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Assessment of surface ship environment adaptability in seaways: A fuzzy comprehensive evaluation method

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Abstract

Due to the increasing occurrence of maritime accidents and high-level requirements and modernization of naval wars, the concept of ship environment adaptability becomes more and more important. Therefore, it is of great importance to carry out an evaluation system for ship environment adaptability, which contributes to both ship design and classification. This paper develops a comprehensive evaluation system for ship environment adaptability based on fuzzy mathematics theory. An evaluation index system for ship environment adaptability is elaborately summarized first. Then the analytic hierarchy process (AHP) and entropy weighting methods are applied to aggregate the evaluations of criteria weights for each criterion and the corresponding subcriteria. Next, the multilevel fuzzy comprehensive evaluation method is applied to assess the ship integrative environment adaptability. Finally, in order to verify the proposed approach, an illustrative example for optimization and evaluation of five ship alternatives is adopted. Moreover, the influence of criteria weights, membership functions and fuzzy operators on the results is also analyzed.

Keywords: Ship environment adaptability; Evaluation system; Fuzzy theory; Analytic hierarchy process

1. Introduction

Waterway transportation plays an important role in transporting both goods and passengers all over the world, and it is the proven cheapest mode of goods transportation. However, with the increasing tonnage of ships and the emergence of novel fast ships, problems of maritime safety are emerging day by day (Islam et al., 2015; Psarros et al., 2010; Pak et al., 2015). As a result, more and more maritime accidents have been taken place in the past decades because of the insufficient performances of ships to the specified environments. Furthermore, the integrative performance of warships is of great importance to a country who involved in a naval war, and it largely determines the outcome of the naval war. A sea wave well-suited, fast navigational, radar stealthy ship has great advantages during a sea war. All these cases can be attributed to the evaluation of ship environment adaptability and thus it becomes a common concerned topic of both civilian and military ships.

The ship environment adaptability refers to the endurances of ships in all kinds of external disturbances, e.g. wind load, wave-induced motion and load, currents impact, and brine-induced corrosion experienced during their lifetime (Jiao et al., 2014; Sun et al., 2014a,b). The environment adaptability is an important factor in the evaluation of integrative navigation performance of ships, especially ships sailing in severe sea conditions for high demand tasks execution. A ship with good environment adaptability can not only prevent its functions from failure in a certain circumstance, but also take advantage of the specified environment so as to improve its performance. Ship environment adaptability of different kind of ships should be evaluated purposefully. The main subjects

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in terms of ship performance in naval architecture are: seakeeping performance, wave load, rapidity, stability, maneuverability, etc. Ship environment adaptability system is a multi-variable, multi-objective and multi-hierarchy system which takes different kinds of ship performance into account at the same time.

Assessment of ship environment adaptability in seaways, like many other evaluation issues, is complex because such evaluations usually have many aspects in respects of index factors. Currently, the conventional environment adaptability of ships are evaluated for separate independent performances, e.g. rapidity, seakeeping performance, and wave load behavior, etc., which is quite different from the real navigational conditions. Olson (2009) proposed a method which takes the percent of time that a ship accomplishes a given navigation task in the specified environment as the ship's seakeeping performance evaluation index. Yang et al. (2003) used the fuzzy theory and the genetic algorithm to evaluate the rapidity and maneuverability of ships in calm water. Li and Wu (2004) set up a model to evaluate ship stability by using the height of center of gravity and a new concept of equivalent height of center of gravity. Zhang et al. (2011) summarized the influencing factors on the combat effectiveness of surface ship's acoustic stealth performance.

Currently, a lot of published papers focus on the comprehensive assessment of green shipping. Niese et al. (2015) carried out a ship design evaluation framework in respect of carbon emission by means of Markov decision process. Ship performance in real seas is quite different from that of in still water. Thus ship performance should be evaluated by taking wind and wave effects into account. Class NK carried out the "development of environmental performance technical services of container ships" from 2007 to 2009, which was intended to develop an index of propulsion performance for container ships in actual seas (Nomura et al., 2009). Research and development on 10 mode index for ships at sea have been carried out by Tsujimoto et al. (2012) to study the evaluation approach of ship energy efficiency. Sasa et al. (2015) evaluated the ship performance and analyzed the relationships between ship motions, speed loss and wave conditions from data collected during one-year voyage trials of a 20,000 DWT bulk carrier.

Only a few publications evaluate ship performance by taking multi-subject and multi-variable into consideration. Multidisciplinary design optimization (MDO) has been developed and used by some scholars for ship design. Pan et al. (2009) established a MDO method includes 37 design variables, nine constraints and two objectives for ship optimal design. A MDO based method "Bi-Level Integrated System Collaborative Optimization (BLISCO)" has been adopted to the conceptual design of an human occupied vehicle (HOV), which includes hull module, resistance module, energy module, structure module, weight module, and the stability module (Zhao et al., 2015).

The evaluation of ship integrative performance in wind and wave environment is a reason of concern in the field of naval architecture. Despite a number of current publications are related to the evaluation of ship performance, few of them focus on the comprehensive performance evaluation of ships and this issue is still far from being completely solved. Thus, there is a real need for the development of an evaluation system that considers as more aspects as possible. In this paper, a comprehensive evaluation system for ship environment adaptability is proposed. First of all, criteria and subcriteria with respect to ship environment adaptability are proposed by considering multidisciplinary fields of naval architecture, for example, seakeeping, structural mechanics, resistance, and propulsion. Then Analytic Hierarchy Process (AHP) and entropy weighing method are adopted in weighing each of the criteria and subcriteria. Next, a fuzzy comprehensive evaluation method is established to assess the ship environment adaptability. Lastly, an illustrative example is given to elaborate the method proposed in this paper.

2. Background and evaluation index system

2.1. Background

The shipping industry has witnessed an enormous progress in the last decades for the sake of the rapid growth in waterway transportation needs. However, fatal maritime accidents are the nightmares of seafarers, passengers and the public. Since ships sailing in unknown severe and high-risk environments, many ship accidents occur at seas as well as in river waters. Ship accidents can be categorized into various classification such as collision, capsizing, grounding, material fatigue, hull damage, sinking, etc (Toffoli et al., 2005; Nielsen, 1999; Yip, 2008). All these kinds of accidents can be attributed to the insufficient performances of ships to the specified environments. From a ship accident database collected by Wang (2010) about 677 incidents all over the world were extracted during the period from 1978 to 2008. The classification of these ship accidents is summarized in Fig. 1.

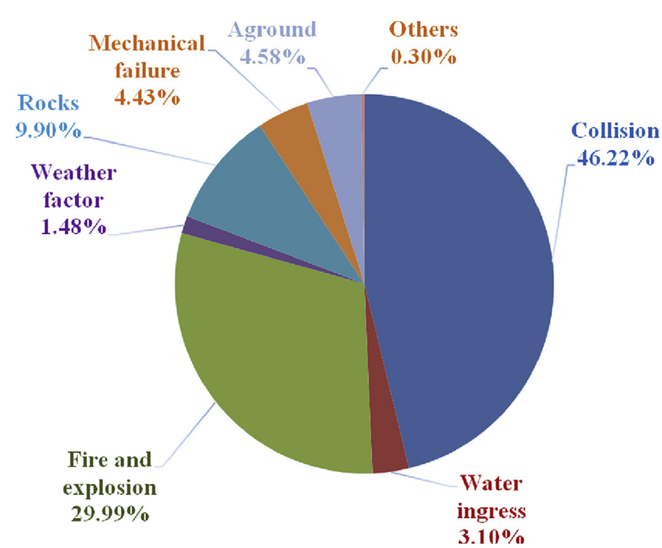

Fig. 1. Classification of ship accidents.