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Estimation of Human Errors During Cargo Unloading Operations on Bulk Carriers Using SLIM and Interval Type 2 Fuzzy Sets

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Abstract

Cargo unloading operations on bulk carriers are critical shipboard operations. Many tasks are expected to fulfill by the ship's personnel to safely complete this type of operation. However, many human errors may occur during this process, and this situation threatens the safety of life and property. In this respect, this study predicts potential human errors and probabilities that may occur during cargo unloading operations on bulk carrier ships. In this study, an integrated human error prediction approach is proposed using interval type 2 fuzzy sets and the success likelihood index method. Thus, within the scope of this study, a model was obtained that allows human errors to be evaluated both qualitatively and quantitatively. Because of the analyzes made, it has been found that the most common human errors that occur while unloading cargo operations on bulk carriers occur in the processes of following the ballast operation and performing the tasks to prevent excessive trim/list formation on board ship, respectively. In addition, it was concluded that the factors that most shape the performance of the ship's personnel are education, communication, and experience.

Keywords: Unloading operation, SLIM, IT2FS, Human error prediction, Bulk carrier

1. Introduction

Global maritime transport is rapidly growing and has become an even more significant mode for the import and export of bulk cargoes. This expanding volume of global trade causes an enormous rise in port cargo handling capacity and, accordingly, operational vulnerabilities. According to bulk cargo trade data, the global average for loading capsize dry bulk vessels was 34.9 tons per minute, while this quantity reached 6.3 tons per minute for dandyize vessels in 2021 [1]. This means that a high volume of bulk cargo is handled onboard the ship at once, which poses a big challenge to planning and managing cargo handling operations. In particular, cargo handling performance increases with ship size because large vessels can be handled by large cranes, conveyor belts, and other advanced technological equipment.

Humans are considered a key element and a contributing factor to most casualties in the maritime transportation industry. In this regard, the International Maritime Organization emphasizes that the safety performance and competence of seafarers are of critical importance in increasing safety and reducing the risk of possible accidents in operations conducted at sea [2]. Indeed, maritime accidents or incidents occur mostly because of human errors [3,4]. Thus, maritime operations and navigation safety can be enhanced by strengthening the focus on the human element

Cargo unloading operations are critical operations that are expected to perform different tasks simultaneously by the ship crew. In this process, factors such as stress and fatigue may compel the crew in charge to neglect pivotal activities that must be properly performed [5]. In this case, different

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types of accidents can occur during the cargo unloading operations due to many reasons such as not following the ballast operation [6], deterioration of the stability of the ships [6], and the for reasons related to improper use of deck cranes, especially [7].

However, to prevent potential incidents or accidents that may be encountered during cargo unloading operations and to make operational processes safer, it is expected that the determined tasks will be fulfilled completely by the ship crew. Furthermore, it is thought that the completion of the tasks that must be performed by the ship crew during the cargo unloading operations is of critical importance not only for the safety of life and property but also for the protection of the marine environment.

Probabilistic risk assessments pointing out the human contribution to operational risks should be the focal point of the research because human error has emerged as a significant factor in unsafe cargo handling operations and maritime accidents in recent decades. Risk determination being distinguished from the safety performance of the responsible crew will cause insufficient detection in maritime incidents, accidents, or any undesired events [5].

In the view of literature research, despite some applicable methods presented related to human reliability assessments in high-risk industries such as offshore [8-12], nuclear [13,14], railway [15,16], chemical [17], and maritime [5,18-21] the research directly focusing on human error contributions in bulk cargo loading/unloading operations is quite limited. At this point, a quantitative approach systematically evaluating the potential human error in critical bulk carrier shipboard operations must reduce operational vulnerabilities and enhance safety.

Although determining the impact of human performance on risks arising in operational processes is a critical issue, most human reliability analysis (HRA) techniques are limited in evaluating human performance in all aspects [22]. To illustrate, first-generation HRA techniques, such as the technique for human error rate prediction [23], the success likelihood index method (SLIM) [24], and the human error assessment and reduction technique [25], facilitate human error quantification. Although they are good at emphasizing the success/failure of activities, they have less consideration for human behaviors. On the other hand, a technique for human error analysis [26], cognitive reliability and error analysis method [27], accident dynamics simulator-information, decision, action in crew context, and standardized plant analysis risk-human reliability analysis [28] are considered second-generation approaches that can be used to evaluate the occurrence of human errors, cognitive processes, and human performance. However, it is necessary to analyze organizational factors very well in determining the failures in studies using these approaches. Third- generation HRA methods, such as the Bayesian network [29], focus on the factors that contribute to the emergence of human errors and other dependent elements associated with these factors, and they are still in progress. Apart from all these, the lack of data is the most significant source of uncertainty in most HRA methods [30]. In particular, data scarcity is the biggest obstacle to HRA applications planned for evaluating human performance during ship operations. In this regard, an effective and consistent HRA implementation must be able to access the data needed for operational processes and evaluate them by an appropriate expert team.

This article aims to quantify the potential human-induced failures in the tasks expected to be performed by ship personnel during the cargo unloading operations of bulk carriers and to provide an idea of what measures may be necessary to prevent future losses. The scarce data for human failure in cargo unloading operations of bulk carrier vessels is the motivation for applying the proposed model consisting of the integration of Type-2 fuzzy logic (T2FL) and SLIM. The SLIM technique is heavily based on domain experts' evaluations that are based on the knowledge and experiences to predict human error. At this point, SLIM has been extended with fuzzy logic to improve consistency and reduce the subjectivity of experts' evaluations. Interval type-2 fuzzy sets (IT2FS) are highly functional for coping with subjectivity and vagueness in the process of using experts' evaluations. While the integrated approach addresses human error probability assessment, the results highlight the importance of human factors in critical cargo unloading operations on bulk carrier vessels.

This paper consists of 5 sections. This section briefly details the human factors, bulk carrier cargo operations, and motivation behind the research. Section 2 introduces the methodologies used in this study and the proposed integrated HRA approach. Chapter 3 estimates human errors and HEPs that may arise during cargo-unloading operations in bulk carrier ships. Section 4 evaluates the outputs of the research. Finally, section 5 concludes the research and advises on future studies.

2. Methodology

2.1. Interval Type 2 Fuzzy Sets (IT2FS)

The conventional fuzzy set, introduced by Zadeh [31] to cope with uncertainties encountered in decision-making processes, was developed as a type-2 fuzzy set (T2FS) in the following years [32]. Although the basic philosophy of both clusters is quite similar, there are also some divergence points. The most obvious aspect of this is that while the membership functions of the traditional fuzzy set consist of exact values, the membership functions of the T2FSs are fuzzy numbers [5]. In addition, T2FSs has more parameters than the traditional fuzzy set [33,34].

Interval type 2 fuzzy sets (IT2FSs) can be expressed as a more specialized version of the T2FS set [5]. Compared to T2FSs with more general cluster characteristics, IT2FS has a lower computation process for expert feedback to be digitized and converted to crisp values [19]. In addition, thanks to the linguistic evaluation scale it provides, it contributes to experts in making better and more effective decisions. Thus, they are more effective in eliminating possible uncertain conditions. In this respect, IT2FSs have been used in various academic studies based on the expert evaluation recently [5,19,35]. Expressions of mathematical operations performed using IT2FS and T2FS are detailed as follows [19,36-38]:

Expression 1: Let us assume that a T2FS $\tilde{\tilde{A}}$ in the universe X is expressed through a type-2 membership function $\mu_{\tilde{\tilde{A}}}(x,u)$. Here, J_X symbolizes an interval in [0, 1] and can be detailed in the following equation (1) [36-38]:

$$\tilde{\tilde{A}} = \{((x,u), \mu_{\tilde{\tilde{A}}}(x,u)) \mid \forall x \in X, \forall u \in J_X \subseteq [0,1], 0 \le \mu_{\tilde{\tilde{A}}}(x,u) \le 1\} \quad (1)$$

In addition, assuming that fuzzy numbers are continuous, T2FS $\tilde{\tilde{A}}$ can be symbolized with the following equation (2) [36]:

$$\tilde{\tilde{A}} = \int_{x\in X} \int_{u\in JX} \mu_{\tilde{\tilde{A}}}(x,u) \,/(x,u) = \int_{x\in X} \left(\frac{\int_{u\in JX} \mu_{\tilde{\tilde{A}}}(x,u)}{u} \right) /X \quad (2)$$

Here, $J_X \subseteq [0,1]$. *Also*, $\iint$ represents session over all admissible *x* and *u* figures.

Expression 2: Let us assume that $\tilde{\tilde{A}}$ is a T2FS in the universe of X, as demonstrated via the type-2 membership function $\mu_{\tilde{\tilde{A}}}(x,u)$. Assuming that all $\mu_{\tilde{\tilde{A}}}(x,u) = 1$, in this case $\tilde{\tilde{A}}$ is defined as an IT2FS [19]. In addition, it can be expressed as shown in equation (3) [33,36]:

$$\tilde{\tilde{A}} = \int_{x\in X} \int_{u\in J_X} 1/(x,u) = \frac{\int_{x\in X} \left(\frac{\int_{u\in J_X} 1}{u} \right)}{x} \quad (3)$$

Here, $J_X \subseteq [0,1]$.

Expression 3: Within the scope of this study, an approach based on taking and evaluating expert opinions using IT2FS is presented. In this direction, the representation of IT2FS covering the upper and lower membership functions is shown in Figure 1. In this respect, the IT2FS used in this study exhibits trapezoidal characteristics.

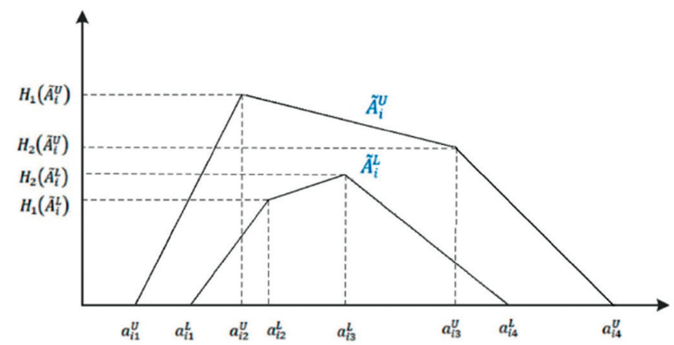

Figure 1. *IT2FS membership functions [36]*

IT2FS with trapezoidal character

$$\tilde{\tilde{A}}_i = (\tilde{A}_i^U, \tilde{A}_i^L) = \left(\left(a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U; H_1(\tilde{A}_i^U), H_2(\tilde{A}_i^U)\right), \left(a_{i1}^L, a_{i2}^L, a_{i3}^L, a_{i4}^L; H_1(\tilde{A}_i^L), H_2(\tilde{A}_i^L)\right) \right)$$

where $\tilde{A}_i^U$ and $\tilde{A}_i^L$ are type-1 fuzzy sets in this expression [19]. In addition, $a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U, a_{i1}^L, a_{i2}^L, a_{i3}^L, a_{i4}^L$ are reference points of the IT2FS $\tilde{\tilde{A}}_i$ [5,36,39]. However, $H_j(\tilde{A}_i^U)$ symbolizes the membership value of the parameter $a_{i(j+1)}^U$ in the upper side of the membership function $\tilde{A}_i^U$, $H_j(\tilde{A}_i^L)$ stands for the membership value of the parameter $a_{i(j+1)}^L$ in the lower side of the membership function $\tilde{A}_i^L$ Here, *j* can vary to include 1 and 2 [39].

Expression 4: The center of area (CoA) technique is used for defuzzification and ranking of IT2FS. In the implementation of this operation, the following equation (4) is used [40]:

$$Defuzzified(\tilde{\tilde{A}}_i) = \frac{\frac{(a_{i4}^U - a_{i1}^U) + (H_1(\tilde{A}_i^U) * a_{i2}^U - a_{i1}^U) + (H_2(\tilde{A}_i^U) * a_{i3}^U - a_{i1}^U)}{4} + a_{i1}^U + \frac{(a_{i4}^L - a_{i1}^L) + (H_1(\tilde{A}_i^L) * a_{i2}^L - a_{i1}^L) + (H_2(\tilde{A}_i^L) * a_{i3}^L - a_{i1}^L)}{4} + a_{i1}^L}{2} \quad (4)$$

There are also more advanced mathematical operations that can be performed using IT2FSs. These will be detailed below [37,38]:

i. Equation (5) is used when performing aggregation between two IT2FS.

$$\tilde{\tilde{A}}_1 = (\tilde{A}_1^U, \tilde{A}_1^L) = \left(\left(a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U; H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U)\right), \left(a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L; H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L)\right) \right)$$

$$\tilde{\tilde{A}}_2 = (\tilde{A}_2^U, \tilde{A}_2^L) = \left(\left(a_{21}^U, a_{22}^U, a_{23}^U, a_{24}^U; H_1(\tilde{A}_2^U), H_2(\tilde{A}_2^U)\right), \left(a_{21}^L, a_{22}^L, a_{23}^L, a_{24}^L; H_1(\tilde{A}_2^L), H_2(\tilde{A}_2^L)\right) \right)$$

$$\tilde{\tilde{A}}_1 \oplus \tilde{\tilde{A}}_2 = (\tilde{A}_1^U, \tilde{A}_1^L) \oplus (\tilde{A}_2^U, \tilde{A}_2^L) = \begin{pmatrix} \left(a_{11}^U + a_{21}^U, a_{12}^U + a_{22}^U, a_{13}^U + a_{23}^U, a_{14}^U + a_{24}^U; \min\left(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)\right), \min\left(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U)\right)\right), \\ \left(a_{11}^L + a_{21}^L, a_{12}^L + a_{22}^L, a_{13}^L + a_{23}^L, a_{14}^L + a_{24}^L; \min\left(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)\right), \min\left(H_2(\tilde{A}_1^L), H_2(\tilde{A}_2^L)\right)\right) \end{pmatrix} \quad (5)$$

ii. When extract two IT2FS, equation (6) given below is used.

$$\tilde{\tilde{A}}_1 \ominus \tilde{\tilde{A}}_2 = (\tilde{A}_1^U, \tilde{A}_1^L) \ominus (\tilde{A}_2^U, \tilde{A}_2^L) = \begin{pmatrix} \left(a_{11}^U - a_{21}^U, a_{12}^U - a_{22}^U, a_{13}^U - a_{23}^U, a_{14}^U - a_{24}^U; \min\left(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)\right), \min\left(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U)\right)\right), \\ \left(a_{11}^L - a_{21}^L, a_{12}^L - a_{22}^L, a_{13}^L - a_{23}^L, a_{14}^L - a_{24}^L; \min\left(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)\right), \min\left(H_2(\tilde{A}_1^L), H_2(\tilde{A}_2^L)\right)\right) \end{pmatrix} \quad (6)$$

iii. If multiplication is to be performed between two IT2FS, the following equation (7) is implemented.

$$\tilde{\tilde{A}}_1 \otimes \tilde{\tilde{A}}_2 = (\tilde{A}_1^U, \tilde{A}_1^L) \otimes (\tilde{A}_2^U, \tilde{A}_2^L) = \begin{pmatrix} \left(a_{11}^U \times a_{21}^U, a_{12}^U \times a_{22}^U, a_{13}^U \times a_{23}^U, a_{14}^U \times a_{24}^U; \min\left(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)\right), \min\left(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U)\right)\right), \\ \left(a_{11}^L \times a_{21}^L, a_{12}^L \times a_{22}^L, a_{13}^L \times a_{23}^L, a_{14}^L \times a_{24}^L; \min\left(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)\right), \min\left(H_2(\tilde{A}_1^L), H_2(\tilde{A}_2^L)\right)\right) \end{pmatrix} \quad (7)$$

iv. If an arithmetic operation is to be performed, equations (8) and (9) given below are used, respectively .

$$k\tilde{\tilde{A}}_1 = \begin{pmatrix} \left(k \times a_{11}^U, k \times a_{12}^U, k \times a_{13}^U, k \times a_{14}^U; H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U)\right), \\ \left(k \times a_{11}^L, k \times a_{12}^L, k \times a_{13}^L, k \times a_{14}^L; H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L)\right) \end{pmatrix} \quad (8)$$

$$\frac{\tilde{\tilde{A}}_1}{k} = \begin{pmatrix} \left(\frac{1}{k} \times a_{11}^U, \frac{1}{k} \times a_{12}^U, \frac{1}{k} \times a_{13}^U, \frac{1}{k} \times a_{14}^U; H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U)\right), \\ \left(\frac{1}{k} \times a_{11}^L, \frac{1}{k} \times a_{12}^L, \frac{1}{k} \times a_{13}^L, \frac{1}{k} \times a_{14}^L; H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L)\right) \end{pmatrix} \quad (9)$$

2.2. SLIM

SLIM is a type of human reliability assessment technique that allows the prediction ofthe probability of human error (HEP) in the process of performing specified tasks in a particular job [41]. In the stages of obtaining HEP values with this technique, factors called performance shaping factors (PSFs) and thought to have a positive or negative effect on the fulfillment of specific tasks are also considered. In addition, the effects/weights of each PSF determined by the SLIM technique on the occurrence of human errors in specific tasks can also be measured. In the literature, the SLIM technique, which is used to perform HRA in many fields such as the petrochemical industry [42], railway driving process [43], maintenance of offshore facilities [44], and lifting operations [45], has a very common usage area. Furthermore, the SLIM technique was used in HRA studies conducted in various fields for the maritime transportation sector [46-48].

Although the SLIM technique allows for very practical HRA, it requires expert judgments in the process of obtaining HEP values [5,41]. PSFs are digitized by expert judgments, and then the Success Likelihood Index (SLI) values are reached for each determined task [5]. Afterward, calibration is performed for the obtained SLI and HEP values are obtained [49]. Thus, the HEP values in the process of performing each task are determined.

2.3. Integration of the Methodology

This section describes the estimation process of human errors that occur during a cargo unloading operation of bulk carrier ships by integrating SLIM and interval type 2 fuzzy sets. The conceptual framework designed for the study is shown in Figure 2.

The application stages of the proposed hybrid approach are detailed below.

Stage 1. Determining related tasks

First, the tasks expected to be fulfilled within the scope of the specific operation type examined are determined. If there is any follow-up order among the defined tasks, hierarchical task analysis is performed among the tasks [5].

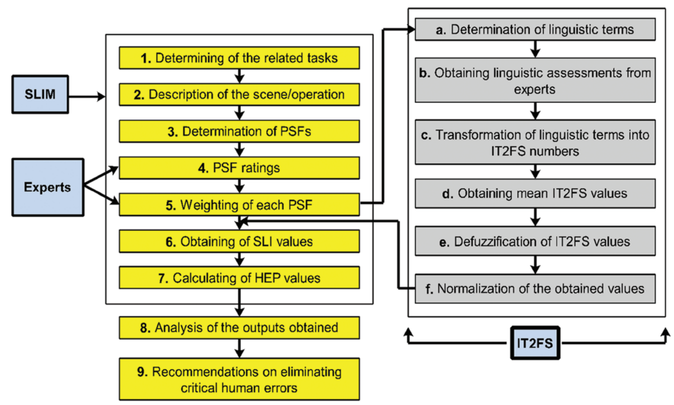

Figure 2. *Conceptual framework for the proposed hybrid HEP prediction approach*

Stage 2. The description of the scene/operation

At this stage, it is considered under which conditions the specific tasks determined are carried out. In this context, a scenario that coincides with real operations is produced by referring to written sources and expert opinions.

Stage 3. Determination of the PSFs

In this section, attention is drawn to the factors that are thought to have a positive or negative effect on the duties expected to be fulfilled. Sometimes this can be human-related factors such as stress, fatigue, and commercial pressure, and sometimes environmental factors such as rain, limited visibility, and sea and wave conditions. All of these factors may vary depending on the conditions under which the specific type of operation to be analyzed is performed. In this respect, PSFs that have a serious impact on the specific type of operation examined are determined in the presence of experts.

Stage 4. PSF ratings

In this section, the effects of the PSFs determined on the fulfillment of each task are evaluated by experts. For this, a linear scale consisting of numbers ranging from 1 to 9 is used. The effects of PSFs on tasks are selected inversely proportional to the magnitude of the values used in the linear scale.

Stage 5. Weighting of each PSF

PSFs have relatively different weights in the fulfillment of the determined tasks [49]. While percentage values are used in the conventional SLIM technique to determine these relative weights, IT2FS is used in the determination of these weights in the proposed approach. In other words, PSF weights are calculated using the linguistic scale within the scope of IT2FS. Thus, possible subjective and ambiguous evaluations by experts are avoided, thus contributing to obtaining more sensitive and realistic results [5].

Stage 6. Obtaining SLI values

The process that needs to be performed immediately after the rating and weighting of the determined PSFs is the obtaining of the SLI values. The SLI value, which plays a critical role in determining the probabilities of the emergence of human errors, is calculated using equation (10) given below [5,50,51].

$$SLI = \sum_{j=1}^{Q} r_j w_j, \quad 0 \leq SLI \leq 1 \tag{10}$$

Here, Q represents the number of PSFs, r_j represents the rating scale of PSFs, and w_j represents the relative importance weight of each PSF.

Stage 7. Calculation of HEP values

After obtaining the SLI values, the HEP values were calculated for each task. This operation is performed using the logarithmic function specified in equation (11).

$$Log\,(HEP) = mSLI + N \tag{11}$$

The m and N values specified in equation (11) are constant figures and are used for the calibration of the obtained SLI values [5,52].

3. Estimating Human Error Probabilities in Cargo Unloading Operations in Bulk Carrier Vessels

3.1. Cargo Unloading Operations in Bulk Carrier Ships

For the safe performance of unloading operations on bulk carriers, a number of tasks must be fulfilled both before and after arrival at the discharging port. The tasks that must be performed by the ship's personnel, especially during cargo watch at port, are critical not only for the safety of the unloaded cargo but also for ensuring the safety of the ship and its personnel. For example, implementation of the prepared discharging plan, monitoring the ballast operation, checking deck cargo cranes, grabs, and checking the stability of the ship can be shown among these tasks.

Some ship staff have been charged with responsibilities within the scope of the company Safety Management System (SMS) to keep safe cargo watch at the discharging ports. The ship master, chief officer, officer of watches (OOWs), electro-technical officer (ETO), and other deck crew can be shown as examples. In order for the ship discharging operations to be completed safely, each member of this team is expected to work effectively and in coordination. In company SMS, OOWs are generally expected to keep cargo watches at port alternately under the supervision and control of the ship's captain and chief officer during ship unloading operations. In addition, the ETO and other ship crews are requested to assist in this process. Cargo watches at the discharging port continue until the unloading of the cargo is completed.

3.2. Problem Statement

Because of technological developments, the cargo handling capacities of bulk cargo terminals have increased [1]. This significantly reduces the length of the stay of bulk carriers in ports. In this respect, the intensity of the duties that the ship's bulk carrier staff must fulfill in routine cargo shift increases. This situation increases the risk of encountering accidents during unloading operations for seafarers, who have a perilous and challenging working environment Moreover, seafarers try to cope with many factors that can prevent or delay the fulfillment of their assigned duties, such as stress, environmental factors, and fatigue, during a cargo watch carried out as part of the discharging operation. Considering that most accidents/incidents are caused by human errors [19,53], estimating the HEP in the tasks expected to be completed by the ship's staff during a cargo watch at the discharging operation is of critical importance in terms of preventing possible accidents. For this, the method of finding HEP values for each determined task is followed.

3.3. Prediction of the Human Error Probability

Because of the examination of the reports of classification societies [54], circulars of the maritime authorities [55], company SMSs, and consulting expert opinions, the tasks that the ship's personnel must fulfill during a bulk carrier unloading operation have been determined. The determined tasks were then divided and categorized in the presence of experts. The identified and categorized tasks are detailed in Table 1.

To conduct a realistic and effective risk analysis, it is critical to utilize the right experts with sufficient knowledge and experience on the specific subject under investigation. In this regard, 10 marine experts who have served on bulk carriers for many years and are familiar with unloading operations were used in this study. The profiles of the experts who contributed to this study are detailed in Table 2.

Later PSFs that could have a positive or negative impact on the tasks expected to be fulfilled during cargo unloading operations on bulk carrier ships were determined with the help of the experts detailed in Table 2. The PSFs derived in this context are given in Table 3.

In the next stage, the effect of the determined PSFs on each task was evaluated by the experts using a dinner scale varying between 1 and 9. In this context, PSF ratings were performed by 10 experts for each task. Table 4 gives the geometric means of the PSF ratings performed by 10 experts.

In this step of the study, IT2FS was used to obtain the relative weights of the PSFs. In this context, IT2FS numbers

Table 1. Tasks and subtasks to be fulfilled during the bulk carrier unloading operation

Task/Sub-tasks	The description of tasks and subtasks
1	**Tasks related to the unloading operation follow-up**
1.1	Become familiar with the unloading sequence plan
1.2	Monitor the start of the discharge operation and record the time
1.3	Maintain constant communication with the foreman to avoid potential delays in the unloading operation.
1.4	Make sure the discharged cargo is correct and in good condition
2	**Ship stability/ballast operation-related tasks**
2.1	Do not allow the excessive trim/list formation on the ship
2.2	Check ship drafts at regular intervals using an electronic gage
2.3	Check ship drafts at regular intervals from draft marks on hull
2.4	Ensure that the ballast operation continues in the scheduled order
2.5	Monitor soundings from ballast tanks against possible overflow
3	**Other ship/crew/cargo safety-related tasks**
3.1	Check that the bulldozers and grabs are working without damaging the cargo holds, frames, and tank top.
3.2	Record and report damage to both ship and cargo during the unloading operation to the Chief Mate/Master
3.3	Check mooring ropes/lines with the deck crew at regular intervals
3.4	Ensure the hatch lights are working properly at night
3.5	Check that the non-return valves fitted to the hatch comings are functional.
3.6	Check bilge high-level alarms at routine intervals
3.7	Periodically check the weather reports and report any expected adverse weather conditions to the Chief Mate/Master.
3.8	Record all events during the unloading process in the port/deck logbook
3.9	Ensure that stoppers are rigged/secured after opening hatch covers
3.10	Ensure that no one is in the cargo hold before closing the hatch covers.
3.11	Ensure that there are no obstructions in the hatch chamber when closing hatch covers.
3.12	Make sure personal protective equipment is always used on deck
3.13	Control that the gangway or accommodation ladder is properly positioned.
3.14	Monitor the hoisting and luffing wires of deck cargo cranes against possible twisting at routine intervals
3.15	Ensure the limit switches of deck cargo cranes are set correctly to use the proper angle

corresponding to the linguistic evaluations taken by experts are needed. Table 5 lists the IT2FS linguistic terms used by experts and their equivalent IT2FS numbers. In addition, Table 6 represents the linguistic evaluations made by the experts for each PSF.

Linguistic evaluations performed by marine experts to obtain PSF weights were converted to corresponding IT2FS numbers. Then, the mean IT2FS values for each PSF were obtained and defuzzified using equation (4) [40]. In the following process, normalization was performed. The average IT2FS numbers and normalized weights corresponding to each PSF are given in Table 7.

In the following process, SLI values for each task were obtained using equation (10) [5,50,51], and HEP values were computed using equation (11) [5,52]. In this context, the SLI, log (HEP), and HEP values obtained for each task are given in Table 8.

4. Findings and Discussion

In this study, HEP values were obtained for each subtask expected to be performed by the ship's personnel during the cargo-unloading operation on bulk carrier ships. The subtask with the highest HEP value during unloading operations carried out on such ships was found to be 2.4 (Make sure the ballast operation continues in the scheduled order) with a HEP value of 9.74E-01. This result shows that the subtask is (2.4), where the probability of the ship crew making a mistake during the unloading of bulk carriers is the highest. It is thought that the increase in the cargo discharging capacities of the ports and the failure to comply with the planned unloading sequence have a significant impact on this. During ship-unloading operations, ballast is taken simultaneously with the discharged cargo holds [54]. For this, the capacity of the ship's ballast pumps and the cargo discharge capacity of the port are considered. If a compromise cannot be reached between these two critical parameters, undesirable situations, such as delays or premature termination, may occur in the scheduled ballast operations. In addition, the indifference of the ship personnel responsible for the ballast operation to the operation, not having the tank water levels measured on time, and not using the ballast pumps efficiently can also be an obstacle to the fulfillment of subtask 2.4. To eliminate this risk, it is necessary to reach a full agreement between the ship and the port on the cargo discharge plans before the cargo unloading operation begins [55]. Ship personnel responsible for ballast operation should always be careful, check tank levels at regular intervals, and use ballast pumps at the appropriate level and capacity.

The subtask with the second highest HEP value was obtained as 2.1 (Do not allow excessive trim/list formation on board

Table 2. *Profile details of the experts*

Marine Expert	Professional Position	Competency	Educational Level	Experiences with Bulk carriers (Years)	Age
1	Operational Manager	Oceangoing Master	Bachelor's Degree	25	52
2	Designated Person Ashore	Oceangoing Master	Master's Degree	24	50
3	Designated Person Ashore	Oceangoing Master	Bachelor's Degree	25	51
4	Designated Person Ashore	Oceangoing Master	Master's Degree	25	53
5	Superintendent	Oceangoing Master	Master's Degree	25	54
6	Superintendent	Oceangoing Master	Master's Degree	26	50
7	Designated Person Ashore	Oceangoing Master	Master's Degree	24	50
8	Operational Manager	Oceangoing Master	Master's Degree	24	51
9	Designated Person Ashore	Oceangoing Master	Bachelor's Degree	23	54
10	Designated Person Ashore	Oceangoing Master	Bachelor's Degree	24	51

Table 3. *PSFs that impact the specified tasks*

PSF No	The description of the PSFs
PSF 1	Fatigue
PSF 2	Training
PSF 3	Experiences
PSF 4	Stress level
PSF 5	Safety culture
PSF 6	Complexity
PSF 7	Communication

ship) with an HEP value of 9.20E-01. It is thought that the lack of experience and training of the responsible personnel is of great importance in the emergence of failures during the fulfillment of this task. In addition, it should not be overlooked that it is very tedious to constantly check the ship list and trim in a working environment where cargo discharge continues rapidly and many tasks are carried out by the personnel simultaneously. In this respect, the distribution of duties must be made clearly and precisely in order not to exceed the ship's stability limits and to safely complete the load unloading operation. In addition, this should be stated in writing in the company's safety SMS. In addition, before joining the ship, it should be tested that the officer responsible for cargo and stability and other ship personnel assisting in this regard have sufficient knowledge and experience. In addition, detailed training should be provided to the ship's personnel in this regard.

The third subtask with the highest HEP value was found to be 3.10 (Ensure that no one is in the cargo holds before closing the hatch covers) with an HEP value of 8.93E-01. Closing hatch covers can have devastating consequences if port workers or ship crew is present inside the hold, on the stairs, or on platforms. As a result of closing the hatch covers, a dark environment will be created inside the cargo holds. This situation may cause injury or even death of

Table 4. *Geometric means of PSF ratings based on marine experts' judgments*

	PSFs						
Sub-Tasks	Fatigue	Training	Experiences	Stress	Safety Culture	Complexity	Communication
1							
1.1	5	4	4	5	5	5	5
1.2	4	5	4	6	5	5	5
1.3	5	5	5	6	4	6	3
1.4	4	5	5	5	3	5	3
2							
2.1	3	3	3	3	3	3	3
2.2	4	4	5	6	3	4	4
2.3	3	3	3	3	2	3	3
2.4	4	3	3	3	2	3	2
2.5	4	5	4	6	4	5	5
3							
3.1	4	4	4	6	4	5	6
3.2	5	5	5	5	5	5	3
3.3	4	4	3	5	2	5	5
3.4	5	4	5	6	3	5	6
3.5	5	4	5	6	4	5	5
3.6	5	5	5	6	3	5	5
3.7	5	4	4	5	3	6	3
3.8	5	5	4	6	3	5	5
3.9	4	5	5	5	4	5	5
3.10	3	4	3	3	2	3	2
3.11	4	5	4	6	4	4	4
3.12	5	3	3	6	2	7	6
3.13	4	3	4	4	2	3	3
3.14	4	4	4	6	3	4	5
3.15	3	2	3	3	2	4	3

Table 5. *Linguistic terms and the corresponding IT2FS numbers [5]*

Linguistic Terms	Abbreviations	Equivalent IT2FS numbers
Very Low	VL	((0.0;0.0;0.0;0.1;1.0;1.0), (0.0;0.0;0.0;0.05;0.9;0.9))
Low	L	((0.0;0.1;0.1;0.3;1.0;1.0), (0.05;0.1;0.1;0.2;0.9;0.9))
Medium Low	ML	((0.1;0.3;0.3;0.5;1.0;1.0), (0.2;0.3;0.3;0.4;0.9;0.9))
Medium	M	((0.3;0.5;0.5;0.7;1.0;1.0), (0.4;0.5;0.5;0.6;0.9;0.9))
Medium High	MH	((0.5;0.7;0.7;0.9;1.0;1.0), (0.6;0.7;0.7;0.8;0.9;0.9))
High	H	((0.7;0.9;0.9;1.0;1.0;1.0), (0.8;0.9;0.9;0.95;0.9;0.9))
Very High	VH	((0.9;1.0;1.0;1.0;1.0;1.0), (0.95;1.0;1.0;1.0;0.9;0.9))

Table 6. *Linguistic judgments of marine experts for each PSF determined*

PSFs	E.1	E.2	E.3	E.4	E.5	E.6	E.7	E.8	E.9	E.10
Fatigue	H	MH	VH	M	VH	H	H	VH	MH	H
Training	VH	H	VH	VH	VH	VH	H	H	VH	VH
Experience	VH	MH	VH	VH	VH	H	MH	VH	H	VH
Stress Level	MH	MH	ML	L	H	H	M	M	MH	M
Safety Culture	H	MH	H	VH	H	H	H	MH	VH	MH
Complexity	ML	ML	MH	H	M	ML	M	M	H	VH
Communication	H	VH	H	VH	VH	H	MH	VH	VH	VH

Table 7. *Calculated mean IT2F values and normalized weights for each PSF*

PSFs	Mean , IT2FSs	Normalised Weight
Fatigue	((0.68;0.85;0.85;0.95;1;1) , (0.77;0.85;0.85;0.9;0.9;0.9))	0.148
Training	((0.84;0.97;0.97;1;1;1) , (0.91;0.97;0.97;0.99;0.9;0.9))	0.165
Experience	((0.78;0.92;0.92;0.98;1;1) , (0.85;0.92;0.92;0.95;0.9;0.9))	0.158
Stress Level	((0.39;0.58;0.58;0.76;1;1) , (0.49;0.58;0.58;0.67;0.9;0.9))	0.108
Safety Culture	((0.68;0.86;0.86;0.97;1;1) , (0.77;0.86;0.86;0.92;0.9;0.9))	0.151
Complexity	((0.4;0.59;0.59;0.75;1;1) , (0.5;0.59;0.59;0.67;0.9;0.9))	0.109
Communication	((0.8;0.94;0.94;0.99;1;1) , (0.87;0.94;0.94;0.97;0.9;0.9))	0.161
Total		**1**

the personnel on the platforms or on the stairs inside the cargo holds by falling. In addition, it may cause the death of personnel exposed to an airless environment after a certain period. In this respect, the hatch covers of the ship must be checked in detail before closing. These controls should be done not only by looking from the hatch coamings but also by entering the cargo holds safely, and it should be reported by walkie talkie that there is no one in the hatch.

Another subtask with the highest HEP value was calculated as 3.15 (make sure the limit switches of deck cargo cranes are set correctly to be used proper angle) with HEP values of 6.39E-01. On bulk carriers, unloading operations can sometimes be performed by the ship's own deck cargo cranes. Therefore, limit switches play a decisive role in the safe use of deck cargo cranes by adjusting the tilt angle. In this regard, adjustments outside the safe limits may cause damage or even breakage of the deck cranes. It is thought that the selection of unsuitable personnel, the lack of training and experience are quite effective in making this mistake quite often. In this respect, according to the company SMS, it is necessary to be very meticulous in the selection of personnel held responsible for this subtask. It should be ensured that the selected personnel have experience with crane bulk carrier vessels. In addition, necessary checks for deck cranes and limit switches should be performed before each cargo unloading operation, and improper limit switch angle adjustments that could lead to possible unsafe use should be avoided [56].

Because of the analysis performed for PSFs, it is understood that the most effective PSF on the tasks/subtasks expected to be fulfilled by the ship's personnel is training with 0.165 weighting value. This was followed by communication with a weight value of 0.161. In addition, another effective PSF was

***Table 8.** Obtained SLI and HEP values for each task*

Sub-Task	Calculated SLI	Log -HEP	HEP
1.			
1.1	4.51	-4.23	5.90E-05
1.2	4.70	-4.71	1.96E-05
1.3	4.72	-4.78	1.68E-05
1.4	4.25	-3.54	2.90E-04
2.			
2.1	2.90	-0.04	9.20E-01
2.2	4.24	-3.53	2.98E-04
2.3	2.97	-0.23	5.92E-01
2.4	2.89	-0.01	9.74E-01
2.5	4.70	-4.72	1.90E-05
3.			
3.1	4.80	-4.98	1.05E-05
3.2	4.71	-4.76	1.74E-05
3.3	3.98	-2.85	1.40E-03
3.4	4.74	-4.83	1.49E-05
3.5	4.75	-4.86	1.38E-05
3.6	4.79	-4.96	1.09E-05
3.7	4.24	-3.52	3.04E-04
3.8	4.60	-4.46	3.47E-05
3.9	4.73	-4.79	1.63E-05
3.10	2.90	-0.05	8.93E-01
3.11	4.30	-3.69	2.04E-04
3.12	4.37	-3.87	1.34E-04
3.13	3.30	-1.08	8.34E-02
3.14	4.34	-3.79	1.62E-04
3.15	2.96	-0.19	6.39E-01

obtained with a weight value of 0.158. In this respect, special attention should be paid to these 3 critical PSFs to eliminate possible human errors during unloading operations and to perform safer operations on bulk carrier ships. Therefore, sufficient training should be given to the ship's personnel and attention should be paid to the selection of experienced personnel. Furthermore, during the unloading operation, effective communication should be established between onboard personnel and the shipport.

From another viewpoint, with the human error estimation approach obtained using both SLIM and IT2FS methods, human errors were evaluated both qualitatively and quantitatively. Thus, this study provides an opportunity to express the potential human errors encountered in this process and the possibilities of their occurrence in a more striking way considering numerical data. In addition, this study is the first to predict potential human errors that may occur in cargo unloading operations on bulk carriers and the probability of these errors occurring. In this respect, this study contributes to the academic literature. In addition, this approach obtained within the scope of this study will contribute to the measurement of human errors and their probability of occurrence in different areas of the maritime industry. Furthermore, because the outputs of the study highlight the human errors that are frequently made during cargo unloading operations on bulk carriers, it will raise awareness among all ship staff to prevent such mistakes. Thus, it will contribute to the execution of safer operations by preventing future accidents during the cargo-unloading operation of bulk carrier ships. This will not only contribute to the prevention of possible loss of life but also to the prevention of economic losses that may be encountered. In addition, by evaluating the most common human errors in unloading operations, new protective and preventive rules can be introduced by policy makers to prevent such errors from recurring. Thus, a more sustainable maritime transport environment will be created.

5. Conclusion

Preventing human errors that may be encountered during cargo unloading operations on bulk carrier ships is of critical importance for increasing operational safety. In this respect, estimating human errors in operational processes is an important approach for preventing possible accidents and loss of life [5]. In this study, the HEP occurring in the tasks/subtasks expected to be performed by the ship's personnel during the cargo unloading of bulk carrier ships has been estimated. Thus, the first three subtasks with the highest HEP values during cargo unloading operations of bulk carriers were found to be 2.4 (Make sure the ballast operation continues in the scheduled order), 2.1 (Do not allow excessive trim/list formation on board ship), and 3.10 (Ensure that no one is in the cargo holds before closing the hatch covers) In addition, the PSFs most effective on the tasks/subtasks to be performed during this operational process have been determined. It has been concluded that these are training, communication, and experience. In addition, a quantitative HEP estimation approach based on SLIM and IT2FS, which can be used for other specific areas in the future, was obtained.

From another point of view, in the estimation of human errors that may occur during cargo unloading operations on bulk carrier ships, the evaluations were made regardless of the type of bulk cargo being unloaded. In this respect, the study has a generic feature and is a source for future cargo-specific studies. It is thought that future studies on the prediction of human errors that may occur during the discharging of bulk cargoes with flammable properties, such as bulk coal or sulfur, will contribute to the literature.

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References

[1] United Nations Conference on Trade and Development (UNCTAD) (2022). Review of Maritime Transport 2022. Geneva: United Nations.

[2] IMO (2004). Human Element Vision, Principles and Goals for the Organization. Resolution A.947(23). London: IMO.

[3] K. Pazouki, N. Forbes, R. A. Norman, and M. D. Woodward, "Investigation on the impact of human-automation interaction in maritime operations." *Ocean Engineering*, vol. 153, pp. 297-304, Apr 2018.

[4] D. A. Wiegmann, and S. A. Shappell, "A human error approach to aviation accident analysis: The human factors analysis and classification system." Routledge. 2017.

[5] P. Erdem, and E. Akyuz, "An interval type-2 fuzzy SLIM approach to predict human error in maritime transportation." *Ocean Engineering*, vol. 232, pp. 109161, 2021

[6] International Association Of Classification Societies (IACS). Bulk carriers, Guidance and Information on Bulk Cargo Loading and Discharging to Reduce the Likelihood of Over-stressing the Hull Structure. London: IACS. 2018.

[7] The North of England P&I Association Limited. Bulk Cargoes: A guide to good practice. The Quayside, Newcastle upon Tyne, UK: The North of England P&I Association Limited. 2015.

[8] H. Rozuhan, M. Muhammad, and U. M. Niazi, "Probabilistic risk assessment of offshore installation hydrocarbon releases leading to fire and explosion, incorporating system and human reliability analysis." *Applied Ocean Research*, vol. 101, pp. 102282, Aug 2020.

[9] R. Islam, and H. Yu, "Chapter three - human factors in marine and offshore systems" *Methods in Chemical Process Safety,* vol. 2, pp. 145-167 2018

[10] D. G. DiMattia, F. I. Khan, and P. R. Amyotte, "Determination of human error probabilities for offshore platform musters." *Journal of Loss Prevention in the Process Industries*, vol. 18, pp. 488-501, July-November 2005.

[11] D. G. DiMattia, "Human error probabilty index for offshore platform musters. (Doctoral dissertation)." Halifax, NS, Canada: Dalhousie University. 2004.

[12] R. G. Bea, "Risk assessment and management of offshore structures." *Progress in Structural Engineering and Materials,* vol. 3, pp. 180-187, Aug 2001

[13] M. A. B. Alvarenga, P. F. Frutuoso e Melo, and R. A. Fonseca, "A critical review of methods and models for evaluating organizational factors in human reliability analysis." *Progress in Nuclear Energy,* vol. 75, pp. 25-41, 2014.

[14] I. Jang, A. R. Kim, M. A. S. Al Harbi, S. J. Lee, H. G. Kang, and P.H. Seong, "An empirical study on the basic human error probabilities for NPP advanced main control room operation using soft control." *Nuclear Engineering and Design*, vol. 257, pp. 79-87, April 2013.

[15] W. Wang, X. Liu, and Y. Qin, "A modified HEART method with FANP for human error assessment in high-speed railway dispatching tasks." *International Journal of Industrial Ergonomics,* vol. 67, pp. 242-258, Sep 2018

[16] M. Grozdanovic, "Usage of human reliability quantification methods." *International Journal of Occupational Safety and Ergonomics*, vol. 11, pp. 153-159, 2005

[17] D. E. Embrey, T. Kontogiannis, and M. Green, Guidelines for Preventing Human Error in Process Safety. Center for Chemical Process Safety. New York: American Institute of Chemical Engineers. 1994.

[18] S. T. Ung, "Evaluation of human error contribution to oil tanker collision using fault tree analysis and modified fuzzy Bayesian Network based CREAM." *Ocean Engineering*, vol. 179, pp. 159-172, May 2019.

[19] E. Akyuz, and E. Celik, "A quantitative risk analysis by using interval type-2 fuzzy FMEA approach: the case of oil spill." *Maritime Policy & Management*, vol. 45, pp. 979-994, 2018.

[20] Y. T. Xi, Z. L. Yang, Q. G. Fang, W. J. Chen, and J. Wang, "A new hybrid approach to human error probability quantification–applications in maritime operations." *Ocean Engineering*, vol. 138, pp. 45-54, July 2017.

[21] B. Wu, X. Yan, Y. Wang, and C. G. Soares, "An evidential reasoning-based CREAM to human reliability analysis in maritime accident process." *Risk Analysis*, vol. 37, pp. 1936-1957, Jan 2017.

[22] M. Konstandinidou, Z. Nivolianitou, C. Kiranoudis, and N. Markatos, "A fuzzy modeling application of CREAM methodology for human reliability analysis." *Reliability Engineering & System Safety*, vol. 91, pp. 706-716, June 2006.

[23] A. D. Swain, and H. E. Guttmann. Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications. Washington, DC: Nuclear Regulatory Commission. 1983.

[24] D. E. Embrey, P.C. Humphreys, E.A. Rosa, B. Kirwan, and K. Rea. SLIMMAUD: an approach to assessing human error probabilities using structured expert judgement. NUREG/CR-3518. Washington DC : US Nuclear Regulatory Commission. 1984.

[25] J. C. Williams, "A data-based method for assessing and reducing human error to improve operational performance. *In: Proceedings of IEEE 4th Conference on Human Factor and Power Plants.* Monterey, California, pp. 436-450, 1988

[26] S. E. Cooper, A. M. Ramey-Smith, and J. Wreathall, "A technique for human event analysis (ATHEANA) – technical basis and methodological description." Upton (NY): Brookhaven National Laboratory; 1996. (US Nuclear Reg- ulatory Commission; report no. NUREG/CR-6350).

[27] E. Hollnagel. Cognitive Reliability and Error Analysis Method (CREAM). (1st edition). Elsevier. 1998.

[28] D. I. Gertman, H. S. Blackman, J. L. Marble, C. Smith, and R. L. Boring. The SPAR-H human reliability analysis method. In: Fourth American Nuclear Society International Topical Meeting on Nuclear plant Instrumentation, Controls and human-machine interface technologies (NPIC &HMIT 2004). pp. 1-8, Columbus-Ohio.

[29] Almond, R. "An extended example for testing graphical belief." *Statistical Science Research Report 6,* 1-18, 1992.

[30] X. He, Y. Wang, Z. Shen, and X. Huang, "A simplified CREAM prospective quantifi- cation process and its application." *Reliability Engineering & System Safety*, vol. 93, pp. 298-306, 2008.

[31] L. A. Zadeh, "Fuzzy sets." *Information and Control,* vol. 8, 338-353, June 1965.

[32] L. A. Zadeh, "The concept of a linguistic variable and ıts application to approximate reasoning-1," *Information Sciences*, vol. 8, pp. 199-249, 1975.

[33] O. Castillo, and P. Melin, "Type-2 fuzzy logic: theory and applications." Springer-Verlag Berlin Heidelberg. 2008.

[34] J. M. Mendel, "Advances in type-2 fuzzy sets and systems." *Information Sciences*, vol. 177, pp. 84-110, 2007.

[35] E. Celik, and E. Akyuz, "Application of interval type-2 fuzzy sets DEMATEL methods in maritime transportation: the case of ship collision." *International Journal of Maritime Engineering*, vol. 158, pp. 359-371, 2016.

[36] J. M. Mendel, R. I. John, and F. Liu, "Interval type-2 fuzzy logic systems made simple." *IEEE Transactions on Fuzzy Systems*, vol. 14, pp. 808-821, Dec 2006

[37] S. M. Chen, and L. W. Lee, "Fuzzy multiple attributes group decision-making based on the interval type-2 TOPSIS method." *Expert Systems with Applications*, vol. 37, pp. 2790-2798, 2010

[38] E. Celik, O. N. Bilisik, M. Erdogan, A. T. Gumus, and H. Baracli, "An integrated novel interval type-2 fuzzy MCDM method to improve customer satisfaction in public transportation for Istanbul." *Transportation Research Part E: Logistics and Transportation Review*, vol. 58, pp. 28-51, Nov 2013.

[39] E. Celik, and E. Akyuz, "An interval type-2 fuzzy AHP and TOPSIS methods for decision-making problems in maritime transportation engineering: the case of ship loader." *Ocean Engineering*, vol. 155, pp. 371-381, May 2018.

[40] C. Kahraman, B. Öztayşi, İ. U. Sarı, and E. Turanoğlu, "Fuzzy analytic hierarchy process with interval type-2 fuzzy sets." *Knowledge-Based Systems*, vol. 59, pp. 48-57, March 2014

[41] K. S. Park, and J. in Lee, "A new method for estimating human error probabilities: AHP–SLIM." *Reliability Engineering & System Safety*, vol. 93, pp. 578-587, April 2008.

[42] A. Zare, N. Hoboubi, S. Farahbakhsh, and M. Jahangiri, "Applying analytic hierarchy process and failure likelihood index method (AHP-FLIM) to assess human reliability in critical and sensitive jobs of a petrochemical industry." *Heliyon*, vol. 8, pp. e09509, 2022.

[43] J. L. Zhou, Z. T. Yu, and R. B. Xiao, "A large-scale group Success Likelihood Index Method to estimate human error probabilities in the railway driving process." *Reliability Engineering & System Safety*, vol. 228, pp. 108809, Dec 2022

[44] R. Abbassi, F. Khan, V. Garaniya, S. Chai, C. Chin, and K. A. Hossain, "An integrated method for human error probability assessment during the maintenance of offshore facilities." *Process Safety and Environmental Protection*, vol. 94, pp. 172-179, March 2015.

[45] J. Tu, and Y. Lou. "A SLIM based methodology for human reliability analysis of lifting operations." In *Proceedings of 2013 International Conference on Mechatronic Sciences, Electric Engineering and Computer (MEC).* IEEE, pp. 322-325, Dec 2013.

[46] G. Kayisoglu, B. Gunes, and E. B. Besikci, "SLIM based methodology for human error probability calculation of bunker spills in maritime operations." *Reliability Engineering & System Safety*, vol. 217, pp. 108052, 2022.

[47] R. Islam, H. Yu, R. Abbassi, V. Garaniya, and F. Khan, "Development of a monograph for human error likelihood assessment in marine operations." *Safety Science*, vol. 91, pp. 33-39, Jan 2017.

[48] F. E. Kizilay, O. Arslan, E. Akyuz, and T. Kececi, "Prediction of human error probabilitiy for officers during watchkeeping process under SLIM approach." *Australian Journal of Maritime & Ocean Affairs*, 1-18, Jan 2023.

[49] E. Akyuz, "Quantitative human error assessment during abandon ship procedures in maritime transportation." *Ocean Engineering*, vol. 120, pp. 21-29, July 2016.

[50] J. Liu, et al. "Prediction of human–machine interface (HMI) operational errors for maritime autonomous surface ships (MASS)." *Journal of Marine Science and Technology*, vol. 27, pp. 293-306, 2022.

[51] R. Islam, R. Abbassi, V. Garaniya, and F. I. Khan, "Determination of human error probabilities for the maintenance operations of marine engines." *Journal of Ship Production and Design*, vol. 32, pp. 226-234, Nov 2016.

[52] E. Stojiljkovic, S. Glisovic, and M. Grozdanovic, "The role of human error analysis in occupational and environmental risk assessment: a Serbian experience." *Human and Ecological Risk Assessment: An International Journal*, vol. 21, pp. 1081-1093, 2015.

[53] Ö. Uğurlu, E. Köse, U. Yıldırım, and E.Yüksekyıldız, "Marine accident analysis for collision and grounding in oil tanker using FTA method." *Maritime Policy & Management*, vol. 42, pp. 163-185, 2015.

[54] International Association of Classification Societies (IACS) (2018). Bulk carriers. London: IACS.

[55] Maritime and Coastguard Agency (MCA). Safe loading and unloading of bulk carriers 2003. Southampton: MCA.

[56] NAMCO. Crane limit switches. Available at: https://www.specialtyproducttechnologies.com/namco/applications/crane-limit-switch. Access Date: 26.04.2023.