Measuring Port Supply Chain Performance Using Fuzzy AHP

WANG Chuanxu
School of Economy and Management, Shanghai Maritime University, P.R.China, 200135

Abstract A port is a complex and multipart organization where institutions and functions often intersect at various level. It should be evaluated from the perspective of supply chain. Measuring the performance of a port supply chain inherently is a multi-criterion problem. In this paper, based on the supply chain operations reference model and previous developed measures, a useful framework for measuring the performance of a port supply chain is presented, and the method of fuzzy analytical hierarchical process (AHP) is applied to compare port supply chain performance.

Key Words Port evaluation, Supply chain performance, Fuzzy set, Analytic hierarchy process

1 Introduction

A port is a place where cargo is transshipped from one transportation mode to another, and it have historically been regarded as the node connecting maritime and inland transport. As the transport is an integral part of the entire supply chain, it is increasingly important to evaluate a port from the perspective of supply chain. A port supply chain consists of supply chain entities, related information and material flow across the supply chain, and logistics relevant to cargo export and import operations.

Measuring supply chain performance has received many attentions in academic literature. At present, the academic literature has been less focused on linking supply chain performance measurements to ports. Exception is Bichou and Gray (2004) who combine logistics and supply chain management approach with port performance, they present a relevant framework of port performance. This paper firstly presents a general framework for measuring the performance of a port supply chain. Since some information is incomplete or unobtainable, port supply chain is evaluated under uncertain environment. Based on the proposed framework, this paper then presents the method of fuzzy analytical hierarchical process (AHP) to compare the different port supply chain performance.

Fuzzy AHP method is a systematic approach to the multi-criteria analysis problem by using the concepts of fuzzy set theory and hierarchical structure analysis. Fuzzy AHP method is widely adopted by various authors and turn out to be the best method among various assessment methods. The fuzzy AHP method was first appeared in Van Laarhoven and Pedrycz (1983). Stam et al. (1996) propose a method based on artificial intelligence techniques to determine or approximate the preference ratings in AHP. Chang (1996) presents triangular fuzzy numbers for pairwise comparison scale and extent analysis method for the synthetic extent values of the pairwise comparison in handling fuzzy AHP.

2 Port supply chain performance

The business process in a port supply chain spans organizational boundaries, encompassing shippers (inbound logistics) or consignees (outbound logistics) and carriers. The basic services performed by a port consist of the services to ships (mooring, pilotage, bunkers, ship repair, etc) and services to cargo (handling, warehousing, consolidation, etc.). Thus, the goal of a port is to satisfy the shippers or consignees and carriers in the chain with greater effectiveness and efficiency than the competitors. The measurement of port supply chain performance needs to incorporate these performance aspects. It should not be focused only on individual functional areas, but rather on the different parties involved in the port supply chain. To this end, the supply chain operations reference model (SCOR) developed by the Supply Chain
Council (SCC) provides a useful framework that considers performance measurement on a supply chain wide basis. Based on SCOR model, three factors of port supply chain performance are defined as Service effectiveness for cargo, Service effectiveness for ships and Operations efficiency for port. These three factors are consistent with the main components for supply chain success considered in the SCOR model. According to SCOR, Service effectiveness for cargo and Service effectiveness for ships are customer-facing measures and concerned with the reliability and responsiveness of a port service to cargo and ships, whereas Operations efficiency for port is concerned with the efficient use of resources in performing services. Based on SCOR, Operations efficiency for port can be classified as cost-related and asset-related components. In agreement with Mentzer and Konrad (1991) [8] as well as Lai et al (2002) [9], the cost-related component is composed of five categories: handling, warehousing, costs related to the facilities and manpower in providing the services, documents processing, and logistics administration. The asset-related component is classified as three aspects: cash-to-cash cycle time, utilization of facilities and manpower used in providing the services, and asset turns. Based on Lai et al (2002) [9], a total of 26 measurements items are developed for the port supply chain measurement instrument:

Nine for service effectiveness for cargo
- Fulfill promise to shippers (or consignees) (C1), Solve shippers’ or consignees’ problem (C2), Performance services for shippers (or consignees) right the first time (C3), Provide services at the time promised to the shippers or consignees (C4), Keep shippers’ or consignees’ records accurately (C5), Tell shippers or consignees exactly when service will be performed (C6), Give prompt services to shippers or consignees (C7), Willingness to help shippers or consignees (C8), Timely response to shippers’ or consignees’ requests (C9)

Nine for service effectiveness for ships
- Fulfill promise to shipping companies (C10), Solve shipping companies’ problem (C11), Performance services for shipping companies right the first time (C12), Provide services at the time promised to the shipping companies (C13), Keep shipping companies’ records accurately (C14), Tell shipping companies exactly when service will be performed (C15), Give prompt services to shipping companies (C16), Willingness to help shipping companies (C17), Timely response to shipping companies’ requests (C18)

Eight for operations efficiency for port
- Reduce document management costs (C19), Reduce costs associated with facilities/equipment/manpower used in providing the services (C20), Reduce warehousing costs (C21), Reduce handling costs (C22), Reduce logistics administration costs (C23), Improve the rate of utilization of facilities/equipment/manpower in providing the services (C24), Improve number of cash to cash cycle time (C25), Improve net asset turns (working capital) (C26)

3 Fuzzy sets theory and the triangular fuzzy number

The fuzzy set theory was first introduced by Zadeh (1965) [10] and was oriented to the rationality of uncertainty due to imprecision or vagueness. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function, which assigns to each object a grade of membership ranging between zero and one. Let \( \tilde{S} \) be called a fuzzy set, the membership function for this fuzzy set is denoted by \( \mu(x|\tilde{S}) \). In this paper, triangular fuzzy numbers are used for a pairwise comparison scale of fuzzy AHP. A triangular fuzzy number \( \tilde{M} \) is denoted simply as \( (l, m, u) \). The parameters \( l \), \( m \) and \( u \) respectively stand for the lower value, the modal value and the upper value. Its membership function can be defined as:
\[ \mu(x|\tilde{M}) = \begin{cases} \frac{x-l}{m-l}, & x \in [l, m] \\ \frac{x-u}{m-u}, & x \in [m, u] \\ 0, & \text{otherwise} \end{cases} \]  

(1)

The degree of possibility of \( \tilde{M}_1 \geq \tilde{M}_2 \) is defined as 
\[ V(\tilde{M}_1 \geq \tilde{M}_2) = \sup_{x \geq y} \min\{\mu(x|\tilde{M}_1), \mu(y|\tilde{M}_2)\} \]  

(2)

When a pair \((x, y)\) exists such that \( x \geq y \) and \( \mu(x|\tilde{M}_1) = \mu(y|\tilde{M}_2) = 1 \), then we have 
\[ V(\tilde{M}_1 \geq \tilde{M}_2) = 1 \]  

Since \( \tilde{M}_1 \) and \( \tilde{M}_2 \) are convex fuzzy numbers we have that: 
\[ V(\tilde{M}_1 \geq \tilde{M}_2) = 1 \iff m_i \geq m_2, \quad V(\tilde{M}_1 \leq \tilde{M}_2) = \mu(\tilde{M}_1 \cap \tilde{M}_2) = \mu(d|\tilde{M}_1), \]  

(3)

where \( d \) is the ordinate of the highest intersection point D between \( \tilde{M}_1 \) and \( \tilde{M}_2 \).

When \( \tilde{M}_1 = (l_1, m_1, u_1) \) and \( \tilde{M}_2 = (l_2, m_2, u_2) \), the ordinate of D is given by equation (4)
\[ V(\tilde{M}_1 \geq \tilde{M}_2) = \mu(\tilde{M}_1 \cap \tilde{M}_2) = \frac{l_1 - m_1}{(m_2 - l_2) - (m_1 - l_1)}, \quad l_1 \leq u_1, \quad \text{others} \]  

(4)

4 The method of fuzzy AHP

Constructing a fuzzy judgement matrix

For some factors (criteria) of the \((k-1)\)th layer, there are altogether \( n \) related factors of the \( k \) layer.

When these \( n \) factors are made for pair-by-pair comparison, we denote comparison quantitatively with the triangular fuzzy number, and get the fuzzy judgement matrix \( A \).

One of the elements of \( A = (a_{ij})_{n \times n} \) can be denote as a triangular fuzzy number \( \tilde{a}_{ij} = [l_{ij}, m_{ij}, u_{ij}] \).

When T experts perform the pair-by-pair comparison, we denote the comparison given by the \( t \)th expert as \( \tilde{a}_{ij} = [l_{ij}^t, m_{ij}^t, u_{ij}^t] \), then \( \tilde{a}_{ij} \) can be obtained by taking the average value of all experts, i.e.
\[ \tilde{a}_{ij} = \frac{1}{T} \otimes \sum_{t=1}^{T} \tilde{a}_{ij}^t. \]

Calculating the value of fuzzy synthetic extent

According to the method of extent analysis, we obtain \( n \) extent analysis values for each factor of the \( k \)th layer. The value of fuzzy synthetic extent can be calculated as :
\[ S_i^k = \sum_{j=1}^{n} \tilde{a}_{ij}^k \otimes \left[ \sum_{i=1}^{n} \sum_{j=1}^{n} \tilde{a}_{ij}^k \right]^{-1} \quad i = 1, 2, \ldots, n \]

(5)

Layer simple sequencing

The degree of possibility for a convex fuzzy number to be greater than \( k \) convex fuzzy numbers \( \tilde{M}_i (i = 1, 2, \ldots, n) \) can be defined by
\[ V(\tilde{M} \geq \tilde{M}_1, \tilde{M}_2, \ldots, \tilde{M}_n) = \min_{1 \leq i \leq n} V(\tilde{M} \geq \tilde{M}_i), i = 1, 2, \ldots, n \]

(6)

Assume that \( d_h(A_j^k) = \min_{i \neq j} V(S_i^j \geq S_i^k) \), for \( j = 1, 2, \ldots, n, j \neq i \), where \( d_h(A_j^k) \) denotes the simple sequencing of \( i \)th factor of the \( k \)th the layer towards the \( h \) the factor of the \((k-1)\)th layer.
Then the sequencing weight vector is given by $W^k_h = (d^1_h(A_1), d^2_h(A_2),...,d^k_h(A_n))^T$, where $A_i (i = 1,2,...,n)$ are $n$ elements. Via normalization, we get the normalized sequencing weight vectors $W^k_h = (d^1_h(A_1), d^2_h(A_2),...,d^k_h(A_n))^T$, where $W^k_h$ is a non-fuzzy number.

Composite total sequencing

When $h = 1,2,...,m$, we get the matrix $(n \times m)$

$$w^i = (w^i_1, w^i_2,...,w^i_n)^T = 
\begin{bmatrix}
w_{11}^i & w_{12}^i & \cdots & w_{1n}^i \\
w_{21}^i & w_{22}^i & \cdots & w_{2n}^i \\
\vdots & \vdots & \ddots & \vdots \\
w_{ni}^i & w_{n2}^i & \cdots & w_{nn}^i
\end{bmatrix}$$

If the sequencing weight vector of the $(k-1)th$ layer factors towards the total goal is $R^{k-1} = (R^{k-1}_1, R^{k-1}_2,...,R^{k-1}_m)^T$, then the sequencing weight of the $kth$ layer towards the total goal is given by the formula

$$R^k = (R^k_1, R^k_2,...,R^k_n)^T = W^k R^{k-1}$$

or

$$R^k = \sum_{j=1}^{m} R^k_j W^k_j, \quad i = 1,2,...,n$$

where $R^2$ is the simple sequencing weight vector.

5 Application of fuzzy AHP in comparing port supply chain performance

A big foreign trade company needs to select a port for transship the cargo. The company should consider a lot of criteria to evaluate the three candidate ports from the perspective of supply chain. The number of the existing ports considered in the comparison is three. The criteria taken into account are the ones given in Section 2. There are three experts take part in the port supply chain evaluation.

The first step: Via pairwise comparison, the fuzzy judgment matrix is constructed (see Table 1). By taking the average value and applying formula (5), we get

$$S_{SE-Argo} = (0.181,0.255,0.364), \quad S_{SE-Ship} = (0.214,0.316,0.477), \quad S_{OE} = (0.296,0.429,0.607)$$

According to the formula (7) and (8), the simple sequencing of the three evaluation indexes towards the total goal is obtained as

$$R = (0.148,0.325,0.527)^T$$

The second step: The experts mark the result of the pairwise comparison of the measurement instruments with respect to three main factors. According to it, we obtain the combination of sequencing weights for the measurement instruments and ports (see Table 2—4)

The third step: The layer’s total sequencing (see table 5) is obtained by using the formula (9) combined with the data in Table 2—4. It can be shown from table 5 that port 2 is the port selected.

6 Conclusions

This paper aims at evaluating the port system from the perspective of supply chain management. Since some information is incomplete, port supply chain is evaluated under uncertain environment. In this case, the theory of fuzzy set can be more useful. Fuzzy AHP evaluation can overcome this difficulty. In this paper, Firstly, a general framework for measuring the performance of a port supply chain is presented with reference to SCOR, and then the performance of different port supply chain is compared using fuzzy AHP. At last, an example is given to illustrated the application of fuzzy AHP in comparing port supply chain performance. Future research will be focused on the applications of other methods in the port supply chain evaluation and the comparison analysis of different methods.
Acknowledgements
This paper is supported by National Natural Science Foundation of China under grant 70573068 and Shanghai Shuguang Program under grant 06SG48.

Table 1 The fuzzy judgment matrix made by three experts

<table>
<thead>
<tr>
<th></th>
<th>SE–Cargo</th>
<th>SE–Ship</th>
<th>OE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE–Cargo</td>
<td>(1,1,1)</td>
<td>(3/2,2,5/2)</td>
<td>(2/7,1/3,2/5)</td>
</tr>
<tr>
<td></td>
<td>(2/3,1,3/2)</td>
<td>(2/7,1/3,2/5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2/5,1/2,2/3)</td>
<td>2/5,1/2,2/3</td>
<td></td>
</tr>
<tr>
<td>SE–Ship</td>
<td>(2/3,1,3/2)</td>
<td>(1,1,1)</td>
<td>(2/5,1/2,2/3)</td>
</tr>
<tr>
<td></td>
<td>(2/5,1/2,2/3)</td>
<td>(2/3,2,5/2)</td>
<td></td>
</tr>
<tr>
<td>OE</td>
<td>(5/2,3,7/2)</td>
<td>(2/3,1,5/2)</td>
<td>(1,1,1)</td>
</tr>
<tr>
<td></td>
<td>(5/2,3,7/2)</td>
<td>(2/5,1/2,2/3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2/3,2,5/2)</td>
<td>(2/1,3,5/2)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Summary combination of sequencing weights: measurement instruments of SE-Cargo

<table>
<thead>
<tr>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>C9</th>
<th>Port sequencing weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Weight 0.179 0.144 0.151 0.122 0.093 0.068 0.141 0.033 0.069</td>
</tr>
<tr>
<td>Port 1</td>
<td>0.556</td>
<td>0.214</td>
<td>0.165</td>
<td>0.333</td>
<td>0.478</td>
<td>0.682</td>
<td>0.715</td>
<td>0.861</td>
<td>0.532 0.451</td>
</tr>
<tr>
<td>Port 2</td>
<td>0.320</td>
<td>0.358</td>
<td>0.421</td>
<td>0.156</td>
<td>0.258</td>
<td>0.237</td>
<td>0.113</td>
<td>0.004</td>
<td>0.242 0.264</td>
</tr>
<tr>
<td>Port 3</td>
<td>0.124</td>
<td>0.428</td>
<td>0.414</td>
<td>0.511</td>
<td>0.268</td>
<td>0.101</td>
<td>0.172</td>
<td>0.135</td>
<td>0.226 0.285</td>
</tr>
</tbody>
</table>

Table 3 Summary combination of sequencing weights: measurement instruments of SE-Ships

<table>
<thead>
<tr>
<th>C10</th>
<th>C11</th>
<th>C12</th>
<th>C13</th>
<th>C14</th>
<th>C15</th>
<th>C16</th>
<th>C17</th>
<th>C18</th>
<th>Port sequencing weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Weight 0.200 0.190 0.135 0.092 0.073 0.048 0.140 0.083 0.039</td>
</tr>
<tr>
<td>Port 1</td>
<td>0.436</td>
<td>0.217</td>
<td>0.234</td>
<td>0.246</td>
<td>0.543</td>
<td>0.240</td>
<td>0.435</td>
<td>0.417</td>
<td>0.450 0.347</td>
</tr>
<tr>
<td>Port 2</td>
<td>0.385</td>
<td>0.428</td>
<td>0.528</td>
<td>0.147</td>
<td>0.189</td>
<td>0.339</td>
<td>0.237</td>
<td>0.224</td>
<td>0.324 0.343</td>
</tr>
<tr>
<td>Port 3</td>
<td>0.179</td>
<td>0.325</td>
<td>0.238</td>
<td>0.607</td>
<td>0.268</td>
<td>0.421</td>
<td>0.328</td>
<td>0.359</td>
<td>0.226 0.310</td>
</tr>
</tbody>
</table>

Table 4 Summary combination of sequencing weights: measurement instruments of OE

<table>
<thead>
<tr>
<th>C19</th>
<th>C20</th>
<th>C21</th>
<th>C22</th>
<th>C23</th>
<th>C24</th>
<th>C25</th>
<th>C26</th>
<th>Port sequencing weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Weight 0.006 0.092 0.057 0.072 0.043 0.079</td>
</tr>
<tr>
<td>Port 1</td>
<td>0.364</td>
<td>0.203</td>
<td>0.255</td>
<td>0.238</td>
<td>0.446</td>
<td>0.257</td>
<td>0.339</td>
<td>0.216</td>
</tr>
<tr>
<td>Port 2</td>
<td>0.457</td>
<td>0.458</td>
<td>0.507</td>
<td>0.258</td>
<td>0.369</td>
<td>0.339</td>
<td>0.437</td>
<td>0.425</td>
</tr>
<tr>
<td>Port 3</td>
<td>0.179</td>
<td>0.339</td>
<td>0.238</td>
<td>0.504</td>
<td>0.185</td>
<td>0.404</td>
<td>0.224</td>
<td>0.359</td>
</tr>
</tbody>
</table>

Table 5 Summary combination of sequencing weights: main factors of the goal

<table>
<thead>
<tr>
<th>SE-Cargo</th>
<th>SE-Ships</th>
<th>OE</th>
<th>Port sequencing weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weight 0.148 0.325 0.527</td>
</tr>
<tr>
<td>Port 1</td>
<td>0.451</td>
<td>0.347</td>
<td>0.278 0.326</td>
</tr>
<tr>
<td>Port 2</td>
<td>0.264</td>
<td>0.343</td>
<td>0.416 0.370</td>
</tr>
<tr>
<td>Port 3</td>
<td>0.285</td>
<td>0.310</td>
<td>0.306 0.304</td>
</tr>
</tbody>
</table>

References

