Analysis of the Choice of Transportation Mode for Cross-border Supply Chain Based on the Belt and Road

Xiangguo Ma, Peijian Sun and Mengsha Feng

ABSTRACT

This paper studies the transportation mode selection of cross-border supply chain under the “the Belt and Road” to find the most suitable transportation mode for cross-border transportation. At first, the overall priority of marine transport and railway transportation is analyzed by analytic hierarchy process, but the analytic hierarchy process has shortcomings and limitations. Therefore, by introducing fuzzy analytic hierarchy process, the complexity of judging the relative importance of the target is simplified, by using the ambiguity of the judgment matrix and the simplicity of the calculation, the deficiencies of the analytic hierarchy method are solved. This paper chooses the optimization idea by considering the cost, running time, transportation capacity and flexibility as the main target transportation mode, according to the characteristics of quantitative and qualitative indicators, the fuzzy hierarchy analysis method is used to establish the hierarchical structure model. Finally, the fuzzy consistent matrix is established to calculate and analyze the optimal solution.

KEYWORDS

The Belt and Road, Mode of transport, Analytic hierarchy process, Fuzzy analytic hierarchy process.

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INTRODUCTION

This paper explores the choice of transportation modes for cross-border supply chains under the “the Belt and Road” through the selection of A’s raw material transportation methods. A is an industrial company in Germany that produces copper and various copper alloys. The purpose of this paper is to find the cheapest cost of transporting materials or pre-rolled materials from the Henan plant in China to the Stolberg plant in Germany. Therefore, this paper will explore how to transfer materials from the B Xinxiang plant to the B plant in an optimal mode of transportation.

Through literature review, Bi G uses the system evaluation method to explore how to rationally select the transportation mode under the premise that the transportation demand is known between two points\textsuperscript{[1]}. Tuzkaya analyzed the application of fuzzy comprehensive evaluation method in the selection of enterprise logistics transportation mode\textsuperscript{[2]}. When analyzing the optimization design technology of logistics and transportation plan, Ji’an constructed the enterprise logistics transportation mode selection model by AHP method\textsuperscript{[3]}. Zang Taotao used the fuzzy analytic hierarchy process to establish a hierarchy of military transport routes from both military and economic benefits\textsuperscript{[4]}. Ma Xin combined with fuzzy comprehensive evaluation method to evaluate the overall safety of dangerous goods transportation according to the calculation of weights of various factors in complex networks\textsuperscript{[5]}

In order to better select the transportation mode for the cross-border supply chain, this paper, on the basis of analytic hierarchy process, comprehensively combines the mathematical knowledge of fuzzy mathematics and optimization, and develops and designs a cross-border supply chain transportation mode selection scheme based on fuzzy analytic hierarchy process.
OVERVIEW OF ANALYTIC HIERARCHY PROCESS MODEL

Analytic hierarchy process is a systematic analysis method that combines quantitative analysis and qualitative analysis in the 1970s. Analytic hierarchy process decomposes complex target problems into different unit factors, and each unit factor is divided into several groups according to different attributes, thus forming several levels, the same level of factors play a dominant role in the underlying factors, and at the same time by the upper factors of the domination.

The analytic hierarchy process consists of the principle of pairwise comparison, the relative importance of the two factors is determined by comparing the two factors. Based on this, the judgment matrix is constructed, the relative weight and the comprehensive weight are calculated by the approximation algorithm, and the weight is verified by the consistency test. Whether the allocation is reasonable. And the scheme is then measured by hierarchical ordering and hierarchical multi-sorting, and the preferred scheme is determined based on the measurement results.

BUILDING A HIERARCHICAL STRUCTURE MODEL

This paper analyzes the elements set and correlation relationship of maritime and railway transportation, and establishes the hierarchical structure model, as shown in Figure 1:
CONSTRUCTING JUDGMENT MATRIX AND CHECKING THE CONSISTENCY OF MATRIX

(1) Starting from the top element and based on the top element, the next layer of elements is compared two by two to establish a judgment matrix.

<table>
<thead>
<tr>
<th>Mode of transportation</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>Priority vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>flexibility</td>
<td>B1</td>
<td>1</td>
<td>1/2</td>
<td>1/3</td>
<td>1/4</td>
</tr>
<tr>
<td>operation hours</td>
<td>B2</td>
<td>2</td>
<td>1</td>
<td>1/4</td>
<td>1/3</td>
</tr>
<tr>
<td>carrying capacity</td>
<td>B3</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>1/3</td>
</tr>
<tr>
<td>freight</td>
<td>B4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

(2) Consistency test
The largest characteristic root is:

\[ \lambda_{\text{max}} = \frac{1}{4} \left[ \begin{array}{cccc}
0.3067 & 0.5395 & 1.2074 & 2.0781 \\
0.0912 & 0.1209 & 0.2854 & 0.4944
\end{array} \right] = 4.0648 \]

\[ \text{CI} = \frac{4.0648 - 4}{4 - 1} = 0.0216 \]

\[ \text{test consistency} \quad CR = \frac{\text{CI}}{\text{RI}} = \frac{0.0216}{0.90} = 0.024 < 0.1 \]

Therefore, the matrix consistency is within the allowable range and the judgment matrix is available.

**BASED ON THE SECOND LAYER OF ELEMENTS, A JUDGMENT MATRIX IS ESTABLISHED FOR THE THIRD LAYER OF ELEMENTS**

Since there are four criteria at this time, there are four judgment matrices.

**TABLE II. PRIORITY RELATIONSHIP MATRIX (FOR B1).**

<table>
<thead>
<tr>
<th>Flexibility B1</th>
<th>A1</th>
<th>A2</th>
<th>Priority vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail transport A1</td>
<td>1</td>
<td>3</td>
<td>0.7500</td>
</tr>
<tr>
<td>Maritime transport A2</td>
<td>1/3</td>
<td>1</td>
<td>0.2500</td>
</tr>
</tbody>
</table>

**TABLE III. PRIORITY RELATIONSHIP MATRIX (FOR B2).**

<table>
<thead>
<tr>
<th>Operation hours B2</th>
<th>A1</th>
<th>A2</th>
<th>Priority vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail transport A1</td>
<td>1</td>
<td>1/5</td>
<td>0.1667</td>
</tr>
<tr>
<td>Maritime transport A2</td>
<td>5</td>
<td>1</td>
<td>0.8333</td>
</tr>
</tbody>
</table>
TABLE IV. PRIORITY RELATIONSHIP MATRIX (FOR B3).

<table>
<thead>
<tr>
<th>Carrying capacity B3</th>
<th>A1</th>
<th>A2</th>
<th>Priority vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail transport A1</td>
<td>1</td>
<td>1/3</td>
<td>0.2500</td>
</tr>
<tr>
<td>Maritime transport A2</td>
<td>3</td>
<td>1</td>
<td>0.7500</td>
</tr>
</tbody>
</table>

TABLE V. PRIORITY RELATIONSHIP MATRIX (FOR B4).

<table>
<thead>
<tr>
<th>Freight</th>
<th>B4</th>
<th>A1</th>
<th>A2</th>
<th>Priority vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail transport A1</td>
<td>1</td>
<td>1/2</td>
<td>0.3333</td>
<td></td>
</tr>
<tr>
<td>Maritime transport A2</td>
<td>2</td>
<td>1</td>
<td>0.6667</td>
<td></td>
</tr>
</tbody>
</table>

ACCORDING TO THE ABOVE MATRIX, THE OVERALL PRIORITY

TABLE VI. OVERALL PRIORITY.

<table>
<thead>
<tr>
<th>Choose transportation method</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>Overall priority</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0912</td>
<td>0.1290</td>
<td>0.2854</td>
<td>0.4944</td>
<td></td>
</tr>
<tr>
<td>Rail transport A1</td>
<td>0.7500</td>
<td>0.1667</td>
<td>0.2500</td>
<td>0.3333</td>
<td>0.3261</td>
</tr>
<tr>
<td>Maritime transport A2</td>
<td>0.2500</td>
<td>0.8333</td>
<td>0.7500</td>
<td>0.6667</td>
<td>0.8790</td>
</tr>
</tbody>
</table>

Overall priority calculation

A1: 0.0912*0.7500+0.1290*0.1667+0.2854*0.2500+0.4944*0.3333=0.3261

A2: 0.0912*0.2500+0.1290*0.8333+0.2854*0.7500+0.4944*0.6667=0.8790

According to overall priority, the overall priority of ocean transportation is
0.8790, the overall priority of rail transport is 0.3261. So A2>A1, we should choose marine transportation.

IMPROVEMENT SCHEME

Analytic hierarchy process is an important solution method, but it also has obvious disadvantages. Therefore, this paper will adopt fuzzy AHP to further analyze the choice of transportation mode.

SELECTION OPTIMIZATION OF CROSS-BORDER SUPPLY CHAIN TRANSPORTATION MODE UNDER "THE BELT AND ROAD" BASED ON FUZZY ANALYTIC HIERARCHY PROCESS

OVERVIEW OF FUZZY ANALYTIC HIERARCHY PROCESS

The combination of fuzzy mathematics and analytic hierarchy process produces a fuzzy analytic hierarchy process. The fuzzy analytic hierarchy process has the characteristics of the ambiguity of the judgment matrix and the simplicity of the calculation. It solves the deficiencies of the general analytic hierarchy method and the difficulty of the judgment matrix consistency. The fuzzy analytic hierarchy process is introduced into the transportation mode selection evaluation model, which makes the transportation mode selection evaluation process clear, simplifies a large number of calculations, and provides a new and effective method for transportation mode selection evaluation.

ESTABLISHMENT OF FUZZY ANALYTIC HIERARCHY PROCESS

INTRODUCTION OF FUZZY CONSISTENT MATRIX

Although the fuzzy analytic hierarchy process based on fuzzy judgment
matrix overcomes some shortcomings of the traditional analytic hierarchy process, it is difficult to guarantee the consistency of the fuzzy judgment matrix. Therefore, the paper is based on this. The concept of fuzzy consistent matrix is introduced, and a more reasonable scheme is selected accordingly to form an ideal decision-making method.

**ALGORITHM STEP**

(1) Construct a priority relationship matrix

You can use 0, 0.5, and 1 scales to determine the factor value. The fuzzy priority relation matrix is first established from single factors $B_k = (b_{ij}^k)_{n \times n}$, the value is:

$$b_{ij}^k = \begin{cases} 
0, & \text{if under factor } k, A_i \text{ is better than } A_j \\
0.5, & \text{if under factor } k, A_i \text{ and } A_j \text{ are excellent} \\
1, & \text{if under factor } k, A_i \text{ is worse than } A_j 
\end{cases}$$

(2) The establishment of a first-order fuzzy matrix

The priority relationship matrix is transformed into a fuzzy consistent matrix and tested to ensure consistency. Single factor evaluation matrix for first-order fuzzy comprehensive evaluation $R_k = (r_{ij}^k)_{n \times n}$, use the following formula:

$$r_{ij}^k = \frac{r_{ij}^k - r_{ij}^k}{2n} + 0.5 \quad r_i = \sum_{i=1}^{n} b_{ii}, \quad r_j = \sum_{j=1}^{n} b_{ij}^k,$$

after the transformation, the fuzzy consistent matrix $R_k (k=1,2,\ldots,m)$ is obtained.

(3) Hierarchical single sort

According to the judgment matrix, the method of calculating the priority of the importance of the factors of the above level is called the hierarchical single ordering. The calculation method of the uniqueness value of the single factor and the index weight is as follows.
Calculate the superiority value $s_i^k$ of the $k$ factor in scenario $A_i$, using square root method:

$$s_i^k = \frac{s_i}{\sum_{j=1}^{n} s_j} \quad (s_j = (\prod_{i=1}^{n} r_{ji}^{1/n}))$$

(2)

(4) Hierarchical total ordering

The so-called total ordering of the hierarchy is to calculate the ranking weights of the factors contained in the same layer for the highest level importance. Can be made by the formula:

$$s_i = \sum_{k=1}^{m} w_k \cdot s_i^k \quad (i=1,2,\ldots,n)$$

(3)

Sorting $s_i = (i=1,2,\ldots,n)$ can get the ranking of the superiority.

APPLICATION OF FUZZY ANALYTIC HIERARCHY PROCESS IN THE SELECTION OF TRANSPORTATION MODE

The application of fuzzy AHP can mainly include several stages such as the construction of hierarchical structure model, expert consultation, calculation ordering and program evaluation.

ESTABLISHING HIERARCHY STRUCTURE BY FUZZY ANALYTIC HIERARCHY PROCESS

This paper used the analytic hierarchy process to analyze and compare, but there are some limitations in the results obtained by AHP. Therefore, we pursue the lowest cost, this paper selects six optimization evaluation indicators, and then selects the optimization model for transportation mode.
The hierarchical structure model is constructed as shown in Figure 2:

![Transportation mode selection hierarchy diagram]

**EXPERT CONSULTATION TO DETERMINE INDICATOR WEIGHTS**

Considering the mode of transportation and combining with the fuzzy analytic hierarchy process, select experts for consultation and determine the corresponding weight value. As shown in Table VII.

**TABLE VII. WEIGHT DETERMINATION TABLE OF TRANSPORT MODE SELECTION EVALUATION INDEX.**

<table>
<thead>
<tr>
<th>Cost (0.35)</th>
<th>Operation hours (0.2)</th>
<th>Transport capacity (0.3)</th>
<th>Flexibility (0.15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport cost (0.7)</td>
<td>Endpoint variable cost (0.3)</td>
<td>Punctuality (1)</td>
<td>Stability (0.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Carrying capacity (0.8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Number of stops (1)</td>
</tr>
</tbody>
</table>
NUMERICAL EXAMPLES FOR SOLVING AND ANALYZING

DATA PROCESSING

Construct a priority relationship matrix for the following six factors: transportation cost, endpoint variable cost, punctuality, stability, carrying capacity, number of stops.

\[
B = \begin{pmatrix}
0.5 & 0 & 0 \\
1 & 0.5 & 0 \\
1 & 1 & 0.5
\end{pmatrix},
B = \begin{pmatrix}
0.5 & 1 & 0 \\
0 & 0.5 & 0 \\
1 & 1 & 0.5
\end{pmatrix},
B = \begin{pmatrix}
0.5 & 0 & 1 \\
1 & 0.5 & 1 \\
0 & 0 & 0.5
\end{pmatrix},
B = \begin{pmatrix}
0.5 & 0 & 0 \\
1 & 0.5 & 1 \\
1 & 0 & 0.5
\end{pmatrix},
B = \begin{pmatrix}
0.5 & 1 & 0 \\
0 & 0.5 & 0 \\
1 & 1 & 0.5
\end{pmatrix},
B = \begin{pmatrix}
0.5 & 1 & 1 \\
0 & 0.5 & 1 \\
0 & 0 & 0.5
\end{pmatrix}
\]

Calculated \( r_i, r_j \) from equation, according to the priority relationship matrix. And according to the calculation results, the fuzzy consistent matrix is constructed:

\[
R = \begin{pmatrix}
1 & 1 & 1 \\
6 & 3 & 2 \\
1 & 2 & 5 \\
6 & 3 & 2
\end{pmatrix},
R = \begin{pmatrix}
1 & 1 & 2 \\
2 & 3 & 3 \\
2 & 1 & 5 \\
3 & 2 & 6
\end{pmatrix},
R = \begin{pmatrix}
1 & 2 & 1 \\
2 & 3 & 3 \\
1 & 1 & 1 \\
3 & 2 & 6
\end{pmatrix},
R = \begin{pmatrix}
1 & 1 & 1 \\
6 & 2 & 3 \\
1 & 5 & 2 \\
6 & 2 & 3
\end{pmatrix},
R = \begin{pmatrix}
1 & 2 & 1 \\
2 & 3 & 3 \\
1 & 1 & 1 \\
3 & 2 & 6
\end{pmatrix},
R = \begin{pmatrix}
5 & 2 & 1 \\
6 & 3 & 2 \\
2 & 1 & 1 \\
3 & 2 & 3
\end{pmatrix}
\]

Then use the square root method to calculate the superiority value \( S_i^k \) of the scheme \( A_i \) under the k factor by the formulas (2):
TABLE VIII. EXCELLENT GENUS VALUE.

<table>
<thead>
<tr>
<th></th>
<th>Transportation cost</th>
<th>Endpoint variable cost</th>
<th>Punctuality</th>
<th>Stability</th>
<th>Carrying capacity</th>
<th>Number of stops</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{S}_1$</td>
<td>0.3029</td>
<td>0.4807</td>
<td>0.4807</td>
<td>0.3029</td>
<td>0.4807</td>
<td>0.6525</td>
</tr>
<tr>
<td>$\bar{S}_2$</td>
<td>0.4807</td>
<td>0.3029</td>
<td>0.6525</td>
<td>0.6525</td>
<td>0.3029</td>
<td>0.4807</td>
</tr>
<tr>
<td>$\bar{S}_3$</td>
<td>0.6525</td>
<td>0.6525</td>
<td>0.3029</td>
<td>0.4807</td>
<td>0.6525</td>
<td>0.3029</td>
</tr>
<tr>
<td>$S_1^k$</td>
<td>0.2109</td>
<td>0.3347</td>
<td>0.3347</td>
<td>0.2109</td>
<td>0.3347</td>
<td>0.4544</td>
</tr>
<tr>
<td>$S_2^k$</td>
<td>0.3347</td>
<td>0.2109</td>
<td>0.4544</td>
<td>0.4544</td>
<td>0.2109</td>
<td>0.3347</td>
</tr>
<tr>
<td>$S_3^k$</td>
<td>0.4544</td>
<td>0.4544</td>
<td>0.2109</td>
<td>0.3347</td>
<td>0.4544</td>
<td>0.2109</td>
</tr>
</tbody>
</table>

CALCULATION AND ANALYSIS OF RESULTS

(1) Calculation of results

By means of the weight value obtained by the expert evaluation scoring method and the membership value obtained by the calculation, the final evaluation value of each mode of transport is calculated by using formula (3) as:

$$s_1 = \sum_{k=1}^{6} w_k s_i^k = (0.2109 \times 0.7 + 0.3347 \times 0.3) \times 0.35 + 0.3347 \times 1 \times 0.2 + (0.2109 \times 0.2 + 0.3347 \times 0.8) \times 0.3 + 0.4544 \times 1 \times 0.15 = 0.3363$$

$$s_2 = \sum_{k=1}^{6} w_k s_i^k = (0.3347 \times 0.7 + 0.2109 \times 0.3) \times 0.35 + 0.4544 \times 1 \times 0.2 + (0.4544 \times 0.2 + 0.0219 \times 0.8) \times 0.3 + 0.3347 \times 1 \times 0.15 = 0.3232$$

$$s_3 = \sum_{k=1}^{6} w_k s_i^k = (0.4544 \times 0.7 + 0.4544 \times 0.3) \times 0.35 + 0.2109 \times 1 \times 0.2 + (0.3347 \times 0.2 + 0.4544 \times 0.8) \times 0.3 + 0.2109 \times 1 \times 0.15 = 0.3483$$
(2) Analysis of results

From the operation process of fuzzy analytic hierarchy process, it can be known that the fuzzy matrix is established by taking the small value as the best, and the value in the evaluation index is as small as possible, and the transportation distance is short, and the transportation time is less. So the final result of the evaluation is that the smallest value is the optimal solution we want to select.

The calculated final result is the final optimal evaluation value of three modes of transport selection, and the one with the smallest value is the optimal mode of transport. The comparison of the calculated results shows that ocean transportation is the optimal solution, followed by railway transportation, and the air transportation scheme is the worst choice among the three methods.

SUMMARY

By analyzing the factors affecting cross-border transportation, this paper makes a research and analysis by using AHP, and then puts forward a more effective fuzzy analytic hierarchy process in view of the limitation of analytic hierarchy process. In view of the characteristics of cross-border supply chain transportation, the problem is divided into four objectives and combined with the characteristics of indicator ambiguity. The fuzzy theory is used to construct the research model of cross-border transportation mode selection based on fuzzy analytic hierarchy process, and also improves the fuzzy analytic hierarchy process, introduces fuzzy consistent matrix, and optimizes the algorithm steps and application of fuzzy analytic hierarchy method. Finally, a comparative analysis of the results determines the choice of transport mode for cross-border supply chains.

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REFERENCES