number of the accident	1	0.22	0.15	0.26	0.37	{0.2200, 0.1500, 0.2600, 0.3700}

If it is assumed that $A_i=(a_{ij})_{1\times m}, R_i=(b_{ij})_{m\times 4}$, its synthesis operator is

$A_i \circ R_i=(c_{ij})_{1\times 4}$, when c_{ij} is defined $\overset{m}{\underset{k=1}{\vee}}(a_{ik}\wedge b_{kj})$. So we can draw that:

$$A_1 \circ R_1=(c_{1\times 4})=(0.2052, 0.1800, 0.2052, 0.2052),$$
$$A_2 \circ R_2=(c_{1\times 4})=(0.1863, 0.1913, 0.1913, 0.1667),$$
$$A_3 \circ R_3=(c_{1\times 4})=(0.2233, 0.1985, 0.2233, 0.2308),$$
$$A_4 \circ R_4=(c_{1\times 4})=(0.2727, 0.2600, 0.1900, 0.2300),$$
$$A_5 \circ R_5=(c_{1\times 4})=(0.2200, 0.1500, 0.2600, 0.3700),$$

In order to compare these five companies, the level of satisfaction of judge set is expressed as the number of $V=(5,4,3,1)^T$, so each evaluation index of provider x_1 can be quantified, which is

$$x_{11}=(0.2052, 0.1800, 0.2052, 0.2052)\begin{bmatrix}5\\4\\3\\1\end{bmatrix}=2.5668$$

So the magnitude index of provider x_1 is an matrix:

$$x_1=(x_{11},x_{12},x_{13},x_{14})=(2.5668, 2.4373, 2.8112, 3.2035, 2.8500)$$

Similarly the magnitude level indicators of the other four storages are:

$$x_2=(x_{21},x_{22},x_{23},x_{24})=(3.8971, 2.3864, 3.3461, 3.1334, 2.8934)$$
$$x_3=(x_{31},x_{32},x_{33},x_{34},)=(1.2489, 1.6929, 1.9834, 2.3429, 2.0067)$$
$$x_4=(x_{41},x_{42},x_{43},x_{44})=(2.1278, 2.0543, 1.9867, 2.3613, 2.5589)$$
$$x_5=(x_{51},x_{52},x_{53},x_{54})=(4.0067, 3.8972, 3.5547, 2.7786, 3.6400)$$

3.2 Standardizing the Original Data

Using a translation and standardized formula, the original data is standardized:

$$x_{ik}'=\begin{bmatrix}-0.19 & -0.07 & 0.11 & 1.20 & 0.11\\ 1.07 & -0.14 & 0.92 & 1.01 & 0.20\\ -1.44 & -1.07 & -1.14 & -1.15 & -1.48\\ -0.61 & -0.59 & -1.14 & -1.10 & -0.44\\ 1.17 & 1.87 & 1.24 & 0.04 & 1.60\end{bmatrix}$$

Using extreme standardized formula, standardized data can be compressed within closed interval [0, 1]:

$$x''_{ik}=\begin{bmatrix}0.48 & 0.34 & 0.53 & 1 & 0.52\\ 0.96 & 0.32 & 0.87 & 0.92 & 0.55\\ 0 & 0 & 0 & 0 & 0\\ 0.32 & 0.16 & 0 & 0.02 & 0.34\\ 1 & 1 & 1 & 0.51 & 1\end{bmatrix}$$

3.3 Building the Fuzzy Similar Matrix

Using the absolute value subtraction method, a similarity matrix U is drawn, taking c = 0.1

$$r_{ij}=\begin{cases}1 & \text{when } i=j,\ i=1,2,\cdots,5\\ 1-c\sum_{k=1}^{5}\left|x''_{ik}-x''_{jk}\right| & \text{when } i\neq j,\ i=1,2,\cdots,5\end{cases}$$

Get on the similarity matrix U:

$$R=\begin{bmatrix}1 & 0.905 & 0.713 & 0.797 & 0.738\\ 0.905 & 1 & 0.638 & 0.722 & 0.829\\ 0.713 & 0.638 & 1 & 0.916 & 0.549\\ 0.797 & 0.722 & 0.916 & 1 & 0.633\\ 0.738 & 0.829 & 0.549 & 0.633 & 1\end{bmatrix}$$

3.4 Clustering Analysis

Find the equivalent closure of similar matrix using flat method:

$$R^2=R\times R=\begin{bmatrix}1 & 0.905 & 0.797 & 0.797 & 0.829\\ 0.905 & 1 & 0.722 & 0.797 & 0.829\\ 0.797 & 0.722 & 1 & 0.916 & 0.713\\ 0.797 & 0.797 & 0.916 & 1 & 0.738\\ 0.829 & 0.829 & 0.713 & 0.738 & 1\end{bmatrix}$$

$$R^4=R^2\times R^2=\begin{bmatrix} 1 & 0.905 & 0.797 & 0.797 & 0.829 \\ 0.905 & 1 & 0.722 & 0.797 & 0.829 \\ 0.797 & 0.722 & 1 & 0.916 & 0.713 \\ 0.797 & 0.797 & 0.916 & 1 & 0.738 \\ 0.829 & 0.829 & 0.713 & 0.738 & 1 \end{bmatrix}=R^2$$

So R^2 is the desired transitive closure matrix, which is fuzzy equivalent matrix. λ will be descending by clustering:

When λ=1, U is divided into five categories: $\{x_1\}$, $\{x_2\}$, $\{x_3\}$, $\{x_4\}$, $\{x_5\}$;

When λ=0.916, U is divided into four categories: $\{x_1\}$, $\{x_2\}$, $\{x_3, x_4\}$, $\{x_5\}$;

When λ=0.905, U is divided into three categories: $\{x_1, x_2\}$, $\{x_3, x_4\}$, $\{x_5\}$;

When λ=0.829, U is divided into two categories: $\{x_1, x_2, x_5\}$, $\{x_3, x_4\}$;

When λ=0.722, U is divided into one categories: $\{x_1, x_2, x_3, x_4, x_5\}$.

Dynamic clustering diagram is shown in Figure 1:

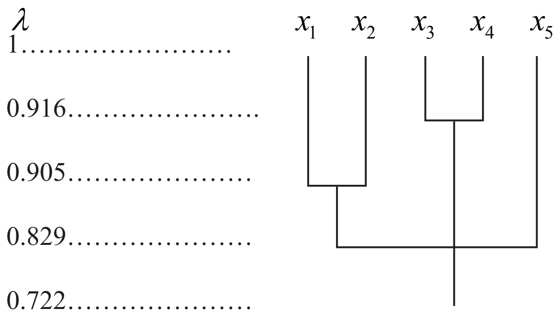

Figure 1
Dynamic Clustering Figure

λ values from 1to 0 gradually, getting different levels of cut sets. When λ=1, they are divided into five categories, indicating that the five storage companies are not comparable; When λ=0.916, they are divided into four categories, and $\{x_3, x_4\}$ is classified as a class, indicating that the two storage business performance is at the same level; When λ=0.905,they are divided into three categories, and $\{x_1, x_2\}$ and $\{x_3, x_4\}$ are classified as a class separately, indicating that five warehousing enterprise performance is further classified in three different performance levels; When λ=0.829, they are divided into two groups, indicating that the five storage enterprises are in two significantly different levels in wide-range.

Through analysis, we can clearly see five different levels of warehousing and logistics business performance, which is the basis for enterprises to select logistics providers. In practical applications, enterprises select a different classification in different cut set levels according to their actual circumstances. The actual survey found that the overall strength of x_1 and x_2 is stronger, and they have the higher management level, while the rate is relatively high; the overall strength of x_3 and x_4 is weak, and they have the lower management level, while the rate is low. It is consistent with the results of this clustering here, illustrating that this sentence "select storage provider by clustering, and do the further choice in a small range" is scientific.

CONCLUSIONS

After analyzing achievement of experts and scholars about storage performance evaluation system, this paper attempts to create a more comprehensive, more scientific, more systematic index system. We have the purpose to promote enterprise storage management using cluster analysis methods, and then take the scientific steps that "first choose warehousing provider in big aspect classification, and then select in a small range, to estimate the performance of logistics enterprises objectively. This will help enterprises to choose their own warehousing and logistics providers. In practice, taking into account the actual situation of different warehousing companies, we can modify the indicators properly. Overall, a good evaluation system needs at any time to improve and perfect according to different situations, to adapt to the requirements and conditions of the environment change.

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