Research on Supply Chain Performance Evaluation of Logistics Enterprise under the Constraint of Carbon Footprint

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Abstract

Due to increase in customer environmental awareness, governments require enterprises to incorporating carbon footprint in the supply chain performance evaluation. For utilizing expert interviews, this paper designs a new supply chain carbon footprint index system from the perspective of economy, resources and environment. The system highlights the logistics enterprises operational status under the constraint of carbon footprint. However, in order to reduce the influence of subjective factors, this study combined the entropy method and fuzzy comprehensive evaluation to establish the performance assessment model. To verify the validity of the model and practical indexes, this paper selects a logistics enterprise for empirical research. Therefore, recommendations are given based on performance evaluation results lay the foundation for the further development of low-carbon supply chain operations.

Keywords: Carbon footprint; Logistics companies; Supply chain; Performance evaluation; Entropy method; Fuzzy comprehensive evaluation

I. INTRODUCTION

Over the past few decades, our earth has witnessed a significant change from local environmental issues to global environmental change, and the irreversible decline in the stock of natural capital and ecosystem services worldwide [1]. Therefore, the measurement of carbon footprint has received extensive attention in academic and industry. However, for the "carbon footprint" is defined, Some scholars argued that the carbon footprint is the total amount of gas emission refers to the impact of human production and consumption activities in climate change, including not only carbon dioxide, but also CH4, N2O, PFCS, HFCS, FS6, for each class of greenhouse gases into "carbon dioxide equivalent value" [2]. In recent years, various industries have begun to take measures to reduce carbon emissions. Thus, the rapid development of the logistics industry carbon produced could not be ignored. According to the study, the logistics of transportation has become the second major carbon emission source, second only to the thermoelectric power [3]. Integrating the "carbon footprint" into the logistics industry is the most important problem to be solved in response to climate change. For promoting the logistics corporate carbon emissions, it is particularly important identify the scope of the carbon footprint of logistics enterprise from the perspective of the supply chain [4]. While each node of the logistics supply chain in the provision of services will be emit greenhouse gas more or less. However, between each node of the supply chain not only includes the transfer of logistics, information flow and capital flow, also includes a carbon flow. Logistics supply chain including transportation, distribution, warehousing and packaging activities. Therefore, for reducing carbon emissions in logistic activities, it is necessary to incorporate the concept of low-carbon in the supply chain, and strive to minimize

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energy conservation, reduce energy consumption and pursuit of the minimum carbon footprint in each stage of the supply chain [5].

In the gradual deterioration of the environment and the growing trend of carbon pollution, countries have begun to formulate policies constraint carbon footprint. Thus, it is necessary to introduce the carbon footprint index into the performance evaluation of the logistics supply chain, and it will affect supply chain service quality, transportation, inventory, storage and so on. Join carbon footprint indicators in the logistics supply chain performance evaluation not only can effectively reflect the status of their own resources, identify logistics supply chain operation problems timely, optimize the supply chain management and follow the trend of low-carbon development but also improve green awareness and establish a good corporate image [6]. Meanwhile, supply chain performance evaluation is the use of qualitative and quantitative methods to make a scientific evaluation of the supply chain under the constraint of the carbon footprint, and gives recommendations based on evaluation results, then to achieve sustainable development [7].

However, in contrast to the wealth of studies exploring the carbon footprint in the manufacturing supply chain there has been less research looking at logistics supply chain performance evaluation. Logistics enterprises as the second major source of carbon emissions need to attract more attention. Only several scholars mainly concentrated in low-carbon logistics and low carbon logistics finance, there are lack researches on the whole process of logistics carbon emission levels, statistics and evaluation. Although, by comparing the current situation of domestic and foreign research found that foreign research has been extended to the operational level, while the domestic still stays in the strategic and tactical levels. Therefore, facing the international pressure of climate change, the research on the performance evaluation of enterprise's carbon footprint has become a trend in the domestic research.

Aiming at the problem of deteriorating ecological environment, this paper puts forward the idea of integrating carbon footprint into the performance evaluation of logistics enterprise supply chain, and constructs a new model of supply chain performance evaluation from the perspective of low carbon. In this study, through the entropy method to determine index weight, reduce the influence of subjective factors, and use the fuzzy comprehensive evaluation method to form a complete evaluation system. The construction of the model will play an important role in balancing the economic interests and environmental protection and sustainable development of enterprises.

II. ESTABLISHMENT OF LOW-CARBON SUPPLY CHAIN INDEX SYSTEM

In the following content, according to the operation of logistics enterprises and research of evaluation of low carbon logistics supply chain, this paper create a low carbon supply chain performance evaluation index system, including the transportation carbon footprint, warehousing carbon footprint, packaging carbon footprint, customer service and low-carbon investment degree these five aspects, represented by Bn (n=1,2,3,4,5) respectively.

B1: Transportation carbon footprint
Transportation is the main source of carbon emissions in supply chain services. Including logistics enterprises themselves, upstream logistics service providers and downstream logistics subcontractor companies. This part of the carbon emissions depends on the fuel type, distance traveled and other factors.

B2: Warehousing carbon footprint
Warehousing carbon footprint refers to the forklift, air conditioning and lighting power consumption carbon emissions. Companies can use low-carbon materials, automated warehousing equipment to reduce carbon footprint.

B3: Packaging carbon footprint
The carbon footprint of this part depends on the degree of difficulty of products and packaging materials processing, use low energy processing equipment can reduce their carbon footprint.

B4: Customer service
Customer service mainly refers to the completion rate of the order, the safe delivery rate and customer complaint rate, etc. If the higher security delivery rate, it can reduce the goods in transit time, thus reducing carbon emissions.

B5: Low-carbon investment degree
Low carbon investment mainly refers to the low carbon equipment utilization rate, low carbon technology and low carbon information level.

Of which: Ci (i=1, 2, 3, … , 22) on behalf of Bn in the next evaluation index, the calculation methods are as following:

a) Emissions compliance rate (C1)-Number of vehicles that achieve emissions standards / Total number of transport vehicles)*100%
b) Loading rate (C2)-(Loaded cargo weight / Rated load capacity)*100%
c) Transport loss rate (C3)-(Quantity of material damage in transit / Total number of cargo transport)*100%
d) Transport carbon intensity (C4)-Total carbon emissions during transportation
e) Warehouse storage loss rate (C5)-(Quantity of material damage in the warehouse / Total quantity of goods in warehouse)*100%
f) Air conditioning carbon intensity (C6)-Air conditioning carbon emissions within a certain period * Carbon emission coefficient
g) Refrigeration systems carbon intensity (C7)-Refrigeration carbon emissions within a certain period * Carbon emission coefficient
h) Lighting carbon intensity (C8)-Lighting carbon emissions within a certain period * Carbon emission coefficient
i) Staff awareness of energy conservation (C9)-The number of staff to turn off the lights / Total number of employees
j) Warehouse surrounding green rate (C10)-(Green area around the warehouse / Warehouse area)*100%
k) Ratio of packing material to weight of goods (C11) - (Packaging Material Weight / Total cargo weight)*100%
l) Ratio of packaging material usage to logistics volume (C12)-(Packaging material usage amount / Total logistics)*100%
m) Ratio of logistics volume to waste packaging material usage (C13)-(Logistics volume / Amount of waste packaging materials)*100%
n) Rate of green packaging materials utilization (C14)-(Number of green packaging materials / Total number of packaging materials)*100%
o) Packaging material recycling rate (C15)-(Number of recycled packaging materials / Total number of recyclable packaging materials)*100%
p) Order completion rate (C16)-(Number of completed orders / Total number of orders)*100%
q) Safe delivery rate (C17)-(Safe delivery times / Total delivery times)*100%
r) Delivery accuracy rate (C18)-(Accurate delivery times within a certain period of time / Total number of deliveries in this time)*100%
s) Customer complaint rate (C19)-(Number of customer complaints within a certain period of time / Number of customer consultation in this time)*100%

t) Low-carbon equipment utilization rate (C20)-(Quantity of low carbon energy saving equipment / Total number of devices)*100%
u) Low carbon technology level (C21)-(Low-carbon technology investment cost / Total cost)*100%
v) Low carbon information level (C22)-(Low-carbon information investment cost / Total cost)*100%

III. ESTABLISHMENT OF LOW-CARBON SUPPLY CHAIN EVALUATION MODEL

A. Determine the index weight based on entropy method

Entropy is a measure to determine the uncertainty of information by using probability theory [8]. For utilizing information entropy to determine the weight, it overcomes the subjectivity of the AHP, the ancient forest method and the comparison method, which makes the weight of each index more objective and scientific. Procedural steps of using entropy approach are described as below:

1) Identify the evaluation object and establish the evaluation index system and then construct the original matrix

\[
R = \begin{bmatrix}
    r_{11} & r_{12} & \cdots & r_{1n} \\
    r_{21} & r_{22} & \cdots & r_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    r_{m1} & r_{m2} & \cdots & r_{mn}
\end{bmatrix}
\]

2) Index value of the normalized

In order to compare various indicators, it should be standardization processing, all indicators should adjusted to forward and dimensionless index. Since the system has both forward index and negative index. Such as material loss rate during transport and warehousing material loss rate are negative index. We can deal with the indicators as follows:

Negative index process: \( r_i^* = \frac{1}{r_i} (r_i > 0) \)

Index normalization process: \( P_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \)

After the standardization process, we obtain the following matrix:

\[
P = \begin{bmatrix}
    p_{11} & p_{12} & \cdots & p_{1n} \\
    p_{21} & p_{22} & \cdots & p_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    p_{m1} & p_{m2} & \cdots & p_{mn}
\end{bmatrix}
\]

3) Calculate the index entropy

\[
e_j = -k \sum_{i=1}^{m} p_{ij} \cdot \ln p_{ij}
\]
\[ k = \frac{1}{\ln m} \]

4) Calculate the index weight

\[ \alpha_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)} = \frac{1-e_j}{m-\sum_{j=1}^{n}e_j} \]

\[ g_j = 1 - e_j \]

\( g_j \) is the coefficient of variation.

B. Low-carbon assessment model based on Fuzzy Comprehensive Evaluation Method

Fuzzy set theory is logically helpful in providing clear information for analyzing the problem under vague and ambiguous surroundings. Steps are as follows:

Step 1: Determine the fuzzy comprehensive evaluation factors set \( B \) and reviews set \( V \).

Criterion level index: \( B=\{b1,b2,b3,b4,b5\} \), \( bi \) as the first level indicators, representing the transportation carbon footprint, warehousing carbon footprint, customer service, low-carbon investment degree. Each object factors as:

\( b1=\{b11,b12,b13,b14\}; b2=\{b21,b22,b23,b24,b25,b26\}; b3=\{b31,b32,b33,b34,b35\}; b4=\{b41,b42,b43,b44\} \) \( b5=\{b51,b52,b53\} \). This paper establish reviews set: \( V=\{v1,v2,v3,v4\} \), Where \( vi \) is the evaluation level, \( v1-v4 \) respectively represent excellent, good, fair, poor grades.

Step 2: Determine the membership of single factor evaluation vector and form a membership matrix \( R \).

\[
R = \begin{pmatrix}
  r_{11} & r_{12} & \cdots & r_{1n} \\
  r_{21} & r_{22} & \cdots & r_{2n} \\
    & \vdots & \ddots & \vdots \\
  r_{m1} & r_{m2} & \cdots & r_{mn}
\end{pmatrix}
\]

Step 3: Derive the weight vector of fuzzy evaluation factors: \( W_b \).

\[ W_b = (w_1, w_2, w_3, \ldots, w_m) \] \hspace{1cm} (10)

Step 4: Fuzzy comprehensive evaluation.

Using suitable appropriate arithmetic to synthesis \( W_b \) and the matrix \( R \) and obtain the fuzzy comprehensive evaluation result vector \( C \).

\[
C = W_b \cdot R = (w_1, w_2, w_3, \ldots, w_m) \begin{pmatrix}
  r_{11} & r_{12} & \cdots & r_{1n} \\
  r_{21} & r_{22} & \cdots & r_{2n} \\
    & \vdots & \ddots & \vdots \\
  r_{m1} & r_{m2} & \cdots & r_{mn}
\end{pmatrix}
\]

\[ = (c_1, c_2, \ldots, c_n) \] \hspace{1cm} (11)

Step 5: Analysis of fuzzy comprehensive evaluation results.

According to the principle of maximum degree of membership, if the maximum value of fuzzy comprehensive evaluation result-vector is \( c_r = \max_{j \in \text{set}} \{ c_j \} \), then the object is subordinate to the \( r \) level.

IV. Empirical Research

This paper selects a leading logistics enterprise A, the company established a branch in a number of cities, forming a nationwide logistics network. Using the model constructed in this
paper to evaluate the A logistics company. Performance evaluation level is divided into four grades: excellent ($v_1$), good ($v_2$), medium ($v_3$), poor ($v_4$).

A. Determine factors set and weights

Due to the use of analytic hierarchy process (AHP) to determine the weights with subjectivity, resulting in a lack of effective evaluation index. However, entropy method lack of horizontal comparison between the indicators. In order to make the two complement each other, this paper integrate entropy method and AHP method to determine index weight. Criteria layer index weight can be obtained by calculating:

$$W_j = \{0.40, 0.30, 0.15, 0.04, 0.11\}$$

Secondary indicators weights shown in Table 1.

### Table 1. Secondary Indicators Weights.

<table>
<thead>
<tr>
<th>Secondary Indicators</th>
<th>Weights ($S_i$)</th>
<th>Degree Of Membership $R_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$v_1$</td>
</tr>
<tr>
<td>B11</td>
<td>0.45</td>
<td>0.10</td>
</tr>
<tr>
<td>B12</td>
<td>0.25</td>
<td>0.15</td>
</tr>
<tr>
<td>B13</td>
<td>0.10</td>
<td>0.30</td>
</tr>
<tr>
<td>B14</td>
<td>0.20</td>
<td>0.10</td>
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<tr>
<td>B21</td>
<td>0.15</td>
<td>0.30</td>
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<tr>
<td>B22</td>
<td>0.25</td>
<td>0.20</td>
</tr>
<tr>
<td>B23</td>
<td>0.15</td>
<td>0.30</td>
</tr>
<tr>
<td>B24</td>
<td>0.05</td>
<td>0.40</td>
</tr>
<tr>
<td>B25</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
<td>B26</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>B31</td>
<td>0.05</td>
<td>0.30</td>
</tr>
<tr>
<td>B32</td>
<td>0.25</td>
<td>0.20</td>
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<tr>
<td>B33</td>
<td>0.35</td>
<td>0.25</td>
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<td>B34</td>
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<td>B35</td>
<td>0.20</td>
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<tr>
<td>B41</td>
<td>0.35</td>
<td>0.30</td>
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<tr>
<td>B42</td>
<td>0.30</td>
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<tr>
<td>B43</td>
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<tr>
<td>B44</td>
<td>0.10</td>
<td>0.20</td>
</tr>
<tr>
<td>B51</td>
<td>0.40</td>
<td>0.30</td>
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<tr>
<td>B52</td>
<td>0.25</td>
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</tr>
<tr>
<td>B53</td>
<td>0.35</td>
<td>0.30</td>
</tr>
</tbody>
</table>

B. Model operation

First, this paper consists of experts to evaluate the secondary indicators. According to $A \cdot R_i = B_i$, that is
The membership degree of index layer
Fuzzy subset as follows: \( B_i = [B_{i1}, B_{i2}, B_{i3}, B_{i4}] \), \( B^s_j \) is the evaluation results of criterion layer, representing the membership degree of the first grade index of transportation, storage, packaging and so on. To transport carbon footprint, for example, 10 experts on the evaluation of emissions compliance rate was \( r_i =(0.10, 0.30, 0.40, 0.20) \). That 1 people consider excellent, 3 people think good, 4 people think medium, 2 people think poor.

Secondary indicators weight:
\( A_{s1} = (0.45, 0.25, 0.10, 0.20) \)
\( A_{s2} = (0.15, 0.25, 0.15, 0.05, 0.20, 0.20) \)
\( A_{s3} = (0.05, 0.25, 0.35, 0.15, 0.20) \)
\( A_{s4} = (0.35, 0.30, 0.25, 0.10) \)
\( A_{s5} = (0.40, 0.25, 0.35) \)

After the calculation, we obtain the following results:
\[
(A_{s1}, A_{s2}, A_{s3}, ..., A_{s5}) = (0.13, 0.36, 0.36, 0.14)
\]
\[
A_{s2}\cdot r_i = (0.15, 0.25, 0.15, 0.05, 0.20, 0.20) *= (0.29, 0.33, 0.23, 0.16)
\]
\[
A_{s3}\cdot r_i = (0.05, 0.25, 0.35, 0.15, 0.20) *= (0.29, 0.30, 0.22, 0.17)
\]

After the calculation, we obtain the fuzzy relation matrix:
\[
\begin{pmatrix}
0.13 & 0.36 & 0.36 & 0.14 \\
0.29 & 0.33 & 0.23 & 0.16 \\
0.24 & 0.35 & 0.28 & 0.13 \\
0.29 & 0.30 & 0.22 & 0.19 \\
0.30 & 0.33 & 0.21 & 0.17 \\
\end{pmatrix}
\]

\[B_1 = \begin{pmatrix}
0.22 & 0.34 & 0.29 & 0.15 \\
0.29 & 0.30 & 0.22 & 0.19 \\
0.30 & 0.33 & 0.21 & 0.17 \\
\end{pmatrix}
\]

According to the fuzzy comprehensive evaluation formula, we get the criterion layer index:

\[C_i = W_iB_1 = (0.40 \ 0.30 \ 0.15 \ 0.04 \ 0.11)^* \]

The calculation results show that the maximum membership degree is 0.34, therefore, the logistics company performance is at a good level.

C. Results analysis

According to the evaluation results, although the company's comprehensive performance level is good, but from the evaluation results of individual indicators, the company's exhaust emissions compliance rate, the carbon intensity of transportation, and other indicators of the evaluation grade is medium. Therefore, the comprehensive performance of the logistics company is still some room for improvement, recommendations are as follows:

1) **Develop the green shipping technologies to reduce carbon emissions**

Implement green freight and install low resistance tires on trucks. Utilize energy-saving equipment, such as air dynamics and driving behavior diagnosis system. Also, in each set of a freight car equipped with GPS to collect real-time fuel consumption data. Give performance bonuses to freight drivers of minimum carbon footprint, thereby improving the driver's driving habits, strengthening low-carbon awareness of drivers. Develop multimodal transport to reduce no-load rate and improve transport intensity.

2) **Develop green packaging**

Improve the packaging technology to improve the utilization of packaging materials. Use green packaging materials, such as biodegradable plastic, edible packaging material and recyclable packaging materials. Logistics enterprises take relevant incentive policies, recycling the customer's packaging waste to maximize recycling.

3) **Implement energy management systems**

Improving energy efficiency is one of the effective measures to reduce the carbon footprint. To strengthen the awareness of energy conservation and energy efficiency, we can set up different carbon emission targets for each sector, while developing energy management objectives, thereby decomposing business goals. Utilize scientific method to evaluate the carbon footprint of the targets at different levels.

V. Conclusion

This paper established a relatively complete set of the logistics enterprise supply chain performance evaluation system under the constraint of carbon footprint. Combine the entropy and fuzzy comprehensive evaluation method to establish model, so as to make up for their shortcomings. The model established in this paper can guide and regulate the implementation of the carbon footprint management of logistics enterprises, thereby promoting the carbon emissions reduction.

However, the evaluation system needs to be further verified in practice, and accumulated experience in the development of logistics enterprises, therefore, some indexes are adjusted to
make it more universal and practical in the performance evaluation of the logistics enterprises
under the constraint of carbon footprint. Meanwhile, the model established in this paper also
needs to be verified in the future, then the evaluation model continuous improvement, so as to
get more long-term development.

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