Ensemble PROMETHEE II Method for Port Competitiveness Evaluation

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Abstract

PROMETHEE is an important method for multi-criteria decision-making. Inspired by ensemble methods, this paper proposes an ensemble PROMETHEE II model, in which multiple preference functions are used to reduce the risk of choosing a particularly preference function. One example of competitiveness evaluation of the ports of Circum-Bohai-Sea is included to illustrate the proposed method. The ranking results show that the whole evaluating procedure is simple and clear, and the model has taken full advantage of information contained in the original data and the subjective information of experts.

Keywords: PROMETHEE II, Entropy, Competitiveness Evaluation

1. Introduction

With the development of the international shipping industry and the global economy, the status and role of the port have been increasing in the global economy, and gradually become an integrated logistics center of regional economic development and international trade. Enhance the port competitiveness is an important work for all levels of government and society. Decision makers in the port management sector frequently face the problem of assessing some ports, and giving some advices to speed up the port development. However, the evaluation decisions are complex, as decision making is more challenging today. There is a need for simple, systematic, and logical methods or mathematical. PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) is an important multi-criteria decision making method developed in [1]. The PROMETHEE family of outranking methods and their applications has attracted much attention from academics and practitioners [2]. In this paper, PROMETHEE II method is employed to evaluate ports competitiveness of Circum-Bohai-Sea. There exist six basic types of preference function in PROMETHEE II method, so decision makers can establish flexible standard according to the requirement of particular job with respect to each criterion by using PROMETHEE II method [3]. In statistics and machine learning, ensemble methods use multiple models to obtain better predictive performance than that could be obtained from any of the constituent models [4,5]. It is important to emphasize that there is no guarantee that the combination of multiple models will always perform better than the best individual model in the ensemble. Nor an improvement on the ensemble’s average performance can be guaranteed except for certain special cases, but it certainly reduces the overall risk of making a particularly poor selection [6].

In this paper, the research objective is to establish ensemble PROMETHEE II method for evaluation seven main ports of Circum-Bohai-Sea. The entropy method is used to determine the index weights. The rest of the paper is organized as follows. In Section 2, PROMETHEE II and entropy method are recalled, Section 3 describes the proposed approach, In Section 4, one example of evaluation of the ports of Circum-Bohai-Sea is given, Section 5 concludes with some suggestions for future research.

2. PROMETHEE II and entropy method

2.1 PROMETHEE II Method

The PROMETHEE II method is a multi-criteria decision-making method, belonging to the family of outranking methods [7]. It is a ranking method quite simple in conception and application compared to other methods for multi-criteria analysis. It is well adapted to problems where a finite number of alternatives are ranked considering several conflicting criteria.
There are six different shapes of preference function in the original PROMETHEE II methods.

Usual: \( P_i(d) = \begin{cases} 1 & \text{if } d > 0 \\ 0 & \text{if } d \leq 0 \end{cases} \) \hspace{1cm} (2.1)

U-Shape: \( P_i(d) = \begin{cases} 1 & \text{if } d > p \\ 0 & \text{if } d \leq p \end{cases} \) \hspace{1cm} (2.2)

V-Shape: \( P_i(d) = \begin{cases} 0 & \text{if } d \leq 0 \\ \frac{d}{p} & \text{if } 0 < d \leq p \\ 1 & \text{if } d > p \end{cases} \) \hspace{1cm} (2.3)

Level: \( P_i(d) = \begin{cases} 0 & \text{if } d \leq q \\ \frac{q}{2} & \text{if } q < d \leq p \\ 1 & \text{if } d > p \end{cases} \) \hspace{1cm} (2.4)

Linear: \( P_i(d) = \begin{cases} 1 & \text{if } d > p \\ \frac{d-q}{p-q} & \text{if } q < d \leq p \\ 0 & \text{if } d \leq q \end{cases} \) \hspace{1cm} (2.5)

Gaussian: \( P_i(d) = \begin{cases} 1-e^{-(d^2/\sigma^2)} & \text{if } d > 0 \\ 0 & \text{if } d \leq 0 \end{cases} \) \hspace{1cm} (2.6)

Some guidelines are given in choosing the right preference function for criterion [8]. The ‘usual function’ is an easy to use preference function and is generally used with quantitative criteria. ‘U-shape function’ uses a single indifference threshold and is generally used with qualitative criteria. ‘V-shape function’ uses a single preference threshold and is often used with quantitative criteria. ‘Level function’ is similar to ‘U-shape’, but with an additional preference threshold and it is mostly used with qualitative criteria. ‘Linear function’ is similar to ‘V-shape’, but with an additional indifference threshold and is often used with quantitative criteria. ‘Gaussian function’ is rarely used [9,15]. However, some preference functions else being equal in given problems, one may be tempted to choose at random, but with that decision come the risk of choosing a particularly poor model. In the follows, we will propose an ensemble PROMETHEE II method.

The PROMETHEE II method encompasses two phases: (i) the aggregation of information about the alternatives and the criteria; (ii) the exploitation of the outranking relation for decision aid [10]. The aggregation phase requires that each point of view would be associated with a generalized criterion to assess the preference for an alternative \( a_i \) with regards to \( a_k \) as a function of \( P_i[C_i(a_i) - C_i(a_k)] = P_i(r_i - r_k) \). In this paper, we will employ six preference functions to get ensemble to assess the preference for an alternative \( a_i \) with regards to \( a_k \) in aggregation phase.

### 2.2. Definite weight of each index with entropy weight

The entropy concept originated from Thermodynamics, which was introduced into information theory by Shannon. Entropy is used in the process of decision-making as an ideal scale, and it can measure the quantity of useful information obtained from dates. The evaluation method based on entropy weight is an effectual method to fix the index weight coefficients in multi-index comprehensive evaluation, the details steps of calculating entropy weights are as follows [11,14]:
(1) Structure matrix \( R = (r_{ij})_{m \times n} \) \((i = 1, 2, \cdots; j = 1, 2, \cdots, n)\), where \( r_{ij} \) is the evaluation values of alternative \( i \) with respect to the evaluation criteria \( j \).

(2) Calculate the evaluation values proportion \( f_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}} \).

(3) Calculate the entropy \( e_j \) of the evaluation criteria \( j \)
\[
e_j = -\frac{1}{\ln n} \sum_{i=1}^{m} f_{ij} \ln f_{ij},
\]
where, if \( f_{ij} = 0 \), denotes \( \ln f_{ij} = 0 \).

(4) Calculate the variability \( d_j \) of the \( j \)th criterion as follows:
\[
d_j = 1 - e_j, \quad j = 1, 2, \cdots, n.
\]

(5) Take weight normalization, and get the weight of each criterion:
\[
\tilde{w}_j = d_j / \sum_{j=1}^{n} d_j, \quad j = 1, 2, \cdots, n.
\]

According to the thought of entropy, the quantity and quality of the obtained information is one of the determinants about the accuracy and reliability of decision-making [12].

3. Ensemble PROMETHEE II Method

Inspired by ensemble methods [5,13], ensemble PROMETHEE II is proposed to rank the alternatives, which is organized as follows:

**Step 0: Choose the right preference functions**

In this paper, we choose the six preference functions to get the partial and complete rankings for each alternative. \( P_k(\cdot) \) represents the \( k \)th type of preference function selected by DMs. In real applications, one can takes some preference functions according to the guidelines given in [8].

**Step 1: Determine the weight vector**

Denote the set of alternatives \( A = \{a_1, a_2, \ldots, a_m\} \) and the set of evaluation criteria \( C = \{c_1, c_2, \ldots, c_n\} \). Usually, for the same problem, DMs may have different opinions on the chosen preference functions. For this purpose, given that each DMs’ view may not be equally important on the chosen preference functions, we let \( w = [w_1, w_2, \ldots, w_k]^T \) be the weight vector of preference functions given by the DMs, such that \( w_i \geq 0(i = 1, 2, \ldots, k) \), and \( \sum_{i=1}^{k} w_i = 1 \). Since each criterion \( C_j \) may not be equally weighted, let \( \tilde{w} = [\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n]^T \) be the weight vector of the criteria, such that \( \tilde{w}_i \geq 0(i = 1, 2, \ldots, n) \), and \( \sum_{i=1}^{n} \tilde{w}_i = 1 \).

In this paper, the entropy method is used to determine the weight vector \( \tilde{w} = [\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n]^T \).

**Step 2: Evaluate pairs of alternatives**

The deviation between any two possible alternatives can be determined as follows:
\[
P_k[C(a_i) - C(a_j)] = P_k(r_{ij} - r_{ji}) \in [0,1], \quad k \in \{1,2,3,4,5,6\},
\]
where \( P_k(r_{ij} - r_{ji}) \) denotes the difference between alternatives \( a_i, a_j \) on criterion \( t \) with respect to the preference function \( P_k \), \( k \in \{1,2,3,4,5,6\} \).

**Step3: Ensemble for the multi preference functions**

\[
P[C(a_i) - C(a_j)] = \sum_{i=1}^{n} w_i \cdot P_k(r_{ij} - r_{ji}) \in [0,1],
\]
where \( w = [w_1, w_2, \ldots, w_k]^T \) be the weight vector of preference functions given by the DMs.

**Step 4: Compute an aggregate evaluation index**

For any \( a_i, a_j \in A \), denote
\[ \pi(a_i, a_j) = \sum_{i=1}^{n} (P(C_i(a_i) - C_j(a_j))) \cdot \hat{w}_i \]
\[ = \sum_{i=1}^{n} (P(r_i - r_j)) \cdot \hat{w}_i \quad (3.1) \]

where \( \pi : A \times A \rightarrow [0,1] \) is defined as the weighted sum of \( P(r_i - r_j) \) for criterion \( t \), and \( \hat{w}_k \) is the weight associated with criterion \( t \). Also, \( \pi(a,b) \) expresses the degree to which \( a \) is preferred to \( b \) for all criterias.

**Step 5: Find the outranking flows and the rankings for each alternative**

We calculate the positive and negative outranking flows for alternative \( a_i \) respectively, by which the net outranking flow for alternative \( a_i \). The final ranking is obtained as the higher the net flow, the better the alternative.

**Positive outranking flows** :
\[ \Omega^+(a_i) = \frac{1}{m-1} \sum_{j=1, j \neq i}^{m} \pi(a_i, a_j) \quad (3.2) \]

**Negative outranking flows** :
\[ \Omega^-(a_i) = \frac{1}{m-1} \sum_{j=1, j \neq i}^{m} \pi(a_j, a_i) \quad (3.3) \]

**Net outranking flows** :
\[ \Omega(a_i) = \Omega^+(a_i) - \Omega^-(a_i) \quad (3.4) \]

**4. Case example**

To illustrate the performance of ensemble PROMETHEE II model, we consider the competitiveness evaluation of the ports of Circum-Bohai-sea in China. As a general rule used for reference, the Circum-Bohai-Sea region is a good example. The development of Circum-Bohai-Sea area is not only related to region development, but also connected with strategic plan of nation. In this part, the research objects are seven main ports of Circum-Bohai-Sea, depending on the chosen 13 indicators of the competitiveness. The entropy method is use to determine the weights of the competitiveness index.
<table>
<thead>
<tr>
<th>Index</th>
<th>Port</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dalian</td>
</tr>
<tr>
<td></td>
<td>Yingkou</td>
</tr>
<tr>
<td></td>
<td>Tianjin</td>
</tr>
<tr>
<td></td>
<td>Qinhuangdao</td>
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<tr>
<td></td>
<td>Qingdao</td>
</tr>
<tr>
<td></td>
<td>Yantai</td>
</tr>
<tr>
<td></td>
<td>Rizhao</td>
</tr>
</tbody>
</table>

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$ (TEU)</td>
<td>22286</td>
<td>12207</td>
<td>30946</td>
<td>24893</td>
<td>26502</td>
<td>10129</td>
</tr>
<tr>
<td>$C_2$ (%)</td>
<td>11.2</td>
<td>28.8</td>
<td>20.1</td>
<td>18.23</td>
<td>21.49</td>
<td>18.66</td>
</tr>
<tr>
<td>$C_3$ (TEU)</td>
<td>381.3</td>
<td>137.1</td>
<td>710.2</td>
<td>30</td>
<td>946.59</td>
<td>125</td>
</tr>
<tr>
<td>$C_4$ (%)</td>
<td>18.7</td>
<td>28.62</td>
<td>19.36</td>
<td>45</td>
<td>22.05</td>
<td>18.66</td>
</tr>
<tr>
<td>$C_6$ (unit)</td>
<td>226</td>
<td>48</td>
<td>142</td>
<td>80</td>
<td>67</td>
<td>82</td>
</tr>
<tr>
<td>$C_7$ (unit)</td>
<td>74</td>
<td>30</td>
<td>71</td>
<td>42</td>
<td>48</td>
<td>39</td>
</tr>
<tr>
<td>$C_8$ (%)</td>
<td>3.27</td>
<td>6.25</td>
<td>5</td>
<td>5.25</td>
<td>7.16</td>
<td>4.76</td>
</tr>
<tr>
<td>$C_{10}$ (100 million yuan)</td>
<td>31746</td>
<td>9349</td>
<td>25607</td>
<td>12245</td>
<td>14969</td>
<td>12048</td>
</tr>
<tr>
<td>$C_{11}$ (100 million yuan)</td>
<td>3000</td>
<td>500</td>
<td>493</td>
<td>498</td>
<td>3400</td>
<td>2640</td>
</tr>
<tr>
<td>$C_{12}$ (10$^4$ square meters)</td>
<td>142</td>
<td>240</td>
<td>71</td>
<td>428</td>
<td>113.2</td>
<td>250.2</td>
</tr>
<tr>
<td>$C_{13}$ (unit)</td>
<td>1005</td>
<td>682</td>
<td>1184</td>
<td>428</td>
<td>752</td>
<td>482</td>
</tr>
</tbody>
</table>

where $C_1$: port’s cargo throughput, $C_2$: port’s cargo throughput growth rate, $C_3$: port’s container throughput, $C_4$: port’s container throughput growth rate, $C_5$: the ratio of container to cargo throughput, $C_6$: number of berths, $C_7$: number of 10,000 ton berths, $C_8$: the ratio of 10,000 ton berths to total number of berths, $C_9$: operating quay length, $C_{10}$: GDP of direct hinterland economic, $C_{11}$: GDP of indirect hinterland economic, $C_{12}$: square of storage yard, $C_{13}$: number of handling machinery.

Through the entropy method to obtain weight vector for every evaluation criterion as follows: $\hat{w} = [0.0339, 0.0320, 0.2193, 0.0569, 0.1350, 0.0810, 0.0267, 0.0182, 0.0516, 0.1739, 0.0524, 0.0458, 0.0732]^T$, and takes the weight vector of preference functions as $w = [0.2, 0.1, 0.2, 0.2, 0.2, 0.1]^T$. Leaving, entering and net flow values for different ports of Circum-Bohai-Sea are showed in Table 2.

<table>
<thead>
<tr>
<th>Ports</th>
<th>Leaving flow</th>
<th>Entering flow</th>
<th>Net flow</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_1$</td>
<td>Dalian</td>
<td>3.0013</td>
<td>1.0728</td>
<td>1.9285</td>
</tr>
<tr>
<td>$a_2$</td>
<td>Yingkou</td>
<td>0.9348</td>
<td>2.3755</td>
<td>-1.4407</td>
</tr>
<tr>
<td>$a_3$</td>
<td>Tianjin</td>
<td>3.1043</td>
<td>1.1249</td>
<td>1.9794</td>
</tr>
<tr>
<td>$a_4$</td>
<td>Qinhuangdao</td>
<td>0.7774</td>
<td>2.8039</td>
<td>-2.0265</td>
</tr>
<tr>
<td>$a_5$</td>
<td>Qingdao</td>
<td>3.6944</td>
<td>0.6307</td>
<td>3.0637</td>
</tr>
<tr>
<td>$a_6$</td>
<td>Yantai</td>
<td>1.4634</td>
<td>2.1743</td>
<td>-0.7109</td>
</tr>
<tr>
<td>$a_7$</td>
<td>Rizhao</td>
<td>0.4700</td>
<td>3.3900</td>
<td>-2.9200</td>
</tr>
</tbody>
</table>

So the ranking order of alternatives is $a_5 > a_1 > a_4 > a_6 > a_3 > a_4 > a_7$. The results are in accord with that presented in [11]. The example presented above showed that the improved PROMETHEE II method is suitable for dealing with the problems of ports management.
According to the table 1 and 2, the ports of Dalian, Tianjin and Qingdao are more competitive than others, because these have excellent natural conditions and geographical location, sufficient development financing and high throughput. On one hand, these seven ports, whose developments mainly depend on the 13 indicators mentioned above undoubtedly. On the other hand, the initial purposes of them are similar. As a result, simple function and waste of resources can hardly be avoided, which will hamper the promotion of competitiveness of the ports in Circum-Bohai-Sea area. Faced with the good development opportunity and the positive policy support, Circum-Bohai-Sea area still needs a perfect strategic plan, and a reasonable region development pattern, to guarantee the stable and fast development. Therefore, it is useful to do some research on the competitiveness of the formation of the ports in the Circum-Bohai-Sea area to discover the advantages and disadvantages of every port. All these will benefit the harmonious promotion of the ports in this area.

5. Conclusions

This paper proposes a evaluation model with multi-index attributes by using the improved PROMETHEE II method, in which multiple preference functions are used to establish the ensemble PROMETHEE II model to reduce the risk of choosing a particularly preference function. One example of evaluation of the Ports of Circum-Bohai-Sea is included to illustrate the method. The ‘Positive flow’, ‘Negative flow’ and ‘Net flow’ of each suggestion are calculated, and the ranking of those suggestions are established according to the value of the net flow. The ranking results show that the whole evaluating procedure is simple and clear, and the model has taken full advantage of information contained in the original data and the subjective information of experts by adjusting weights. Moreover, the proposed model is easy to be applied to the fields of the ports management.

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