A Theoretical Model Design for Third Party Logistics Selection in Warehouse Receipt System Using Unascertained Mathematics

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Abstract: The third party logistics selection is one of the most important steps in a warehouse receipt implementation program and is critical to the system success. Due to inherent complexity of warehouse receipt system, selecting an appropriate third party logistics is a risky, difficult and time-consuming task for the system. In this research, a comprehensive hybrid multi-criteria decision making model is developed in two stages using unascertained mathematics to evaluate and rank the alternatives. The model combines the weight determined by experts and entropy weight to solve the index weight, which gives a comprehensive consideration of subjective and objective factors and the method can improve the accuracy of weight value and the reliability of evaluation results. The proposed model is practical and quite simple in real world problems of selecting the most appropriate third party logistics for the warehouse receipt systems.

Key words: Warehouse receipt system, unascertained measure, information entropy, analysis hierarchy process, multi-criteria decision-making

INTRODUCTION

The existing research suggests that warehouse receipt systems ease access to finance at all levels in the marketing chain, moderate seasonal price variability and promote instruments to mitigate prices (Coulter and Onumah, 2002). In the warehouse receipt systems, the warehouse operator as the agent of the depositors to hold the stored commodity by way of safe custody and provide the storage voucher to depositors, then the depositors can transfer the receipts to bank, where the stored commodity is pledged as security for a loan, the banks determine the lines of credit based on the receipts. Hence, there exists the principal-agent relationship between warehouse operators and depositors or between warehouse operators and banks. The warehouse receipts strength rely on the third party logistics enterprises, implying the supporting management and service of the third party logistics and being formed the three-party close corporation relationship among bank and the third party logistics enterprise and depositor (Li and Kung, 2012). Therefore, the three-party agency relationship exists in warehouse receipt systems and in this system, the third party logistics enterprises play a very important role. Therefore the bank, during the construction process of the warehouse receipt system, should select the third party logistics as a partner carefully so as to ensure the stable operation of the whole system and lowered credit risk of the banks. Based on this point, this study is devoted to study the selection problem of logistics enterprise in setting up the warehouse receipt systems.

When selecting the third party logistics as a partner, this study employ both qualitative and quantitative indexes and take into account of the actual situation of warehouse receipt systems in china. Many researchers have studied the methods of selecting the third party logistics as a partner, including mathematical programming method, data envelopment analysis, analytic network process, ABC method, Analysis Hierarchy Process (AHP), Fuzzy Comprehensive Evaluation (FCE), neural network algorithm, genetic algorithm, gray situation decision method and so on. These research methods have provided very good analysis tools for logistics partner selection, but the methods have their own limitation. According to the characteristics of the selection indexes of logistics partner in the warehouse receipt systems, This study proposes here to use the unascertained measure method basing on information entropy and AHP method to set up comprehensive evaluation model.

MATERIALS AND METHODS

Setting $x_1, x_2, ..., x_n$ is n evaluation objects and evaluation object space is $X = \{x_1, x_2, ..., x_n\}$. If $x_i \in X$ and $l_1, l_2, ..., l_n$ are m assessment indexes, then index space is $I = \{l_1, l_2, ..., l_n\}$. $x_i$ is observed value of object $x_i$, $C = \{c_1, c_2, ..., c_l\}$ is evaluation space and $c_k (1 \leq k \leq K)$, is the kth remark rating.
Uncertained measure of single index: When observed value of object \(x_i\) about index \(I_j\) is different, the remark rating of index \(x_i\) is different too. Setting the extent of \(x_i\) belonging to remark rating \(c_j\) is \(\mu_{ij} = \mu(x_i \in c_j)\), then \(\mu_{ik}\) is test results of extent. And \(\mu\) is need to meet three conditions as follow (Lu et al., 2008; Shi et al., 2008; Liu and Pang, 2000):

\[
0 \leq \mu(x_i \in c_j) \leq 1, \quad i = 1, 2, \ldots, n; \quad j = 1, 2, \ldots, m; \quad k = 1, 2, \ldots, K
\]

\[
\mu(x_i \in \bigcup_{j=1}^{m} c_j) = \sum_{k=1}^{K} \mu(x_i \in c_k), \quad k = 1, 2, \ldots, K
\]

The above principals are nonnegative and normalization and additivity, if \(\mu\) satisfies all principals, \(\mu\) is unascertained measure (Xiao et al., 2009):

\[
\left(\mu_{ij}\right)_{n \times K} = \begin{bmatrix}
\mu_{i1} & \mu_{i2} & \cdots & \mu_{ik} \\
\mu_{i2} & \mu_{i2} & \cdots & \mu_{ik} \\
\vdots & \vdots & \ddots & \vdots \\
\mu_{in} & \mu_{in} & \cdots & \mu_{ik}
\end{bmatrix}, \quad i = 1, 2, \ldots, n
\]

And matrix \((\mu_{ij})_{n \times K}\) is evaluation matrix about single index of object \(x_i\), \(\mu_{ij}\) is unascertained measure about objective value \(x_i\) belonging to remark rating.

Determining index weight: Traditional evaluation method of unascertained measure employs the information entropy method to determine the weight of index. But due to the obvious shortcomings in the nature and definition of entropy, the knowledge and experience of experts and the opinion of decision makers, very important factors in index weighting, are impossible to be captured by the information entropy method. Hence, the traditional evaluation method of unascertained measure generates more objective weight value and there often exists obvious deviation may between the weight generated by entropy and the actual degree of importance. It may even lead to completely incorrect weighting. However, the analytical hierarchy process can remedy this shortage (Xiao et al., 2007; Cuo et al., 2006). Therefore, this study applies the analytical hierarchy process to modify the weight value by information entropy. Next, the concrete steps of the modified entropy method will be illustrated.

Categorization weight determined by information entropy method: Entropy is a kind of measure about uncertainty of system status, information entropy is mainly to solve the measure of the amount of information, that is the amount of information about the demand on grasping uncertainty which can be expressed by the extent on being solved of uncertainty. And entropy weight can be expressed by the coefficient of degree of relative fierce and the larger the variation degree is, then the smaller the value of information entropy, which shows the index provides larger information and the weight value is larger (Tseng and Lin, 2012; Li et al., 2004).

Steps of information entropy method is introduced as follow:

Let \(\mu_{ij}\) is unascertained measure of object \(x_i\), which objective value \(x_i\) about index \(I_j\) is belonging to \(c_1, c_2, \ldots, c_k\) then:

\[
\mu_{ij} = \left(\mu_{i1}, \mu_{i2}, \ldots, \mu_{ik}\right)
\]

Index weight \(w_i\) is used to describe classification contribution about index \(I_j\) to object \(x_i\) and \(w_i\) depends on the extent of focus and scatter of every components of \(\mu_{ij}\), the extent of focus and scatter of every components of \(\mu_{ik}\) has many methods, this paper uses entropy. Entropy \(H(j)\) is decided by measure \(\mu_{ik}\) and:

\[
h(j) = -\sum_{k=1}^{K} \mu_{ik} \cdot \log \mu_{ik}
\]

\[
s_i = 1 - \log K \cdot h(j) - 1 + \frac{1}{\log K} \sum_{k=1}^{K} \mu_{ik} \cdot \log \mu_{ik}
\]

Setting:

\[
v_i = \frac{s_i}{\sum_{j=1}^{n} s_j} \quad \text{(obvious 0} \leq v_i \leq 1 \text{ and } \sum_{j=1}^{n} v_i = 1)
\]

According to nature of entropy: (1) If and only if

\[
\mu_{i1} = \mu_{i2} = \cdots = \mu_{ik} = \frac{1}{K}
\]

\(g_i\) is equal to zero which is the minimum; (2) if and only if \(\mu_{i1} = 1\) and other \(K-1\) is zero all, \(g_i\) is equal to one which is the maximum; (3) if \(\mu_{ik}\) is focus more, \(g_i\) is near one more, on the contrary \(\mu_{ik}\) is scatter more, then \(g_i\) is near zero more.

According to above natures of \(g_i\), \(v_i\) is classification weight of index \(I_j\) about \(x_i\), then

\[
v = (v_1, v_2, \ldots, v_n)
\]

Index weight determined by analytic hierarchy process: The steps of analysis hierarchy process to determine index weight can be approximately dived into two stages. Firstly, Expert opinion method is utilized to solve the important ranking of every index and the weight value of index in the every hierarchy can be calculated. Secondly,
it is necessary to check consistency test and consistency test of judgment matrices meets requirements if consistency ratio is less than 0.1, it is need to notices that all judgment matrices are required to meet consistency test. The detailed description of AHP can has been found in many literatures (Zhang and Fu, 2012, Yu, 2012, Liu et al., 2012), so the concrete steps of AHP is not being illustrated in detail. The classification weight of index $I_i$ about $x_i$ is denoted by $\mu'_i$, then $\mu'_i = (\mu'^1_i, \mu'^2_i, ..., \mu'^K_i)$ is the classification weight vector of indexes $I_1, I_2, ..., I_n$ about $x_i$.

**Comprehensive weight determined by modified entropy method:** According to the calculation results of index weight by entropy and AHP, the index weight of modified entropy can be determined and denoted as $w_i$. Then:

$$w_i = \frac{w_i \mu_i}{\sum_{j=1}^{n} w_j \mu_j} \quad (6)$$

**Comprehensive evaluation system:** If $w'_i = 0, \mu_0$ is rewrote to $w_i, \mu_0 = w'_i, \mu_0 + (1-w'_i), \mu_0$, and $w'_i, \mu_0 = 0$, if $w'_i > 0$, notice following:

$$0 \leq \sum_{k=1}^{K} w'_i \mu_{ik} \leq 1$$

$$\sum_{i=1}^{n} \left( \sum_{k=1}^{K} w'_i \mu_{ik} \right) = \sum_{i=1}^{n} \left( w'_i \sum_{k=1}^{K} \mu_{ik} \right) = \sum_{i=1}^{n} w'_i = 1 \quad (7)$$

Then:

$$\sum_{i=1}^{n} w'_i \mu_{ik}$$

is unascertainment measure for $x_i$ belonging to $k$th remark rating.

Setting:

$$\mu' = (\mu_1, \mu_2, ..., \mu_{ik}) = (w'_1, w'_2, ..., w'_n, \mu_{ik})$$

$$\mu' = (\mu_1, \mu_2, ..., \mu_{ik})$$

Then, $\mu'$ is evaluation vector of $x_i$.

**Evaluation criteria:** Remark rating is ordered, the $k$th remark rating $c_{ik}$ is better than $k+1$th remark rating $c_{i(k+1)}$. So, recognition criteria about greatest measure is inappropriate, recognition criteria about confidence level is introduced.

If $\{c_1, c_2, ..., c_k\}$ satisfies that $c_i > c_{i+1}$ for $i = 1, 2, ..., k-1$, setting $\lambda (0.5 < \lambda < 1)$ is confidence level, usually $\lambda$ is 0.6 or 0.7 and:

$$k_i = \min \left[ \frac{1}{\sum_{k=1}^{K} \mu_{ik}} \right] \quad k = 1, 2, ..., K \quad (9)$$

Then, $x_i$ belongs to $k_i$th remark rating $c_{i(k)}$.

**Case study:** To demonstrate the performance of the proposed method for selecting the third party logistics in warehouse receipt system, a case study is given in this section.

**Indexes system:** According to the actual situation of warehouse receipts business in china and reference to the existing research results, this paper builds up the indexes system of logistics partner selection in warehouse receipt systems from different aspects, which follow the principles of the establishment of indexes system (Table 1).

Firstly, the experts score for every evaluation factor by evaluation rank, the evaluation ranks have been divided into 6 and can been marked as $C = \{c_1, c_2, ..., c_6\} = \{5A, 4A, 3A, 2A, A, none\}$.

Grade standard of some appraisal indexes in logistics enterprises is showed as Table 2.

**Algorithm:** In this section, the study implied the algorithm introduced by section 2 and the indexes system established by section 3 to select the logistics partners for commercial bank. According to statistical data and evaluation grade from experts, the measure matrix of single index is calculated by unascertainment measure function and is showed as following:

$$\mu_{ik} = \begin{bmatrix} 0 & 0 & 0.2 & 0.8 & 0 & 0 \\ 0 & 0.35 & 0.65 & 0 & 0 & 0 \\ 0.375 & 0.625 & 0 & 0 & 0 & 0 \\ 0 & 0.5 & 0.2 & 0.3 & 0 & 0 \\ 0.1 & 0.3 & 0.3 & 0.2 & 0.1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\mu'_{ik} = \begin{bmatrix} 0.1 & 0.1 & 0.6 & 0.1 & 0.1 & 0 \\ 0.2 & 0.1 & 0.4 & 0.3 & 0 & 0 \\ 0 & 0.786 & 0.114 & 0 & 0 & 0 \\ 0.081 & 0.919 & 0 & 0 & 0 & 0 \\ 0 & 0.6 & 0.3 & 0.1 & 0 & 0 \\ 0.157 & 0.843 & 0 & 0 & 0 & 0 \\ 0.215 & 0.785 & 0 & 0 & 0 & 0 \\ 0.3 & 0.2 & 0.2 & 0.3 & 0 & 0 \end{bmatrix}$$
Table 1. The indexes system of logistics partner selection in warehouse receipt systems

<table>
<thead>
<tr>
<th>Target layer</th>
<th>Rule layer</th>
<th>Index layer</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensive quality of logistics partner in warehouse receipt systems</td>
<td>Resource status of logistics enterprise</td>
<td>The logistics enterprise’s private warehousing and storage area</td>
<td>Units: Square meter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distribution sites</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>The total assets of the logistics enterprise</td>
<td>Units: Yuan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Staff quality</td>
<td>Staff proportion who have educated in junior college or higher school level or have achieved the logistics professional qualification authentication</td>
</tr>
<tr>
<td>Logistics enterprise competence</td>
<td>Credit records</td>
<td>Expert evaluation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Standardization degree of business operation</td>
<td>Whether the business operation has implement the standardization</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Commodity intact rate</td>
<td>Commodity intact rate is equal to the number of commodity which has none any value lost is divided by the total number of commodity in stock in report period</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inventory turnover</td>
<td>Inventory turnover is equal to cargo throughput is divided by average stock in report period</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Logistics market share</td>
<td>Logistics market share is equal to the logistics enterprise's operating income is divided by the operating income of the same industry in report period</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Automation</td>
<td>Expert evaluation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Integration ability of external resource</td>
<td>Expert evaluation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The ability of providing and implementing logistics service schemes</td>
<td>Expert evaluation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Business scope</td>
<td>International, national, trans-province, or inter-province</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Customer satisfaction</td>
<td>The investigation and statistics on customer satisfaction situation every year</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Informatization degree</td>
<td>The proportion of business information realizing informatization management</td>
<td></td>
</tr>
<tr>
<td>The management state of logistics enterprise</td>
<td>The operating income of warehousing and storage every year</td>
<td>The income from enterprise finishing warehousing and storage or distribution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Logistics enterprise business hours</td>
<td>Units: Year</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total assets turnover ratio</td>
<td>Total assets turnover ratio is equal to total liabilities are divided by total assets</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Asset-liability ratio</td>
<td>Asset-liability ratio is equal to total liabilities are divided by total assets</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Service increasing ratio</td>
<td>Service increasing ratio is equal to income increase in current year is divided by total income in previous year</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Impact index of the logistics enterprise</td>
<td>Expert evaluation</td>
<td></td>
</tr>
<tr>
<td>Corporate state</td>
<td>Internationalization degree</td>
<td>Expert evaluation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooperative time</td>
<td>Unit: Year</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corporation the perfection</td>
<td>Expert evaluation</td>
<td></td>
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<tr>
<td></td>
<td>Information communication</td>
<td>Expert evaluation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Information system compatibility</td>
<td>Expert evaluation</td>
<td></td>
</tr>
</tbody>
</table>

\[
\mu_{ij} = \begin{bmatrix}
0.375 & 0.625 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 \\
0.106 & 0.894 & 0 & 0 & 0 & 0 \\
0 & 0.091 & 0.909 & 0 & 0 & 0 \\
0 & 0.217 & 0.783 & 0 & 0 & 0 \\
0.3 & 0.2 & 0.4 & 0.1 & 0 & 0 \\
0.2 & 0.2 & 0.5 & 0.1 & 0 & 0 \\
\end{bmatrix}
\]
Table 2: Grade standard of some appraisal indexes

<table>
<thead>
<tr>
<th>Evaluation indexes</th>
<th>Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logistics enterprise’s private warehousing and storage area</td>
<td>5A (c1)</td>
</tr>
<tr>
<td>(Units: Square meter)</td>
<td></td>
</tr>
<tr>
<td>Distribution sites (Units: Number)</td>
<td>More than 400</td>
</tr>
<tr>
<td>The total assets of the logistics enterprise (Units: Yuan)</td>
<td>More than 1 billion</td>
</tr>
<tr>
<td>Customer satisfaction</td>
<td>More than or equal 98%</td>
</tr>
<tr>
<td>The operating income of warehousing and storage every year (Units: Yuan)</td>
<td>More than 600 million</td>
</tr>
<tr>
<td>Logistics enterprise business hours (Units: Year)</td>
<td>More than 3 years</td>
</tr>
<tr>
<td>Asset-liability ratio</td>
<td>No more than 70%</td>
</tr>
</tbody>
</table>

\[ \mu_{Lc} = \begin{bmatrix} 0 & 0 & 0.416 & 0.384 & 0 & 0 \\ 0.4 & 0.4 & 0.2 & 0 & 0 \\ 0.5 & 0.3 & 0.2 & 0 & 0 \\ 0.1 & 0.3 & 0.3 & 0.2 & 0 \end{bmatrix} \]

According to 4-6, the weight vector of index classification can be calculated by the modified entropy, corresponding results of every steps are:

\[ v = (0.0514, 0.0456, 0.0450, 0.0303, 0.0114, 0.0225, 0.0204, 0.0359, 0.0601, 0.0356, 0.0394, 0.0204, 0.0540, 0.0506, 0.0169, 0.0450, 0.0713, 0.0576, 0.0592, 0.0505, 0.0204, 0.0227, 0.0443, 0.0293, 0.0303, 0.0114) \]

\[ u = (0.061, 0.023, 0.038, 0.041, 0.069, 0.017, 0.014, 0.036, 0.05, 0.02, 0.019, 0.032, 0.057, 0.079, 0.025, 0.047, 0.054, 0.043, 0.072, 0.03, 0.026, 0.015, 0.033, 0.035, 0.046, 0.018) \]

\[ w_j = (0.0741, 0.0247, 0.0404, 0.0294, 0.0186, 0.009, 0.0067, 0.0459, 0.071, 0.0168, 0.0177, 0.0154, 0.0727, 0.0494, 0.0100, 0.0499, 0.0910, 0.0888, 0.1066, 0.3578, 0.1251, 0.0081, 0.0345, 0.0242, 0.033, 0.0049) \]

Then, evaluation vector of the logistics computed by 8 is:

\[ \mu = w_j \times \mu_{Lc} = (0.1997, 0.3876, 0.2013, 0.2020, 0.0048, 0) \]

Setting \( \lambda = 0.7 \) and according to (9), if \( k_0 = 3, 0.1997 + 0.3876 + 0.2013 + 0.7886 = 0.7. \) So, the comprehensive evaluation result of the logistics enterprise is good and the confidence level is no less than 70%, which illustrates that the commercial bank can choose this logistics enterprise as their partner.

According to the above-mentioned result and combining the actual situation in this logistics enterprise, this study finds that the private warehousing and storage area of this logistics enterprise is not formed into the large scale, which cause to lower the company’s comprehensive evaluation result, so the logistics enterprise should expand the private warehousing and storage area in the future development to enhance the core competence. Overall, this logistics enterprise has stronger advantage, that is the company has the large percentage total assets, rapid inventory turnover, larger logistics market share, higher customer satisfaction, good operating income of warehousing and storage every year and rapid total assets turnover ratio.

**CONCLUSION**

The unascertained measure model is based on order of evaluation space and uncertainty of information, gives reasonable confidence criteria and ranking scores criteria, which makes the result is more reasonable and identifiable. And the model can process the quantitative indicators and qualitative indicators existing in one model simultaneously. In addition, unascertained measure model can give order of quality and also give grade estimation. Therefore, the unascertained model provides a good method to evaluation field. But traditional unascertained model utilized the entropy to solve the weight, which has some shortcoming. It is well known that the weight value has great influence on evaluation result in assessment model, so it is important to determine the weight scientifically. For shortcoming of the weight value by entropy in traditional model being more objective, this study established unascertained comprehensive evaluation model basing on modified entropy, the model combines the advantages of the entropy method and the AHP to determine the index weight, which makes the evaluate result to be more scientific and reasonable.
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