Decision making on an optimal port choice under z-information

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Abstract

The decision of shipping lines as to which port to use is a strategic one, and it is one of the most crucial factors to influence the operational and business performance of the organizations. The existing decision theories are not sufficiently adequate to account for imprecision and partial reliability of decision-relevant information in real-world problems. Prof. Zadeh suggested the concept of a Z-number which is able to formalize imprecision and partial reliability of information. In this article, we consider a hierarchical multiattribute decision problem of an optimal port choice under Z-number-based information. The solution of the problem is based on the use of Z-number-valued weighted average aggregation operator. The obtained results show validity of the suggested approach.

Keywords: discrete Z-number, port choice, expert opinion, partial reliability

1. Introduction

Port selection decisions of shippers are crucial for policy formulation in ports and shipping lines\textsuperscript{1}. Researches use a discrete choice model where each shipper faces a choice of 14 alternatives based on shipping line and port combinations, and makes his decision on the basis of various shipper and port characteristics. The results show that the distance of the shipper from port, distance to destination, port congestion and shipping line’s the play an important role.

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Providers of port infrastructure and services are interested in finding out critical port choice factors as rational basis for formulating sustainable port reform policy. In Ref. 2, questionnaires were distributed to collect data on observed port choice made by shippers under study. A discrete choice model was applied to estimate the shipper’s port utility function. Policy implications of the estimated utility function are discussed.

In Ref. 3 fuzzy analytic network process and extended fuzzy VIKOR methodologies are used for solving the problem of cruise port place selection in Istanbul. Comparison of the obtained results is provided.

Analysis proposed in Ref. 4 is based on a survey conducted among major shipping lines operating in Singapore and Malaysia. The results show that port charges and wide range of port services are the only significant factors in port choice. However, the results show no consistency between the stated and revealed preferences of shipping lines.

In Ref. 5 appraisal of the container terminals or ports is implemented by using a fuzzy multicriteria decision making method. This model is illustrated with a numerical example.

In Ref. 6 five port intangible resources were identified. A survey questionnaire was sent to 21 experts. It was found that customer and relational resource contributes most to the delivery of port service quality. The port of Hong Kong appeared to be the port where intangible resources were most highly evaluated. This research helps to enrich the literature on port service quality and port choice evaluation.

In Ref. 7 they identify the factors affecting shipping companies’ port choice based on a survey to a sample of shipping companies. Six factors were considered: local cargo volume; terminal handling charge; berth availability; port location; transshipment volume and feeder network. Exploratory factor and confirmatory factor analyses identified five port choice categories, i.e. advancement/convenience of port; physical/operational ability of port; operational condition of shipping lines; marketability; and port charge. Moreover, the main haul shipping lines are more sensitive to port cost factors.

The studies investigating the port selection process had one thing in common: they analyze the declared preferences of the port agents. In Ref. 8 it is suggested to study the port choice through revealed port selection instead of asking port stakeholders about the main factors in port selection.

In Ref. 9 they identified factors that affect port selection. They consider three ports: Antwerp, Rotterdam and Hamburg and three types of decision makers: shippers, carriers and freight forwarders. Also, it is discussed how port policymakers must continuously make an effort to understand what factors influence port users’ port choice. The Analytical Hierarchy Process method was applied. The results show the following ranking of port selection criteria in decreasing order of importance: port costs, geographical location, quality of hinterland connections, productivity and capacity. Of the three ports studied, Antwerp was found to be the most attractive, followed by Rotterdam and then Hamburg.

Several authors have been invested decision making by use of fuzzy approach 10.-15. However, it is needed to mention that a port selection problem, as a real-world problem, is characterized by imprecise and partially reliable information. Unfortunately, this is not taken into account in the existing studies. In order to deal with imprecise and partially reliable information, Prof. Zadeh suggested the concept of a Z-number. A Z-number, is a pair of fuzzy numbers $Z=(A,B)$, where $A$ is a soft constraint on a value of a variable of interest, and $B$ is a soft constraint on a value of a probability measure of $A$, playing a role of reliability of $A$. In this paper we consider multattribute decision making on port selection under Z-number-valued information. All the criteria evaluations and criteria importance weights are described by Z-numbers.

The remainder of this paper is organized as follows. Section 2 introduces preliminary information such as operations over Z-numbers which are used in the sequel. In Section 4, an application of decision making on port selection under imprecise and partially reliable information is considered. The problem is solved by using aggregation of Z-number valued information on the basis of operations over Z-numbers. Section 5 the concludes the paper.

2. Preliminaries

Definition. A discrete Z-number 13,14,16. A discrete Z-number is an ordered pair $Z=(A,B)$ where $A$ is a discrete fuzzy number playing a role of a fuzzy constraint on values of a random variable $X : X is A$. $B$ is a discrete fuzzy number with a membership function $\mu_B : \{b_1, b_n\} \rightarrow [0,1]$, playing a role of a fuzzy constraint on the probability measure of $A : P(A) = \sum_{i=1}^n \mu_A(x_i)p(x_i)$ is $B$. 

Operations over Discrete Z-numbers: Let $X_1$ and $Z_2 = (A_2, B_2)$ be discrete Z-numbers describing information about values of $X_1$ and $X_2$. Consider computation of $Z_{12} = Z_1 * Z_2$, $* \in \{+, -, \cdot, /\}$. The first stage is computation of $A_{12} = A_1 * A_2$.

The second stage involves construction of $B_{12}$. We realize that in Z-numbers $Z_1$ and $Z_2$, the ‘true’ probability distributions $p_1$ and $p_2$ are not exactly known. In contrast, fuzzy restrictions represented in terms of the membership functions are available

$$
\mu_{p_1}(p_1) = \mu_{\tilde{A}_1} \left( \sum_{i=1}^{n} \mu_{A_1}(x_{1i}) p_1(x_{1i}) \right), \quad \mu_{p_2}(p_2) = \mu_{\tilde{A}_2} \left( \sum_{i=1}^{n} \mu_{A_2}(x_{2i}) p_2(x_{2i}) \right).
$$

Probability distributions $p_j(x_j), k = 1, \ldots, n$ induce probabilistic uncertainty over $X_{12} = X_1 + X_2$. Given any possible pair $p_{12} = p_{12} \circ p_{22}$, the convolution $p_{12s} = p_{12} \circ p_{2l}$ is computed as

$$
p_{12s}(x) = \sum_{x_1 + x_2 = x} p_{1l}(x_1) p_{2k}(x_2), \forall x \in X_{12}; x_1 \in X_1, x_2 \in X_2.
$$

Given $p_{12s}$, the value of probability measure of $A_{12}$ is computed: $P(A_{12}) = \sum_{k=1}^{n} \mu_{A_{12}}(x_{12k}) p_{12s}(x_{12k})$.

However, $p_{1l}$ and $p_{2j}$ are described by fuzzy restrictions which induce fuzzy set of convolutions:

$$
\mu_{p_{12}}(p_{12}) = \max\{\mu_{p_{12}}(p_{12})\} \min\{\mu_{p_1}(p_1), \mu_{p_2}(p_2)\} \quad \text{(1)}
$$

Fuzziness of information on $p_{12s}$ induces fuzziness of $P(A_{12})$ as a discrete fuzzy number $B_{12}$. The membership function $\mu_{B_{12}}$ is defined as

$$
\mu_{B_{12}}(b_{12}) = \sup(\mu_{p_{12s}}(p_{12})) \quad \text{(2)}
$$

subject to

$$
b_{12s} = \sum_{k} p_{12s}(x_k) \mu_{A_{12}}(x_k) \quad \text{(3)}
$$

As a result, $Z_{12} = Z_1 * Z_2$ is obtained as $Z_{12} = (A_{12}, B_{12})$.

A scalar multiplication $Z = \lambda Z_1, \lambda \in R$ is a determined as $Z = (\lambda A_1, B_1)$.

Ranking of Discrete Z-numbers. According to R. Aliev’s approach, Z-numbers are ordered pairs, for ranking of which there can be no unique approach. For purpose of comparison, the author suggests to consider a Z-number as a pair of values of two attributes – “one attribute measures value of a variable, the other one measures the associated reliability”. Then it will be adequate to compare Z-numbers as multiattribute alternatives. Basic principle of comparison of multi-attribute multi-criteria alternatives in this case is the Fuzzy Pareto optimality principle.

3. Decision Making on Port Selection under Z-number-valued Information

The literature review reveals a considerable range of factors that have an influence on the decision of port choice studies. The key influencing factors for port selection are identified in Refs. 17-21. After carefully examining the relevant literature, selected experts have determined the all possible evaluation criteria prior to port choice selection (Table 1). Each criterion and sub-criterion also has its importance weight.

<table>
<thead>
<tr>
<th>Criteria &amp; Sub-criteria</th>
<th>C1: HINTERLAND CONDITION</th>
<th>C2: PORT SERVICES</th>
<th>C3: LOGISTICS COST</th>
<th>C4: CONNECTIVITY</th>
</tr>
</thead>
</table>

Table 1 : Evaluation criteria
1. Professionals and skilled labors in port operation
2. Size and activity of FTZ in port hinterland
3. Volume of total container cargo

C5: CONVENIENCE
1. Water depth in approach channel and at berth
2. Sophistication level of port information & its application scope
3. Stability of Port’s labour

C6: AVAILABILITY
1. Availability of vessel berth on arrival in port
2. Port Congestion

C7: REGIONAL CENTER
1. Port Accessibility
2. Deviation from main trunk routes

Thus, we have seven criteria $C_j$, $j = 1,\ldots,7$: hinterland condition, $C_1$, port services, $C_2$, logistics cost, $C_3$, connectivity, $C_4$, convenience, $C_5$, availability, $C_6$, regional center, $C_7$. Suppose that a decision maker should choose the best port by using the criteria and sub-criteria given in Table 1. The considered alternatives are: port of Busan, port of Tokyo, port of Hong Kong, port of Qingdao, port of Shanghai, port of Kaohsiung, port of Shenzhen. Decision relevant information in the considered problems is characterized by imprecision and partial reliability. In view of this, criteria evaluations and importance weights are expressed by Z-numbers.

Table 2. The encoded linguistic terms for A components of Z-numbers

<table>
<thead>
<tr>
<th>Scale</th>
<th>Level</th>
<th>Linguistic value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Very Low</td>
<td>{0, 1, 1, 0}</td>
</tr>
<tr>
<td>2.</td>
<td>Low</td>
<td>{0, 1, 2, 3}</td>
</tr>
<tr>
<td>3.</td>
<td>Medium</td>
<td>{0, 1, 2, 3}</td>
</tr>
<tr>
<td>4.</td>
<td>High</td>
<td>{0, 1, 4, 5}</td>
</tr>
<tr>
<td>5.</td>
<td>Very High</td>
<td>{0, 1, 5, 5}</td>
</tr>
</tbody>
</table>

Table 3. The encoded linguistic terms for B components of Z-numbers

<table>
<thead>
<tr>
<th>Scale</th>
<th>Level</th>
<th>Linguistic value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Unlikely</td>
<td>{0, 0.05, 0.25}</td>
</tr>
<tr>
<td>2.</td>
<td>Not very likely</td>
<td>{0, 0.25, 0.5}</td>
</tr>
<tr>
<td>3.</td>
<td>Likely</td>
<td>{0, 0.5, 0.75}</td>
</tr>
<tr>
<td>4.</td>
<td>Very likely</td>
<td>{0, 0.75, 1}</td>
</tr>
<tr>
<td>5.</td>
<td>Extremely likely</td>
<td>{0, 1, 1}</td>
</tr>
</tbody>
</table>

Let us solve the considered problem of choosing the best alternative. At first we should compute overall evaluation of each port. Below we provide computation for the port of Hong Kong, computation for the other ports is analogous.

Step 1. Compute the Z-valued criteria evaluations $Z_{ij}$ for $i$-th alternative, $i = 1,\ldots,7$, with respect to $j$-th criterion, $j = 1,\ldots,7$, by using weighted average-based aggregation of the corresponding sub-criteria evaluations.
The weighted average is based on operations over Z-numbers which are given in Section 2 and is expressed as follows:

\[
Z_{\text{avg}} = \frac{\sum_{k=1}^{K_j} Z_{x_{jk}} \cdot Z_{w_{jk}}}{\sum_{k=1}^{K_j} Z_{w_{jk}}},
\]

where \( Z_{x_{jk}} \) is a Z-number-valued evaluation of \( i \)-th alternative with respect to \( k \)-th sub-criterion of \( j \)-th criterion, \( Z_{w_{jk}} \) is a Z-number-valued importance weight of \( k \)-th sub-criterion of \( j \)-th criterion. The obtained results for the port of Hong Kong are as follows.

\[
\begin{align*}
Z_{31} &= \frac{\sum_{k=1}^{3} Z_{x_{31k}} \cdot Z_{w_{31k}}}{\sum_{k=1}^{3} Z_{w_{31k}}} = \frac{(M, EL) \cdot (H, EL) + (H, L) \cdot (H, VL) + (VH, EL) \cdot (H, EL)}{(H, EL) + (H, VL) + (H, EL)} = \\
&= (1.7 \ 4 \ 8)(0.52 \ 0.57 \ 0.93));
\end{align*}
\]

\[
\begin{align*}
Z_{32} &= \frac{\sum_{k=1}^{3} Z_{x_{32k}} \cdot Z_{w_{32k}}}{\sum_{k=1}^{3} Z_{w_{32k}}} = \frac{(VH, VL) \cdot (M, L) + (VH, EL) \cdot (VH, L) + (VH, VL) \cdot (H, VL)}{(M, L) + (VH, L) + (H, VL)} = \\
&= (2.2 \ 5 \ 8.5)(0.96 \ 0.99 \ 1));
\end{align*}
\]

\[
\begin{align*}
Z_{33} &= \frac{\sum_{k=1}^{3} Z_{x_{33k}} \cdot Z_{w_{33k}}}{\sum_{k=1}^{3} Z_{w_{33k}}} = \frac{(L, L) \cdot (M, L) + (M, NVL) \cdot (H, VL) + (L, L) \cdot (H, L)}{(M, L) + (VH, L) + (H, L)} = \\
&= (0.7 \ 2.4 \ 6)(0.5 \ 0.7 \ 0.8));
\end{align*}
\]

\[
\begin{align*}
Z_{34} &= \frac{\sum_{k=1}^{3} Z_{x_{34k}} \cdot Z_{w_{34k}}}{\sum_{k=1}^{3} Z_{w_{34k}}} = \frac{(M, NVL) \cdot (M, L) + (L, L) \cdot (M, L)}{(M, L) + (M, L)} = ((0.5 \ 2.5 \ 7.6)(0.4 \ 0.6 \ 0.7));
\end{align*}
\]

\[
\begin{align*}
Z_{35} &= \frac{\sum_{k=1}^{3} Z_{x_{35k}} \cdot Z_{w_{35k}}}{\sum_{k=1}^{3} Z_{w_{35k}}} = \frac{(VH, VL) \cdot (H, EL) + (H, L) \cdot (M, VL) + (M, VL) \cdot (H, VL)}{(H, EL) + (M, VL) + (H, VL)} = \\
&= (1.44 \ 4 \ 8.48)(0.65 \ 0.71 \ 0.72));
\end{align*}
\]

\[
\begin{align*}
Z_{36} &= \frac{\sum_{k=1}^{3} Z_{x_{36k}} \cdot Z_{w_{36k}}}{\sum_{k=1}^{3} Z_{w_{36k}}} = \frac{(H, EL) \cdot (VH, EL) + (VH, EL) \cdot (VH, VL)}{(VH, EL) + (VH, VL)} = ((2.36 \ 4.5 \ 6.23)(0.94 \ 0.98 \ 0.99));
\end{align*}
\]

\[
\begin{align*}
Z_{37} &= \frac{\sum_{k=1}^{3} Z_{x_{37k}} \cdot Z_{w_{37k}}}{\sum_{k=1}^{3} Z_{w_{37k}}} = \frac{(M, L) \cdot (M, L) + (L, L) \cdot (L, L)}{(M, L) + (L, L)} = ((0.45 \ 2.6 \ 11.6)(0.44 \ 0.77 \ 0.8)).
\end{align*}
\]
Step 2. Compute the overall port evaluation $Z_y$ as the weighted average-based aggregation of the criteria evaluations $Z_{yj}, j = 1, \ldots, 7$ obtained at Step 1:

$$Z_y = \frac{\sum_{j=1}^{7} Z_{yj} \cdot Z_{wj}}{\sum_{j=1}^{7} Z_{wj}} = ((0.89 \ 3.9 \ 9.5)(0.85 \ 0.98 \ 0.99)).$$

Analogously we computed the overall port evaluations $Z_y$ for all the other ports:

- $Z_{yBusan} = \begin{pmatrix} 0.8 & 3.5 & 10.7 \\ 0.5 & 0.7 & 0.8 \end{pmatrix}$;
- $Z_{yShanghai} = \begin{pmatrix} 0.5 & 3.32 & 12.9 \\ 0.48 & 0.81 & 0.82 \end{pmatrix}$;
- $Z_{yKaohsiung} = \begin{pmatrix} 0.62 & 2.98 & 10.3 \\ 0.48 & 0.7 & 0.72 \end{pmatrix}$;
- $Z_{yQingdao} = \begin{pmatrix} 0.7 & 3.5 & 13.4 \\ 0.66 & 0.96 & 0.97 \end{pmatrix}$;
- $Z_{yShenzhen} = \begin{pmatrix} 0.71 & 3.54 & 13.6 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$;
- $Z_{yTokyo} = \begin{pmatrix} 0.48 & 3.10 \\ 0.48 & 0.7 & 0.8 \end{pmatrix}$.

Step 3. Rank the obtained overall evaluations of the all seven ports. For this purpose we use the approach proposed in Ref. 13 and is given in Section 2. The obtained results are given below:

- Port Hong-Kong vs. Port of Busan:
  $do(Z_{yHK}^{Busan}) = 1$, $do(Z_{yBusan}) = 0.08$;
- Port Hong-Kong vs. Port of Qingdao:
  $do(Z_{yHK}^{Qingdao}) = 1$, $do(Z_{yQingdao}) = 0.91$;
- Port Hong-Kong vs. Port of Tokyo:
  $do(Z_{yHK}^{Tokyo}) = 1$, $do(Z_{yTokyo}) = 0$;
- Port Hong-Kong vs. Port of Shanghai:
  $do(Z_{yHK}^{Shanghai}) = 1$, $do(Z_{yShanghai}) = 0.26$;
- Port Hong-Kong vs. Port of Kaohsiung:
  $do(Z_{yHK}^{Kaohsiung}) = 1$, $do(Z_{yKaohsiung}) = 0$;
- Port Hong-Kong vs. Port of Shenzhen:
  $do(Z_{yHK}^{Shenzhen}) = 1$, $do(Z_{yShenzhen}) = 0.23$.

Thus, the port of Hong-Kong is the best port.

4. Conclusion

In this study we consider application of Z-number valued information processing to hierarchical multiattribute decision making on port selection under imprecise and partially reliable information. As a decision rule, the Z-valued weighted arithmetic mean based on operations over Z-numbers is used. For determination of the best port, a
fuzzy Pareto optimality principle based procedure for ranking of Z-numbers is applied. The results show validity of the proposed study on an optimal port choice by using Z-number valued information processing.

References