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# A rating based fuzzy analytic network process (F-ANP) model for evaluation of ship maneuverability

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ABSTRACT

In this paper, a novel rating based fuzzy analytic network process (F-ANP) model is proposed for the evaluation of ship maneuverability and the improvement of maneuverability standards. By incorporating the F-ANP technique into the American Bureau of Shipping (ABS) maneuverability standards, the proposed model is able to solve the problem of mutual dependencies of the maneuvering factors inherent in the evaluation of ship maneuverability and the insufficiency of unreasonable weights of maneuvering factors assigned in current maneuverability standards. Following this model, the more synthesized and advanced evaluation process for ship maneuverability is achieved and the more reasonable weights for each maneuvering factor are assigned. The pairwise comparison matrices are formed by the expert team. To deal with the problem of ambiguity and vagueness, the index attribute values are fuzzied with triangular fuzzy number. Furthermore, the maneuvering data of three ships are applied to the case studies and discussions to illustrate the reasonableness, effectiveness and advantages of the proposed rating based F-ANP model by comparing with the common F-AHP model and current ABS standards. The comparative results are encouraging, and show that the proposed rating based F-ANP approach is a viable and effective tool for evaluation of ship maneuverability.



## 1. Introduction

Ship maneuverability weighs the response capability when ship is handled by operator or interfered by external environment force (Hong and Yang, 2012). The study of maneuverability performance of ship is a major and important issue in the study of ship due to the maritime safety and environmental protection, e.g. the relationship between maneuverability and safety was considered with the benefits to ship owners from incorporating maneuverability and safety highlighted (Biancardi, 1993).

In order to prevent that ships are built with very poor maneuverability, the standards are essential to be used to evaluate the ship maneuverability and to improve those responsible for ship design, construction, repair and operation to ensure that ships comply with the standards. For the standards of ship maneuverability, much significant developments have been achieved. By evolving over a long period of time in formulation, the International Maritime Organization (IMO) adopted the resolution MSC. 137(76), which is "Standards for Ship Maneuverability" (IMO, 2002a, 2002b). However, the IMO standards are minimal standards by its very nature, which define the minimal level of maneuvering performance representing an internationally accepted level of safety. Meanwhile, based on a large amount of full-scale (builder's) trials data, the outcome of research (Barr et al., 1981) was a rating system of maneuvering criteria, which not only established a minimally acceptable standard, but also gave credit for enhanced maneuvering performance. Subsequently, a rating-based maneuvering standard (Belenky and Falzarano, 2006) which combines the IMO requirements as a minimum with the slightly improved rating-based system was described. This approach is implemented in the published American Bureau of Shipping (ABS) Guide for Vessel Maneuverability (ABS, 2006), which the optional class notation is in compliance with IMO standards and signifies demonstration of maneuvering performance superior to IMO standards.

Nonetheless, in current ABS standards the resultant rating is calculated as an average of all the individual ratings, this is equivalent to the assumption that all maneuvering factors are equally important. The ABS has pointed out that this assumption is inadequate due to lack of sufficient data and the analysis of the relative importance of the different maneuvering factors is one of the directions for future research.

Essentially, the evaluation of ship maneuverability is a multi-criteria decision-making (MCDM) problem. With the development of the research of multi-criteria decision technique, in recent

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years, a number of alternative approaches have been proposed for the evaluation of ship maneuverability and many significant results have been achieved (Hong and Jia, 2002; Qiu et al., 2005; Spyrou, 1994). For example, based on the maneuvering test data of 6 model large ships, the Analytical Hierarchy Process (AHP) approach was applied to rank the ship maneuverability (Hong and Jia, 2002). And a comprehensive assessment model of ship handing performance was constructed based on the AHP and Fuzzy theory (Qiu et al., 2005).

However, there is one limitation exists in aforementioned alternative approaches, that is the assumption of independence among various maneuvering factors. Just like many MCDM problems, the dynamic nature of ship maneuverability determines that factors considered in the evaluation process are often not independent, the decision will mostly affect the performance of not just one, but other factors (Chan and Wang, 2013). Therefore, both the evaluation of ship maneuverability and the improvement of maneuverability standards require intensive analysis and should be evaluated and improved from a holistic point of view.

In recent years, among the available multi-attribute decision making methods, only ANP can be used to evaluate performance systematically due to the dependencies and feedbacks caused by the mutual effects of the criteria. The ANP, introduced by Saaty (1996), is a generalization and extension of the analytic hierarchy process (AHP) . Saaty suggested the use of AHP to solve the problem of independence on alternatives or criteria, and the use of ANP to solve the problem of dependence among alternatives or criteria. The ANP feedback approach replaces hierarchies with networks in which the relationships between levels are not easily represented as higher or lower, dominant or subordinate (Meade and Sarkis, 1999). For instance, not only does the importance of the criteria determine the importance of the alternatives, but also the importance of the alternatives may have impact on the importance of the criteria. Hence, the ANP is the most comprehensive framework available for the analysis of corporate decisions. Several studies (Demirtas and Ustun, 2009; Onut et al., 2009; Sarkis, 2002; Tuzkaya and Onut, 2008; Wey and Wu, 2007; Yurdakul, 2003) have adopted the ANP to evaluate performance. For example, a systemic ANP model was presented to evaluate environmental practices and programs (Sarkis, 2002) in analyzing various projects, technological or business decision alternatives. To address the interrelated attributes of a manufacturing system, the literature (Yurdakul, 2003) employed the ANP approach and developed a performance measurement model.

Nevertheless, ANP does not allow for any uncertainty among factors. Due to incomplete information or knowledge, complexity and uncertainty within the decision environment, it is relatively difficult for the decision maker to make a correct judgment or objective evaluation during the evaluation process. Thereby, fuzzy logic, which can be employed to deal with uncertain parameters and information, is introduced in the pairwise comparison of ANP to make up for this deficiency in conventional ANP. Recently, many researchers combine fuzzy set theory and ANP and have applied F-ANP to several research fields (Dagdeviren et al., 2008; Dagdeviren and Yuksel, 2010; Liu and Lai, 2009; Luo et al., 2010; Mikhailov and Madan, 2003; Mohanty et al., 2005; Tuzkaya et al., 2009). Specifically, the literature (Liu and Lai, 2009) proposed an integrated decision support framework for the environmental impact assessment of construction project. To quantify the qualitative indexes and deal with the interaction of some indexes during the process of VRC performance evaluation, a comprehensive performance evaluation method based on triangular fuzzy number and ANP was proposed in Luo et al. (2010).

Based on above observation in this paper, and in order to overcome the disadvantages of current ABS standards and existing decision making approaches, the F-ANP technique is employed to the evaluation of ship maneuverability and the improvement of maneuverability standards in this paper. Although F-ANP has been applied to a few decision making or evaluation performance processes, to the best knowledge of the authors, there is not any research using the F-ANP method for the evaluation of ship maneuverability and the improvement of maneuverability standards. In the meantime, the evaluation model of ship maneuverability includes many factors and a factor could affect another factor. Moreover, it can be suggested that there may be some interactions among these factors. For above reasons, this study is concentrate on applying the rating based F-ANP model to evaluate the ship maneuverability and improve the maneuverability standards systematically.

The rest of the paper is organized as follows. Section 2 briefly describes the F-ANP model. The rating based maneuverability standards are described in Section 3. In Section 4, the calculation process of rating based F-ANP model for evaluation of vessel maneuverability is presented in detail. Then the maneuvering data of three ships are applied to case studies and discussions in Section 5. The paper ends with conclusion in Section 6.

## 2. Fuzzy analytic network process

### 2.1. Fuzzy sets and fuzzy number

Zadeh (1965) introduced the fuzzy set theory to deal with the uncertainty due to imprecision and vagueness. A major contribution of fuzzy set theory is its capability of representing vague data. The theory also allows mathematical operators and programming apply to the fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function, which assigns to each object a grade of membership ranging between zero and one. Fuzzy set theory provides numerous methods to represent the qualitative judgment of the decision maker as quantitative data. There are two most commonly used fuzzy numbers: trapezoidal fuzzy number and triangular fuzzy number. Triangular fuzzy numbers are used in this paper to assess the preferences of decision maker since they are easy to use and easy to interpret.

A triangular fuzzy number is defined as a triple $(l, m, u)$, as shown in Fig. 1. The parameters $l$, $m$ and $u$ denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event, respectively. Each triangular fuzzy number has linear representations on its left and right side such that its membership function can be defined as (Tuzkaya and Onut, 2008):

$$\mu_A(x) = \begin{cases} (x-l)/(m-l), & l \le x \le m, \\ (x-u)/(m-u), & m \le x \le u, \\ 0, & x < l \ \ or \ \ x > m. \end{cases} \tag{1}$$

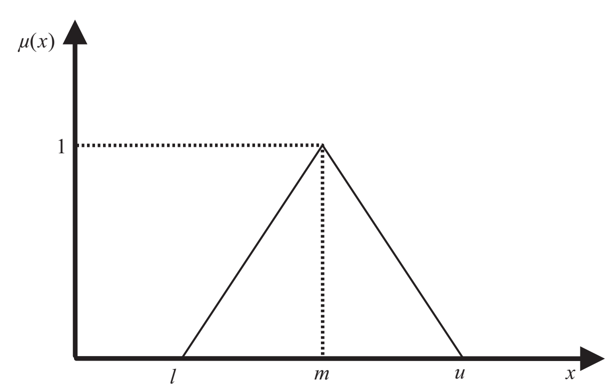


**Fig. 1.** Triangular fuzzy number.