A Fuzzy Screening System for Effectively Solving Maritime Shipping Problems

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ABSTRACT. This paper presents a fuzzy screening system for effectively solving maritime shipping problems. The inherent subjectiveness and imprecision of the evaluation process is modeled by using linguistic terms characterized by triangular fuzzy numbers. A new algorithm based on the concept of the positive and negative ideal solutions is developed to avoid the complex and unreliable process of comparing fuzzy numbers usually required in fuzzy multicriteria decision making. An expert system is proposed to facilitate the evaluation and selection process. A maritime shipping problem is presented to demonstrate the effectiveness of the approach.

KEYWORDS. Uncertainty; Decision making; Screening; Expert system; Maritime shipping.

1. INTRODUCTION

With the increasing globalization and the rapid growth in international trade, maritime shipping becomes increasingly important to all the organizations involved in international trade. To improve the performance and competitiveness of these organizations, evaluating and selecting a suitable ship for a specific requirement has become one of the most critical issues faced by organizations in the maritime shipping industry (Balmat et al., 2009).

To effectively evaluate and select the suitability of available ships is complex. The complexity of the evaluation process is due to (a) the large number of alternatives available, (b) the presence of multiple evaluation criteria, (c) the existence of subjectiveness and uncertainty involved in the human decision making process, and (d) the limited information processing capabilities of the decision maker (DM). To adequately solve the problem of evaluating the suitability of individual ships, a structured approach capable of systematically evaluating each ship available across all the evaluation criteria is necessary.

A common approach to deal with this type of evaluation and selection problem is to allow the DM to allocate scores on all alternatives and selection criteria, and then generate an overall performance index based on the utility theory using the subjective scores above for each alternative across all criteria (Deng, 2005). The use of this approach, however, requires considerable information from the DM and therefore is found to be time consuming and expensive. As a result, a screening approach that is capable of reducing the complexity of the decision problem and the effort required from the DM in identifying a preferred decision outcome is desirable.

Screening refers to the process of identifying potentially important alternatives by eliminating those of probably lesser significance (Hobbs and Meier, 2000). Based on the screening approach, the DM is able effectively reduce a large number of alternatives to a smaller number of alternatives in a timely manner (Valls et al, 2009). Therefore, the application of such an approach would greatly reduce the difficulty and the complexity of solving the maritime shipping evaluation and selection problem.

Much research has been done on the development and application of screening approaches for solving various decision problems (Lootsma et al, 1986; Hobbs and Meier, 2000; Mussati et al, 2008; Valls et al, 2009). Lootsma et al (1986), for example, apply the lexicographic based approach for selecting research and development projects. Their approach compares alternatives based on their most important criterion and the one with the highest value on that criterion is selected. The advantage of this approach is that the criterion importance to the selecting parties can be made without defining that criterion quantitatively. Hobbs and Meier (2000) apply the pareto-comparison based approach for analyzing the impacts of energy and environmental policies. This approach is used to identify a range of strategies with corresponding costs by comparing alternatives and discarding the less dominant one (Staschus et al, 1991). This approach does not require the quantification of values for alternatives to be considered in the process. Valls et al (2009) apply the conjunctive based approach for measuring the risk of contamination. Based on this approach, the alternatives are classified into four ordered categories for measuring the global risk of contamination, based on a condition that all criteria of the alternatives have a minimum acceptable threshold level. An alternative that does not meet the minimal acceptable level for all criteria is rejected. The advantage of this approach is that the criteria and the threshold level do not need to be measured in commensurate units. Mussati et al (2008) propose the disjunctive based approach for analyzing the impact of combined cycle power and desalination plant. Using this approach, the optimal unit configuration and operating conditions are taken into consideration and an alternative is acceptable if any one criterion of the alternatives meets the acceptable threshold level defined by the DM.

These approaches however are not totally satisfactory. They often suffer from (a) the inability to tackle the subjectiveness and imprecision of the selection process, (b) the failure to adequately handle the multi-dimensional nature of the problem, (c) cognitively very demanding on the DM, and (d) the lack of flexibility to accommodate the various needs of the DM.

To effectively address the problem described as above, this paper presents a fuzzy screening system for effectively solving the maritime shipping evaluation and selection problem. A fuzzy screening approach is developed for screening the most suitable alternative across all the evaluation criteria. An expert system is proposed for facilitating the evaluation and selection process in an effective and efficient manner. An example is presented to demonstrate the applicability of the proposed fuzzy screening system for solving the maritime shipping problem.

In what follows, we first present a fuzzy screening approach for solving the maritime shipping problem. We then present an example to demonstrate the applicability of the proposed fuzzy screening system for solving a real maritime shipping problem.

2. THE FUZZY SCREENING APPROACH

Evaluating and selecting available ships is always complex and challenging due to (a) the large number of alternatives available for selection, (b) the multi-dimensional nature of the selection process, (c) the presence of subjectiveness and uncertainty involved in the decision making process, and (d) the limited information processing capabilities on the DM. Modeled as a multicriteria decision making problem, the evaluation and selection of ships usually involves in (a) discovering all the ships, (b) identifying the selection criteria, (c) assessing the ships' performance ratings and the criteria weights, and (d) selecting the best ship in the given situation (Deng, 2005). To model the subjectiveness and imprecision in ship evaluation and selection, fuzzy numbers denoted as (a_1, a_2, a_3) where $a_1 < a_2 < a_3$ are used to represent the subjective assessment of the DM.

The proposed algorithm starts with the determination of the performance of each ship A_i ($i = 1, 2, \ldots, n$) with respect to each criterion C_j ($j = 1, 2, \ldots, m$). As a result, a decision matrix for all the alternative ships can be obtained as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \quad (1)$$

The relative importance W ($j = 1, 2, \ldots, m$) of the selection criteria C_j can be assessed qualitatively using fuzzy numbers, given as

$$W = (w_1, w_2, ..., w_j, ..., w_m) \quad (2)$$

The weighted fuzzy performance matrix that represents the overall performance of each alternative on each criterion can be determined by multiplying the fuzzy criteria weights (w_j) by the alternatives' fuzzy performance ratings (x_{ij}) as

$$Z = \begin{bmatrix} w_1 x_{11} & w_2 x_{12} & \cdots & w_m x_{1m} \\ w_1 x_{21} & w_2 x_{22} & \cdots & w_m x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ w_1 x_{n1} & w_2 x_{n2} & \cdots & w_m x_{nm} \end{bmatrix} \quad (3)$$

To avoid the complex process of comparing fuzzy utilities, the area center method is applied. This method is based on the geometric center of a fuzzy number for evaluating the fuzzy decision alternatives (Chen and Hwang, 1992). Given the fuzzy vector ($w_j x_{1j}$, $w_j x_{2j}$, …, $w_j x_{mj}$) of the weighted fuzzy performance matrix for the criterion C_j in (3), the fuzzy performance rating among all the alternatives with respect to the criterion C_j can be defuzzified as

$$r_{ij} = \frac{\int x \mu_{w_j x_{ij}}(x)dx}{\int \mu_{w_j x_{ij}}(x)dx} \quad (4)$$

To determine the most preferred ship of all the alternative ships, the concept of the positive and negative ideal solutions is used. The positive (or negative) ideal solution consists of the best (or worst) values attainable from all the ships (Hwang and Yoon, 1981; Yeh et al., 2000). The most preferred ship should not only have the shortest distance from the positive ideal solution, but also have the longest distance from the negative ideal solution (Deng, 2005). Based on the concept of the ideal solution, the positive ideal solution A^+ and the negative ideal solution A^- can be determined as

$$A^+ = (a_1^+, a_2^+, ..., a_m^+), \quad A^- = (a_1^-, a_2^-, ..., a_m^-), \quad (5)$$

where $a_j^+ = \sup(r_{1j}, r_{2j}, ..., r_{nj}), \quad a_j^- = \inf(r_{1j}, r_{2j}, ..., r_{nj}),$ (6)

From (5) - (6), the Euclidean distance method can be applied to aggregate the distances between A_i and A^+, and between A_i and A^-, respectively as

$$S_i^+ = \left[\sum_{j=1}^{m} (h_{ij}^+)^2 \right]^{1/2}, \qquad S_i^- = \left[\sum_{j=1}^{m} (h_{ij}^-)^2 \right]^{1/2}, \quad (7)$$

where $h_{ij}^+ = (a_j^+ - r_{ij}), \quad h_{ij}^- = (r_{ij} - a_j^-), \quad i = 1,2,...,n, \quad j = 1,2,...,m.$ (8)

To reduce the number of alternatives that do not meet the requirements of the DM in the evaluation and selection process, the concept based on a screening index χ is introduced. This screening index is used to identify whether the performance of each alternative is of an acceptable level to the specified screening threshold pre-determined by the DM. This is done by comparing the calculated value of an individual alternative to the screening threshold value. The screening index in regards to the performance ratings and the criteria weights for all available ships across the criteria can be defined as

$$\chi \geq (S_i^+), \quad \text{or} \quad \chi \leq (S_i^-) \quad (9)$$

The alternative ship is suitable for selection if it meets the requirement of the DM as shown in (9). If the distance S_i^+ of a ship A_i is higher than the screening threshold value or if the distance S_i^- of a ship A_i is lower than the screening threshold value, the alternative ship is found to be unacceptable and rejected for selection. This process helps to reduce the number of alternatives that do not meet the requirements of the DM in an effective manner.

The procedure for screening alternatives using the fuzzy screening procedure is summarized as

Step 1. Obtain the decision matrix as expressed in (1).
Step 2. Determine the weighting vector for the criteria as expressed in (2).
Step 3. Calculate the weighted fuzzy performance matrix as expressed in (3) by multiplying (1) and (2).
Step 4. Defuzzify the weighted fuzzy performance matrix by (4).
Step 5. Determine the positive ideal solution and the negative ideal solution by (5) and (6).
Step 6. Calculate the distances between A_i and A^+, and between A_i and A^- by (7) and (8).
Step 7. Obtain the screening index for individual alternatives as expressed in (9).
Step 8. Obtain the screening threshold value from the DM.
Step 9. Compare the screening index value of individual alternatives with the pre-determined screening threshold value.

To help the DM solve the maritime shipping evaluation and selection problem in a user-friendly manner, we propose an expert system. Through interaction, the system helps the DM adopt a problem-oriented approach for solving the maritime shipping decision problem effectively and efficiently (Deng and Wibowo, 2008).

This proposed expert system consists of six modules, namely, (a) knowledge base module, (b) working memory module, (c) inference engine module, (d) user interface module, (e) knowledge acquisition module, and (f) explanation module. The knowledge base stores the domain knowledge and experience acquired from human experts for the particular area of expertise. These knowledge and experience are represented in the form of IF-THEN rules. The working memory module stores the input data and the information generated through the processing of rules. The inference engine module performs the function of reasoning mechanism. The user interface module serves to integrate various other modules as well as to be responsible for user friendly communications between the expert system and the DM. The knowledge acquisition module provides the DM with appropriate tools useful during knowledge acquisition procedures, and finally the explanation module that allows the system to present its reasoning regarding its conclusions. The explanation module is to enable the system display the motivation for all of its actions and conclusions to the DM.

The application of the proposed expert system consists of five phases, including: (a) identification of the DM's goals and requirements, (b) construction of fuzzy rules, (c) determination of the performance ratings of alternatives and criteria weights, (d) the utilization of the fuzzy screening process, and (e) selection of the most appropriate alternative as shown in Figure 1.

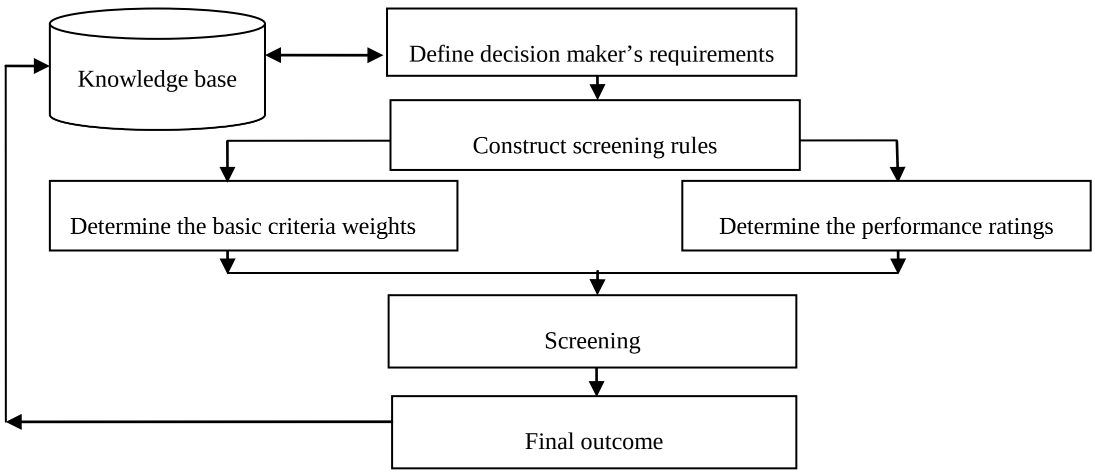

Figure 1. The expert system framework for maritime shipping evaluation and selection

The first phase starts with the collection and compilation of a list of requirements, evaluation criteria, available alternatives, and the screening threshold value from the DM. The next phase continues with the construction of fuzzy rules. The third phase involves the determination of the performance ratings of alternatives with respect to each criterion and criteria weights. In practical applications, all the assessments with respect to criteria importance and alternative performance are not always fuzzy. Both crisp and fuzzy data are often present simultaneously in a specific problem (Deng, 2005). Each performance ratings of alternative can be assigned as crisp numbers or linguistic terms depending on the preference of the DM. To maintain the effectiveness of data evaluated, crisp numbers in the range of 1 to 9 can be used to represent the DM's quantitative assessments. This is followed by the fuzzy screening phase whereby the system evaluates the suitability of available ships with respect to each criterion against pre-determined screening threshold value, and eliminates the alternatives that do not meet the requirements in an effective manner. In the final phase, the most suitable alternative that fulfils the requirements of the DM will then be recommended to the DM. This leads to effective decisions being made based on the recommendation by the system (Deng and Wibowo, 2008).

3. AN EXAMPLE

To demonstrate the applicability of the proposed approach above, a problem of evaluating and selecting a suitable ship for a shipping company is presented. The maritime shipping selection starts with the formation of a project team involving three DMs for selecting among six alternatives. A Delphi process is used to determine a set of selection criteria which meet the requirements of the selection problem. The process helps prioritize the criteria and reaches a consensus about the important criteria for evaluating and selecting the available ships. As a result of the process, four evaluation areas in relation to the requirements of the problem are identified, including ship characteristics (C_1), route characteristics (C_2), and cargo characteristics (C_3) (Balmat et al., 2009).

The ship characteristics (C_1) reflect on the subjective assessment of the DM regarding features and specifications of the available ships. This is assessed by the length of the ship (C_{11}), the width of the ship (C_{12}), and the year of construction (C_{13}). The route characteristics (C_2) reflect the DM's subjective assessments regarding the destination of travel that the ship is undertaking to deliver the cargo. This is measured by the traffic condition and traffic density (C_{21}), the port of call (C_{22}), and the likelihood of piracy (C_{23}). The cargo characteristics (C_3) are used to reflect the DM's concerns on the type of cargo to be transported by the ship. This is measured by the level of corrosiveness (C_{31}), the level of toxicity (C_{32}), and the level of flammability (C_{33}) of the cargo.

The selection process starts with the system instructing the DM to enter the set of alternatives, evaluation criteria, and the screening threshold value to be used for the maritime shipping evaluation and selection problem. The performance ratings and criteria weights for selecting the suitable ship are obtained directly from the DM to reflect on his/her subjective assessments and they are shown in Table 1.

Table 1. Linguistic terms for assessing performance ratings and criteria weights of alternative ships

Criteria	Alternatives						Criteria weights
	A_1	A_2	A_3	A_4	A_5	A_6	
C_{11}	(7,9,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(7,9,9)	(7,9,9)
C_{12}	(1,3,5)	(7,9,9)	(1,3,5)	(5,7,9)	(1,3,5)	(7,9,9)	(5,7,9)
C_{13}	(3,5,7)	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)
C_{21}	(7,9,9)	(3,5,7)	(5,7,9)	(7,9,9)	(1,3,5)	(5,7,9)	(5,7,9)
C_{22}	(1,3,5)	(3,5,7)	(5,7,9)	(7,9,9)	(3,5,7)	(7,9,9)	(7,9,9)
C_{23}	(5,7,9)	(5,7,9)	(7,9,9)	(1,3,5)	(7,9,9)	(7,9,9)	(5,7,9)
C_{31}	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(5,7,9)	(1,3,5)	(7,9,9)
C_{32}	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
C_{33}	(5,7,9)	(1,3,5)	(5,7,9)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)

In this situation, the DM has assigned the threshold value to be 0.70 and requested that the condition $\chi \leq (S_i^-)$ is applied. Based on all the information provided by the DM in Table 1, the system computes and compares the acceptable screening threshold across the alternatives using (1)-(9). Alternatives A_1, A_2, and A_4 are eliminated for further evaluation as they are found to have lower distance values as compared to the pre-determined screening threshold value as shown in Table 2.

Table 2. The alternatives and their overall distances

Alternatives	S_i^+	S_i^-
A_1	0.78	0.63
A_2	0.72	0.59
A_3	0.41	0.81
A_4	0.82	0.64
A_5	0.54	0.75
A_6	0.48	0.72

4. CONCLUSION

Evaluating and selecting ships is a complex process, as it requires the DM making subjective and imprecise assessments in relation to multiple decision alternatives and evaluation criteria. To address this complex issue, we have formulated the selection problem as a fuzzy multicriteria decision making problem and developed an effective algorithm for solving the problem. With its simplicity in concept and computation, the algorithm is effective for solving the general maritime shipping evaluation and selection problem.

REFERENCES

Balmat JF, Lafont F, Maifret R, Pessel N, Maritime Risk Assessment (MARISA) - A fuzzy approach to define an individual ship risk factor, *Ocean Engineering* 36, 15-16, 2009.

Chen SJ, Hwang CL, *Fuzzy Multiple Attribute Decision Making: Methods and Applications*, Springer-Verlag, New York, 1992.

Deng H, A Fuzzy Approach to Selecting Information Systems Projects, *International Journal of Computers and Information Sciences* 6, 13-21, 2005.

Deng H, Wibowo S, A Decision Support System for Evaluating and Selecting Information Systems Projects, *IAENG Transactions on Engineering Technologies*, American Institute of Physics, 2008.

Hobbs BF, Meier P, *Energy Decisions and the Environment: A Guide to the Use of Multicriteria Methods*, Kluwer Academic, Dordrecht, The Netherlands, 2000.

Hwang CL, Yoon KS, *Multiple Attribute Decision Making: Methods and Applications*, Springer, Berlin, 1981.

Lootsma FA, Meisner J, Schellemans F, Multi-criteria decision analysis as an aid to the strategic planning of Energy R&D, *European Journal of Operational Research* 25, 216-234, 1986.

Mussati SF, Barttfeld M, Aguirre PA, Scenna NJ, A disjunctive programming model for superstructure optimization of power and desalting plants, *Desalination* 222, 457-465, 2008.

Staschus K, Davidson, J, Gross G, Logan D, Perone S, Shirmohammadi D, Vojdani A, A multi-attribute evaluation framework for electric resource acquisition in California, *International Journal of Electrical Power and Energy Systems* 13, 73-80, 1991.

Valls A, Batet M, López EM, Using expert's rules as background knowledge in the ClusDM methodology, *European Journal of Operational Research* 195, 864-875, 2009.

Yeh CH, Deng H, Chang YH, Fuzzy Multicriteria Analysis for Performance Evaluation of Bus Companies, *European Journal of Operational Research* 126, 1-15, 2000.