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Selection of maritime safety control options for NUC ships using a hybrid group decision-making approach

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ABSTRACT

Maritime safety control is an essential step to mitigate risk in the well-known formal safety assessment framework. The selection of safety control options for NUC (not under control) ships is a challenge due to many influencing factors, together with the different preference formats on the attributes among the multiple involved organizations. This paper proposes a hybrid group decision-making approach to facilitate NUC ship safety control by incorporating fuzzy logic, consistency-based linear programming and Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). The kernel of the new method is to use fuzzy logic to obtain the attributes values by integrating the associated influencing factors, to employ consistency-based linear programming model to gain the interval weights of attributes, and to introduce TOPSIS for final decision-making. Consequently, this work provides a practical decision framework for NUC ship safety control.

1. Introduction

Ships not under control (NUC), a frequently-occurring incident, have recently attracted an increasing attentions of Jiangsu maritime safety administration (MSA), who is in charge of the downstream maritime safety in Yangtze river (Sun et al., 2013). According to the statistical data, around 100 such incidents occurred per year from 2007 to 2012. Unlike the NUC incidents that occurred in the open sea, where the NUC ship can drift with the current and avoid collision by broadcasting a navigational warning via very high frequency, the inland waterway transportation is restricted under the harsh navigational environment, including the dense traffic flow, and heavy weather (Wu et al., 2015). Moreover, as the NUC ship is a vessel which through some exceptional circumstance is unable to maneuver as required by these Rules and is therefore unable to keep out of the way of another vessel from the definition of Convention on the International Regulations for Preventing Collisions at Sea (IMO, 1972), this means the not under control of ships will trigger an urgent situation in inland transportation.

In order to mitigate such risk, maritime safety control is therefore essential to be adopted considering the severe consequences of such incidents. Otherwise, it will not only cause the direct loss, but also cause the collateral damage. It is discovered by Mazaheri et al. (2014) that the NUC ship would develop into a sequence of accidents if an effective safety control option (SCO) is not taken timely, and some collision accidents were also caused by ships not under control (Hänninen and Kujala, 2012). Moreover, the risk of second tier accidents was also studied when analyzing the risk of vessel traffic in the Strait of Istanbul (Uluscu et al., 2009). Zhang et al. (2014a) presented that the risk of congestion arose due to maritime accidents in Yangtze River. Goerlandt and Montewka (2014) predicted the probability of cargo oil outflow from product tankers after ship–ship collision; moreover, in their recent research (Goerlandt and Montewka, 2015), they proposed a framework for analyzing the risk of oil spill after ship–ship collision in the Gulf of Finland, which estimated both the probability and the consequence of such risk. In a wider domain, the maritime safety control also plays a significant role in prevention of accident with different types. For example, the risk of ship collision in the Portuguese coast (Silveira et al., 2013), and grounding (Prestileo et al., 2013) was also studied and in particular oil pollution collision accidents were analyzed (Gouveia and Guedes Soares, 2010), as well as their consequences (Sebastião and Guedes Soares, 2007).

The researches on effectiveness of maritime safety control have also been carried out to gain insightful thoughts on this topic. Wu et al. (2015) proposed an improved data envelopment analysis method to assess the effectiveness of maritime safety control.

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The authors first thoroughly reviewed the influencing factors and, then, by treating the navigational environment factors as input variables and the accident data as output data, they discovered that the maritime safety were highly related to the number of accidents especially in harsh navigational environment. In addition, Zhang et al. (2014b) studied the performance of maritime safety control using search and rescue data and remarked that the maritime safety control was beneficial for consequence reduction in Yangtze River. Moreover, Hänninen et al. (2014) established a Bayesian Network to analyze the influencing factors of maritime safety management, such as accident involvement and vessel traffic service, and the authors concluded that the results were useful for maritime safety control.

It can be seen from the prior studies that the majority of the researches focused on maritime safety control from the perspective of risk management. The well-known formal safety assessment framework (Kragh et al., 2010; Zhang et al., 2013) stresses the importance of risk control in the third step. Moreover, the risk control options were widely used in maritime transportation, including the risk-based ship design (Konovessis et al., 2013), the standardization of the legislation (Bhattacharya, 2012; Tzannatos and Kokotos, 2009), and the safety management system (Akyuz and Celik, 2014; Montewka et al., 2014). It should be mentioned that the abovementioned risk control options were designed to reduce the risk to an acceptable level, which means the risk control options are proposed to reduce the risk in the future.

However, the safety control of NUC ships requires an early-stage response, and in essence, it can be assumed to be selection of a collective of safety control options. From the historical data, the safety control options, together with the associated navigational environment factors, which are manually recorded after an incident occurs, can be found in the incident database of Jiangsu MSA. This database includes different types of incidents, such as NUC, collision and fire.

Normally, there are four maritime safety control options for NUC ships. The detailed description of the maritime safety control options are as follows. Tug assistance operation (A1): The NUC ship is assisted by towed tugs to continue the uncompleted task, such as berthing, sailing, and anchoring. Beaching or anchoring in the outer limit of the fairway (A2): Beaching means that NUC ship grounds on purpose in the shallow water, and anchoring in the outer limit of the fairway means the NUC ship anchors in the outer limit of fairway so that it will not influence the sailing ships in the fairway. Anchoring in nearby anchorage (A3): The ship anchors in the nearby anchorage by using its own propulsion or tug assistance, the key factor to differentiate A3 from A1 is whether the ship stopped the initial task or not. Immediate anchoring in fairway (A4): The NUC ships grape the bottom of the fairway in order to make the ship stop immediately. The statistical data of SCOs in different failure modes for NUC ships are shown in Fig. 1.

After a NUC ship incident occurs, three organizations are involved to take actions. Specifically, they are the NUC ship itself, ships passing by and MSA. The ships passing by are involved in this safety control because they will be significantly influenced by the action of the NUC ships. For example, if the NUC ship is immediately anchoring in fairway (A4), the ships passing by especially those ships with large size have to anchor too, since the fairway is occupied by the NUC ship. Similarly, the MSA have to make sure the safety in this waterway area, which means it has to take an optimal option to consider the safety of both NUC ship and ships passing by. The cooperation between the involved organizations will make the decision-making process complex and challenging as they may prefer different formats of information. Xu (2007b) proposed a consistency-based goal programming method to aggregate these three different formats, and this method is also extended in Xu and Chen (2008). The beauty of this consistency-based goal programming method can be seen in many aspects including (a) the cooperation of involved organizations are considered; (b) the computation process is easy and straightforward; (c) the three used preference formats of the involved organizations can be aggregated; and (d) the optimization tool is a widely used method and can achieve an acceptable result. However, some problems may be discovered when it is used to select the safety control options of NUC ships, including:

1. The influencing factors are too few to make a comprehensive assessment on the alternatives.
2. Lack of a hierarchy evaluation framework for selection of alternatives.
3. It is impossible for the involved organizations to make judgments if the influencing factors increases as then the experts will be confused to make too many judgments.
4. The objective function in the final decision-making manages to maximize the overall assessment on the attributes, which ignores the minimum values to rank the alternatives in the objective function.

In order to deal with the abovementioned drawbacks, the fuzzy logic method, which show advantages from the literature (Krohling and Campanharo, 2011; Perera et al., 2010; Wang et al., 2013), is introduced to solve the former three problems. The alternative methods of fuzzy logic are fuzzy Bayesian network (Yang et al., 2008, 2013) and fuzzy evidential reasoning (Yang et al., 2009b, 2014), which are also widely used to risk analysis and decision-making. However, both the fuzzy Bayesian network and fuzzy evidential reasoning method manage to overcome the problems of incomplete information in the description of linguistic variables, and the principle of these two methods is to construct an improved IF–THEN rule with multiple-input multiple-output compared to the traditional multiple-input single-output.

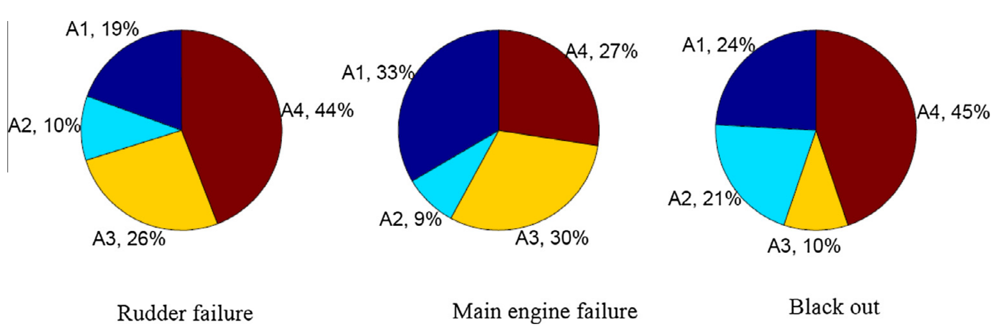

Fig. 1. Statistical data of SCOs for NUC ships.