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Quantitative human error assessment during abandon ship procedures in maritime transportation

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ABSTRACT

Human error prediction is always onerous work in the maritime domain since it is very difficult to obtain empirical data. One accepted method, Success Likelihood Index Method (SLIM), is utilized to assess human error as data is very scarce in the marine industry. The SLIM provides a quick tool to predict human error and evaluate human error probability (HEP) that occurs during the completion of a specific task. The weakness of the method is the subjectivity in the process of experts' judgments causing difficulties in ensuring consistency. To remedy this gap, this paper proposes a fuzzy based SLIM technique which provides more accurate estimation during human error quantification. In the proposed approach, while the SLIM is utilized to estimate HEP, the fuzzy sets deal with the vagueness of expert judgments and expression in decision-making during the weighting process of performance shaping factors (PSF). To illustrate the proposed approach, the abandon ship procedure in marine transportation has been selected since the evacuation of the ship is critical to prevent the loss of life in the case of emergency. The outcomes of the paper can be utilized by ship owners, safety managers as well as ship management companies to minimize the likelihood of human error occurring within a specific task and to enhance overall levels of safety on-board a ship in the marine environment.

1. Introduction

In maritime transportation, human error assessment can pose a major challenge since there are numerous hazardous jobs such as cargo loading, cargo unloading, ballasting, de-ballasting, cargo tank washing, gas inerting, gas freeing, ship to ship cargo transferring, etc. performed on-board ship. Statistics show that most marine accidents are due to human error (EMSA, 2015; Akyuz, 2015a; Corovic and Djurovic, 2013). The consequence of human error may pose acute hazards to human life, the ocean environment and property. The human factor is critically important for maritime transportation, however, the quantification of human error is quite difficult due to data scarcity in records (Akyuz and Celik, 2015a). Despite a set of rules and regulations adopted by maritime authorities to reduce marine accidents caused by human errors in recent years, many studies have highlighted that accidents continue to occur (Ugurlu et al., 2015; Chauvin et al., 2013; Gaonkar et al., 2011). Therefore, maritime safety practitioners are seeking alternative solutions to minimize human error and enhance safety in maritime transportation. In this context, this paper suggests an alternative practical approach to quantify human errors. Thus, critical human failure can be assessed from technical and operational aspects.

In cases of maritime disaster such as collision, grounding, flooding or fire on-board ship, the decision to abandon ship can be ordered by the master of the vessel to prevent the loss of life. At this point, crew performance plays a critical role to minimize hazards that may arise due to human errors. In the literature, although numerous research papers have been undertaken, those related to emergency ship procedures have been limited. In their article, Hu et al. (2013) discussed flooding emergencies on-board ships. The authors adopt M-H method to solve problems during flooding emergencies. A similar study was conducted to support emergency planning decisions during ship flooding emergency response (Varela et al., 2014). The paper utilizes the benefits of a simulation which is supported by a Virtual Environment in real-time. There has been a variety of research addressing passenger ship evacuation in an emergency situation since the consequences could be disastrous in the case of a serious accident occurring (Vanem and Skjong, 2006). Therefore, much attention has been given to the enhancement of evacuation techniques on board passenger ships as they are carrying thousands of passengers on-board ship (Lee et al., 2003). For instance, Park et al. (2015) have recently introduced evacuation analysis on passenger ships by using experimental scenarios. In the paper, authors focus on the validation of SIMPEV by using computer simulation. Likewise, another study was performed to simulate and validate a passenger

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ship evacuation case (Wang et al., 2014a). Furthermore, another study with respect to the evacuation of passenger ships was proposed by Vanem and Ellis (2010) in order to provide substantial decision support to the ship's officer in charge of evacuation. The paper presents a cost-effectiveness assessment by using RFID technology. A study, introduced by Jasionowski (2011), was prepared from a different perspective in terms of evacuation of a passenger ship. The study discusses a prototype of an ergonomic decision support function in response to a distressed flooding situation. There are also a couple of novel studies upon evacuation in an emergency situation in different industries such as off-shore platforms, the energy sector, petrochemicals, mining, etc. (Shen et al., 2015; Wang et al., 2014b; Deacon et al., 2013; Cruz and Krausmann, 2009; Dimattia et al., 2005).

Since emergency evacuation is one of the most critical issues in various domains, human error assessment is quite substantial in the event of abandoning ship to enhance safety and prevent the loss of life in the marine environment. The well-known case of the Costa Concordia, in which 32 people lost their lives, is a tragic example that illustrates the importance of the role of human error during an evacuation process. Therefore, the aim of this paper is to introduce a practical hybrid tool for performing quantitative human error assessment in the event of abandoning ship in maritime transportation. The proposed approach can be used to determine HEP by overcoming the vagueness of experts' judgments. Thus, quantification of human error for each step of the abandon ship procedure can be calculated. On the basis of outcomes, human error reduction measures will be recommended to prevent the loss of life and to improve safety levels on-board ships. The proposed approach attempts to combine fuzzy sets into SLIM technique in order to get a comprehensive and rational framework to assess HEP. In this context, the paper is organized as follows; this section gives an introduction and a brief literature review of evacuation. The next section introduces methodologies and defines the proposed approach. Section three illustrates how the proposed approach can be applicable to the abandon ship procedure. Section four includes the conclusion and the contribution of research to maritime transportation.

2. Research methodology

This study presents a hybrid approach by combining fuzzy sets and SLIM technique in order to quantify HEP values systematically in the event of an abandon ship event in maritime transportation. A brief definition of both methodologies are presented in the next section.

2.1. Fuzzy sets

Fuzzy sets are employed if there is vagueness or imprecision in human judgments in the decision making process. Zadeh (1965) first introduced the theory as an extension of the classical notation of sets. Since then, it has been used in a wide range of disciplines to overcome ambiguity in decision-makers ideas. A linguistic value can be represented by the approximate reasoning of fuzzy set numbers (Celik and Gumus, 2015). The linguistic values are utilized to transform decision makers' ideas or assessments into meaningful information. The theory can be applied models where expert/decision-maker knowledge can be stated in natural language such as high, medium or low (Castiglia and Giardina, 2013). At this point, the fuzzy linguistic concept is very practical to help express very complicated or ill-defined circumstances in traditional quantitative definitions (Casamirra et al., 2009).

In fuzzy set theory, a fuzzy subset A in X is characterized by a membership function $\mu_A(x)$, which associates each element x in X with a real number in the interval [0, 1]. The function $\mu_A(x)$ shows the membership of x in the fuzzy set A (Castiglia and Giardina, 2013). The membership function of fuzzy sets can be expressed in different shapes, triangular or trapezoidal being the most frequent ones in the literature. Triangular fuzzy set numbers are expressed as triplets (x_1, x_2, x_3) and the membership function $\mu_A(x)$ is defined as follows.

$$\mu_A(x)=\begin{cases} \dfrac{x-x_1}{x_2-x_1}, & x_1\le x\le x_2 \\ \dfrac{x-x_3}{x_2-x_3}, & x_2\le x\le x_3, \\ 0, & otherwise \end{cases} \quad where\ x_1<x_2<x_3 \tag{1}$$

On the other hand, trapezoidal fuzzy set numbers are expressed as x_1, x_2, x_3, x_4 and the membership function $\mu_A(x)$ is stated as follows.

$$\mu_A(x)=\begin{cases} \dfrac{x-x_1}{x_2-x_1}, & x_1\le x\le x_2 \\ 1 & x_2\le x\le x_3 \\ \dfrac{x-x_4}{x_3-x_4}, & x_3\le x\le x_4 \\ 0, & otherwise \end{cases}, \quad where\ x_1<x_2<x_3<x_4 \tag{2}$$

2.2. Slim

SLIM (Success Likelihood Index Method), a decision-analytic approach, is one of the practical techniques to estimate human error probability throughout the completion of a specific task (Embrey et al., 1984). It is quite practical in the human error probability prediction process in cases where it is difficult to acquire human error data (Park and Lee, 2008). Although the method heavily relies on experts' judgments, it can be a good alternative to calculate human error data in maritime transportation due to the lack of error data. The PSF, which has considerable influence on human performance, can be quantified in SLIM and converted into the form of a preference index. Thus, a Success Likelihood Index (SLI) is elicited by using experts' judgments. The SLI is calibrated with existing human error data to calculate the HEP value. The main steps of SLIM can be expressed as follows.

- Task analysis and scenario definition
- PSF derivation
- PSF rating
- Weighting of PSF
- Calculating SLI
- Converting SLI into HEP

In order to calculate SLI values, Eq. (3) is used. In the equation, n denotes the number of PSFs, r_i represents the rating scale of PSFs and w_i gives the weight of importance of the PSF.

$$SLI=\sum_{i=1}^{n} r_i w_i, 0\le SLI\le 1 \tag{3}$$

Accordingly, the SLI value is transformed into the HEP value by using Eq. (4) where a and b are constant (Embrey et al., 1984).

$$Log(HEP)=aSLI+b \tag{4}$$

2.3. Proposed approach: fuzzy SLIM

This section proposes a hybrid approach combining fuzzy sets and SLIM to perform quantitative human error prediction in the event of an abandon ship procedure in maritime transportation. A