A Fuzzy Cognitive Mapping Approach to Conduct Deficiency Investigation under SIRE 2.0 Inspection

Muhittin Orhan[1], Metin Celik[1]

Ship Inspection Report Programme (SIRE) 2.0 has recently become operational as a new vessel inspection regime in the tanker industry. This study proposes a methodology to analyse and address multiple deficiencies observed during SIRE 2.0 inspections. The methodology is structured based on Fuzzy Cognitive Mapping (FCM) to identify and analyse the causes of deficiencies derived from the International Maritime Organization (IMO) classification scheme, including the factors under key dimensions, such as diminished human performance, marine environment, safety administration, and management. An illustrative case study on a set of deficiencies has been conducted to ascertain the utility of the methodology. The results specifically reveal that inadequate situational communication and awareness, inadequate knowledge of ship procedures, regulations, and standards, inadequate supervision, being unaware of role or task responsibility, poor maintenance, etc. are the potential causes that might lead to the occurrence of deficiency items. Considering the dimension-based distributions of causes, the study highlights integrated preventive action recommendations specific to the analysed deficiency cases. Consequently, the study might help tanker shipping companies manage key challenges with SIRE 2.0 implementations.

KEY WORDS

~ SIRE 2.0
~ Tanker shipping
~ Deficiency investigation
~ Causation
~ Preventive actions

[1] Department of Basic Science, Istanbul Technical University, Tuzla 34940, Istanbul, Turkey
e-mail: muhittinorhan@yahoo.com
doi: 10.7225/toms.v12.n02.001
Received on: 13 Mar 2923; Revised on: 25 Jun 2023; Accepted on: 18 Jul 2023; Published: 21 Oct 2023

1. INTRODUCTION

Undesirable accidents in the marine domain, commonly resulting in severe outcomes such as casualties, harm to individuals, loss of cargo, impairment of equipment, and ecological contamination, are referred to as marine accidents (Wang et al., 2021; Mullai and Paulsson, 2011; Kum and Sahin, 2015; Corovic and Djurovic, 2013). According to the current literature studies, there exist two distinct strategies for preventing maritime mishaps: reactive and preventative (Hasanspahic et al., 2020). The corrective methodology encompasses the examination and evaluation of accidents through investigation and analysis to identify both the immediate and underlying causes (Celik et al., 2010). The corrective methodology suggests corrective measures and conclusions that have the potential to enhance maritime safety and mitigate the incidence of accidents, based on the results of the investigation and subsequent analysis (Bashan et al., 2020). The term corrective approach is utilised due to the fact that an incident has already transpired, resulting in harm and necessitating costly measures to enhance safety (Akyuz, 2015). The proactive nature of the second approach can be attributed to its incorporation of investigative and analytical measures aimed at identifying deficiencies and non-conformities.

The Oil Companies International Marine Forum (OCIMF) is a self-governing organisation consisting of oil companies with a vested interest in the transportation and storage of crude oil, oil derivatives, petrochemicals, and gas. This association also encompasses companies involved in offshore marine activities that facilitate oil and gas exploration, development, and production (Kartsimadakis, 2023). The objective of the OCIMF is to guarantee that the worldwide maritime sector does not inflict any negative impact on individuals or the natural world. The objective of the OCIMF is to take charge of the worldwide marine industry by advocating for secure and ecologically responsible conveyance of petroleum, oil products, petrochemicals, and gas. Additionally, the organisation aims at instilling these principles in the administration of associated offshore marine activities (Turker and Er, 2008). The task at hand involves the formulation of optimal methodologies pertaining to the conception, fabrication, and secure functionality of tankers, barges, and offshore vessels, as well as their interactions with terminals. Additionally, it is imperative to take into account the influence of human factors in all aspects of this undertaking (Kartsimadakis, 2023).

Since its establishment in 1993, the OCIMF Ship Inspection Report Programme (SIRE) has administered more than 180,000 inspection reports. Hence, the SIRE has made a substantial contribution towards enhancing the maritime industry's overall safety record. As the industry evolves, the same goes for its risk profile. Now more advanced risk measurement and management solutions (OCIMF, 2022) are accessible. In the light of this, it is now essential to reinforce SIRE and assure its continued effectiveness in the current and future maritime environment (Kacmaz et al., 2016). Along with the maritime domain, OCIMF is designing a risk-based vessel inspection program that will replace the current SIRE program. SIRE 2.0 will provide more precise data allowing OCIMF members and program participants to evaluate the quality and future performance of a vessel (Grbic et al., 2018).

Future SIRE 2.0 implementations will incorporate all OCIMF inspection programmes. This includes OCIMF's Barge Inspection Report (BIRE) programme and the Offshore Vessel Inspection Database (OVID). The regime emphasises four major areas such as accuracy, capability, reliability, and adaptability (OCIMF, 2022). The SIRE 2.0 uses a risk-based methodology, a more complete inspection regime with upgraded tools, better governance mechanisms, and more detailed reporting outcomes (Arslan et al., 2016). The inspection regime comprises enhanced inspection standards for equipment, processes, and human factors to promote vessel safety and process control (Christensen, 2013). The use of web-enabled tablets and phones to record and document inspections and comments in real time, in addition to allowing inspections (Cebi et al., 2009). During the SIRE 2.0 inspection deficiencies, described as "an observable scenario where objective evidence shows the non-fulfilment of a specific condition," are identified. Examining the potential causes may be utilized to identify the key points potentially impacting the operational safety of tanker ships (Grbic et al., 2018).

The aim of this study is to examine the SIRE 2.0 deficiency cases and prioritise the potential causes found by using the FCM method and IMO Classification Scheme (HTW 8/INF.3). In this context, the deficiency cases examined have been classified into five dimensions: primarily diminished human performance, marine environment, safety administration, management, and mental action. Then, for each deficiency case, potential causes have been identified by experts, and potential causes prioritised using the FCM method. In this context, it is thought that the study may contribute towards the safety and deficiency investigations on tanker ships.

The organisation of the study is as follows: The first section covers the introduction part of the study. After the introduction section, the results of the literature review will be given in the second section. Then, in the third section, the proposed model will be examined. Furthermore, in the fourth section, the results of the case study will be discussed and the application results of the model will be shown. Finally, in the fifth section, the results will be discussed and suggestions for future studies will be made.

2. LITERATURE REVIEW

In this section, tanker safety, tanker management, SIRE 2.0, deficiency investigation, and FCM studies in the current literature will be discussed.

Understanding the nonconformities is essential for averting accidents on tanker ships Due to the possibility of maritime accidents, nonconformities have the potential to harm individuals, the marine environment, and cargo. Consequently, maritime safety experts concentrate on analysing tanker ship nonconformities and inadequacies. For instance, Maritime Gamentor, a gamified mentoring tool for managing crew upskilling in tanker vetting, standards has been developed. They have examined the newly updated requirements of the SIRE 2.0 and OCIMF in order to conceptualise a comprehensive serious game-based teaching solution (Gurbuz and Celik, 2022). In another study, the authors have emphasised the significance of operational components. In their article the authors have employed the Fuzzy Analytic Hierarchy Process (FAHP) technique to develop a schedule for Vessel Inspection Questionnaire (VIQ) execution in the tanker shipping industry (Raman and Shankaranarayanan, 2018), having conducted extensive data mining to examine the benefits of standards and potential future changes (Heij et al., 2011). Similarly, a thorough data-base has been analysed in order to evaluate tanker ship nonconformities and their root causes (Arslan et al., 2016).

Regular SIRE inspections can improve tanker safety and provide a consistent level of service quality in the tanker shipping industry. During SIRE inspections, non-conformities are identified. Non-conformities are defined as situations where objective evidence indicates that a specified requirement has not been fulfilled (Christensen, 2013). The SIRE inspection reports on non-conformities do not culminate in the detention of the vessel; rather, they enable the charterer to assess the ship's state. The prevalent non-conformities identified in SIRE inspections pertain to human factors, managerial inadequacies, navigational insufficiencies, and cargo equipment (Arslan et al., 2016). The process of pre-vetting inspection, when combined with in-person training, is deemed crucial to enhancing safety and ensuring environmental compliance on tanker ships. This study (Gurbuz and Celik, 2022) developed a maritime augmented mentoring platform, called Maritime Gamentor, as a component of pre-vetting services. The purpose of this platform is to facilitate crew members’ development in tanker vetting necessities. At this juncture, the investigation takes into account the updated prerequisites of the Ship Inspection Report (SIRE 2.0) Programme of the Oil Companies International Marine Forum (OCIMF) in order to develop a comprehensive training solution based on serious gaming. Subsequently, a comprehensive and systematic methodology for the initial design, construction, and prototyping of serious games pertaining to the maritime domain is explained in a sequential manner. The present study focuses on Clause 5.1.4 of SIRE 2.0 and employs a case study approach to investigate the Maritime Gamentor Module-01. Specifically, the study utilises a task-oriented risk assessment (TBRA) to evaluate the enclosed space access operation. Thus the Maritime Gamentor has been conceptualised as a potent educational and mentoring platform catering to the needs of international shipping corporations.

The present study (Soner et al., 2015) puts forth a proactive modelling methodology that integrates Fuzzy Cognitive Mapping (FCM) and Human Factors Analysis and Classification System (HFACS). The proposed model primarily aids in the prediction and mitigation of underlying factors that contribute towards recurrent deficiencies observed on ships. The HFACS-FCM model is exemplified on a database of deficiencies related to fire, with qualitative simulations providing support for the model. The research findings suggest that the underlying factors contributing to a fire-related deficiency on a vessel may be identified at multiple levels, including unsafe actions, pre-existing conditions for unsafe actions, inadequate supervision, and organisational influences. The Safe Ship System Mechanism (SSSM), Safe Ship Operation Mechanism (SSOM), and Safe Ship Execution Mechanism (SSEM) have been established based on a thorough analysis of the underlying root causes and their respective levels of importance. The present study (Akyuz and Celik, 2014) employs a methodology that integrates the Human Factors Analysis and Classification System (HFACS) with Cognitive Map (CM) for the purpose of analysing marine accidents. The HFACS-CM model is acknowledged as a hybrid accident analysis methodology that incorporates operational evidence to provide a distribution of human error. The proposed investigative framework is utilised to examine several instances of marine accidents with the aim of scrutinising the involvement of human elements in the sequence of occurrences. The HFACS-CM approach is demonstrated in practice through the use of a man overboard scenario throughout a lifeboat drill, which is a crucial component of the evacuation protocol on cruise ships.

The present research (Aydin et al., 2022) introduces a methodology aimed at conducting a comprehensive analysis of inspection and audit results collected from multiple sources within a fleet of ships. The ultimate goal of this approach is to facilitate the systematic implementation of proactive measures. The multi-source inspection database comprises benchmarking datasets of various fleets, in addition to the vessel audit reports of Company-A, operating 16 bulk vessels in the Black Sea and the Mediterranean. This article (Wu et al., 2022) provides an overview of the sophisticated methodologies utilised for examining human and organisational variables, which are the primary contributors to maritime mishaps. Additionally, it explores the diverse efforts undertaken to mitigate human errors through recognising the extant obstacles. The paper provides a comprehensive analysis and discussion of advanced techniques for modelling human and organisational factors. These techniques include the identification of human errors in accident investigation, quantification of human error probability in risk analysis, and analysis of human and organisational factors in emergency situations.

Fuzzy Cognitive Mapping, evolving from the traditional cognitive mapping approach developed by Kosko (1986), is an illustrated causal representation (Papakostas et al., 2008). Fuzzy cognitive mapping, which combines aspects of fuzzy logic with neural networks, has been shown to be a viable strategy for forming inferences in circumstances of significant ambiguity, imprecision, and vagueness (Tsadiras, 2008).

The majority of FCM models are built mostly on expert knowledge and system operation experience. In fuzzy cognitive mapping, aggregating information from different experts is a very simple process (Obiedat and Samarasinghe, 2013). Each expert characterises each link, using linguistic variables.

The iterative technique can be more precisely defined as follows: The FCM should be initialised first. In other words, each concept's activation level is assigned a value based on an expert judgement about its current condition or measurements from the real system. Let each concept start with $A_i^{(t)}$, where A_i is the value of concept i at step t, and then simulate repeatedly. The value of each notion in an iteration is subsequently computed (Papageorgiou et al., 2009):

$$A_i^{(t+1)} = f\left(A_i^{(t)} + \sum_{\substack{j=1,\\ j\neq i}}^{n} A_j^{(t)} W_{ji}\right) \tag{1}$$

When the maritime domain studies on FCM were examined, many different studies were found, mostly prioritisation. Some of these studies focus on human factors, root cause finding, route optimisation, and accident analysis. For example, Navas de Maya et al. (2018) offer the initial findings of a study whose objective is to evaluate the elements influencing collision incidents. FCMs approach, calculating and assigning distinct weights to each of these factors in order to evaluate and determine their relative significance. Wang et al. (2019), suggest a method combining a fuzzy inference system with evidential reasoning in order to transform the initial input values of variables. To improve the model, a nonlinear Hebbian learning technique is applied. This work offers a means for maritime safety decision-makers to comprehend the navigational safety state and predict its future development. In addition, (Bakhtavar et al., 2021) examine the uses and developments of FCMs in the field of systems risk analysis until August 2020.

3. PROPOSED MODEL

This section contains a description of the methodology used in the study. To understand the proposed model, first of all, the IMO classification scheme (HTW 8/INF. 3) will be explained, upon which the details of the proposed model will be examined in the Conceptual Framework section. Later, the details of the stages of the FCM method used, such as cause determination, fuzzification, defuzzification, and prioritisation, will be mentioned.

3.1. IMO Classification Scheme (HTW 8/INF. 3)

A comparison of the classification criteria between Human Factor Analysis and Classification System (HFACS) and common human element terms of the IMO, classification scheme dimensions, and distributions of causes are determined.

Divergences are present between the IMO human factor classification and the Human Factors Analysis and Classification System (HFACS) regarding the hierarchical classification of causal factors. The latter is extensively utilised in the research to elucidate the precise causal factors associated with accidents. As delineated in Annex 2, the human factor classification systems of the International Maritime Organization (IMO) and the Human Factors Analysis and Classification System (HFACS) demonstrate a significant 92% congruity in their respective delineations of causal factors. The classification criteria in the initial layer exhibit dissimilarities between the HFACS and IMO classification systems (IMO, 2021). The HFACS employs the designations "external factors", "organisational influences", "unsafe supervision", "unsafe acts" and "preconditions for unsafe acts", while the IMO classification system employs the terms "diminished human performance", "marine environment", "safety administration", "management", and "mental action". The classification of human factors (HFs) within the framework of the Human Factors Analysis and Classification System (HFACS) is founded on the Swiss Cheese Model, which categorises HFs based on the accident process. In contrast, the International Maritime Organization's (IMO) classification of human factors places greater emphasis on the description of HF attributes (IMO, 2021). Furthermore, the human factors components, put forth by the International Maritime Organization (IMO), exhibit a greater level of specificity compared to those outlined in the Human Factors Analysis and Classification System (HFACS) framework (IMO, 2021). The IMO places greater emphasis on technical categorisation as opposed to analytical reasoning, as can be seen in Figure 5.

Table 1. IMO classification scheme dimensions and distributions of causes (IMO, 2021).

Dimension	Cause	Symbol
Diminished human performance (A)	Inattention	A1
	Emotional	A2
	Panic	A3
	Anxiety	A4
	Personal problem	A5
	Mental impairment	A6
	Alcohol use	A7
	Drug use	A8
	Injury	A9
	Mental illness	A10
	Physical illness	A11
	Diminished motivation	A12
	Fatigue	A13
	Low morale	A14
	Lack of self-discipline	A15
	Visual problem	A16
	Excessive workload	A17
	Deliberate misaction	A18
Marine environment (B)	Hazardous natural environment	B1
	Poor operations	B2
	Poor human factors design	B3
	Poor maintenance	B4
Safety administration (C)	Lack of communication or co-ordination	C1
	Inadequate technical knowledge	C2
	Inadequate situational communication/awareness	C3
	Inadequate knowledge of ship operations	C4
	Inadequate knowledge regulations/standards	C5
	Inadequate knowledge of ship procedures	C6
	Inadequate language skills	C7
	Unaware of role/task responsibility	C8
Management (D)	Failure to maintain discipline	D1
	Failure of command	D2
	Inadequate supervision	D3
	Inadequate co-ordination or communication	D4
	Inadequate manpower available	D5
	Inadequate management of physical resources	D6
	Inadequate manning	D7
	Poor job design	D8
	Poor regulations, policies, procedures	D9
	Misapplication of good regulations, policies, procedures	D10
Mental action (E)	Lack of situational awareness	E1
	Lack of perception	E2
	Incorrect recognition	E3
	Incorrect identification	E4

3.2. Conceptual Framework

Utilizing the IMO classification scheme (HTW 8/INF. 3) and FCM model, a new framework for SIRE 2.0 deficiency investigation and finding potential causes is introduced. The proposed model is presented in Fig. 1. Principally, it performs a great deal of proactive safety modelling.

The proposed model consists of four phases in total. In the first phase, analysis is performed for SIRE 2.0 deficiencies. In this context, ship information, risk category, operator response, and deficiency details are examined. Thus, a data pool is created for pre-investigation.

After the necessary data has been collected, the deficiencies need to be clustered and classified. In this context, the IMO classification scheme (HTW 8/INF.3) is used for cause identification. Deficiency data has been analysed and grouped according to diminished human performance, marine environment, safety administration, management, and mental action dimensions. In the completion of this process, the opinions of experts in the maritime field are used. Then each SIRE 2.0 deficiency case is indicated by symbols, such as A1, B2, C3, and D10, and the analysis phase is started. In the analysis phase, the FCM method is used to carry out the prioritisation, simulation, and verification stages (identification of causal relationships, aggregation of weights from multiple maritime experts and defuzzification etc.). It is shown in the proposed FCM methodology (see Figure 2). Finally, in line with the results of the analyses made, preventive actions and fleet circulation stages should be completed. Preventive actions are recommended considering the priority order of potential causes detected in the integration phase. Integrated Preventive Actions (IPAs) represent a set of comprehensive and coordinated measures, designed to proactively address potential risks and hazards in the maritime field. The term ‘integrated’ denotes a comprehensive and mutually beneficial approach, entailing the cooperation and synchronisation of diverse stakeholders, procedures, and mechanisms. The IPAs are strategically developed to incorporate various measures aimed at reducing risks and averting occurrences in the maritime industry. The implementation of Integrated Preventive Actions aims to cultivate a proactive safety culture within the maritime field, with a view to transitioning from a reactive approach to a preventive one. This methodology facilitates the identification of prospective hazards, assessment of their probability and impact, and execution of suitable interventions to preclude or alleviate their escalation into untoward occurrences or mishaps. Through the integration of diverse preventative measures, organisations can enhance their operational performance, adhere to regulatory mandates, and safeguard the environment (Cang et al., 2010; Dimitrios, 2012; Akpan and Ogunsola, 2015; Lazakis and Olcer, 2016; Li et al., 2020; Han et al., 2021; Song et al., 2022).

Integrated preventive actions have been developed through a collaborative effort involving six experts who have contributed to the study. Within this context, the perspectives of these experts have been solicited, and a total of five preventive actions has been identified, taking into consideration the company's requirements and capabilities as the primary factors. It is noteworthy that the proposed preventive actions are not devised on a per-cause basis, but rather on a dimensional approach. This approach aims to facilitate focused planning within departments such as training and HSEQ, ensuring that specific and well-defined preventive actions are implemented rather than multiple actions for each activated cause.

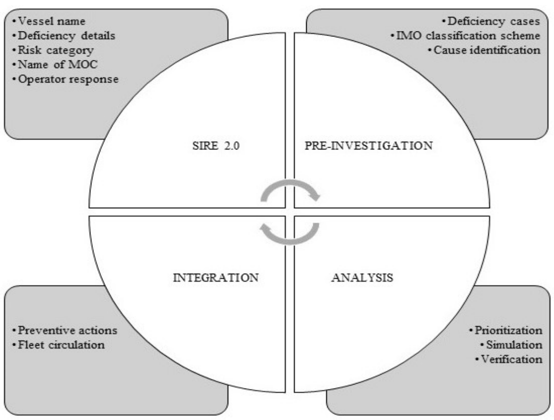

Figure 1. Conceptual framework of the model.

3.3. Modelling potential causes of SIRE 2.0 deficiencies

Prior to recommending integrated preventative actions for deficiencies, it is critical to determine the initial reasons for the existing causal chain that leads to SIRE 2.0 deficiencies on board ships. By addressing only a subset of these defects, many of the undesirable deficiencies can be avoided. A fuzzy cognitive map is generated and analysed in order to identify a list of potential causes and their priority, as summarised in Fig. 2.

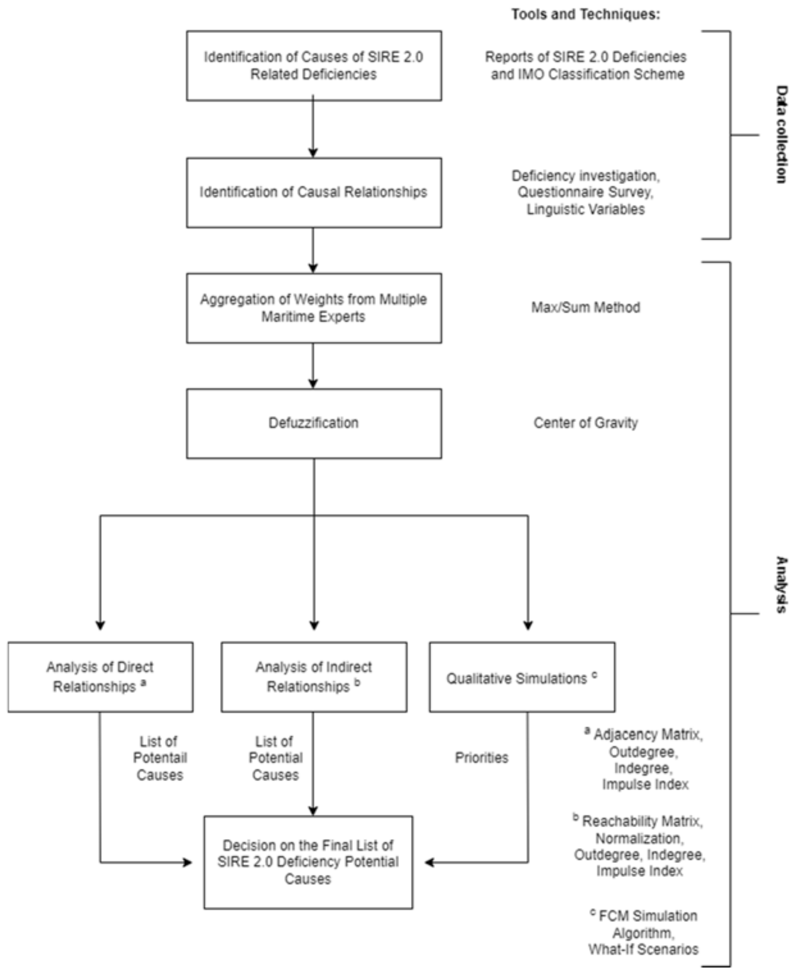

Figure 2. The illustration of proposed FCM methodology (Soner et al., 2015).

3.3.1. Step 1: Identification of causal relationships

As previously stated, the reasons (i.e. ideas in the fuzzy cognitive map) are determined by conducting a review of the SIRE 2.0 deficiencies and applying the IMO classification scheme. The causal relationships between ideas are identified in this stage with ordered pairings of concepts in a questionnaire style (see Fig. 3). This allows for a thorough assessment of all relationships.

Question	Concept i	does not affect at all	weakly affects	weakly-moderately affects	moderately affects	moderately-strongly affects	strongly affects	Concept j
1	Cause 1	O	O	O	O	O	O	Cause 2
2	Cause 1	O	O	O	O	O	O	Cause 3
...	...	...	...	...	...	...	...	...

Figure 3. Questionnaire format concept (Soner et al., 2015).

3.3.2. Step 2: Aggregation of individual weights and defuzzification

A group map has been created to increase the dependability of the final model. The overall language weights and the group adjacency matrix are created by combining the weights provided from several experts. The following equation (Ross, 2004) is used to calculate Center of Gravity, as can be seen in Fig. 4.

$$Z^* = \frac{\int \mu_{\tilde{w}_{ij}}(z)\, z\, dz}{\int \mu_{\tilde{w}_{ij}}(z) dz} \tag{2}$$

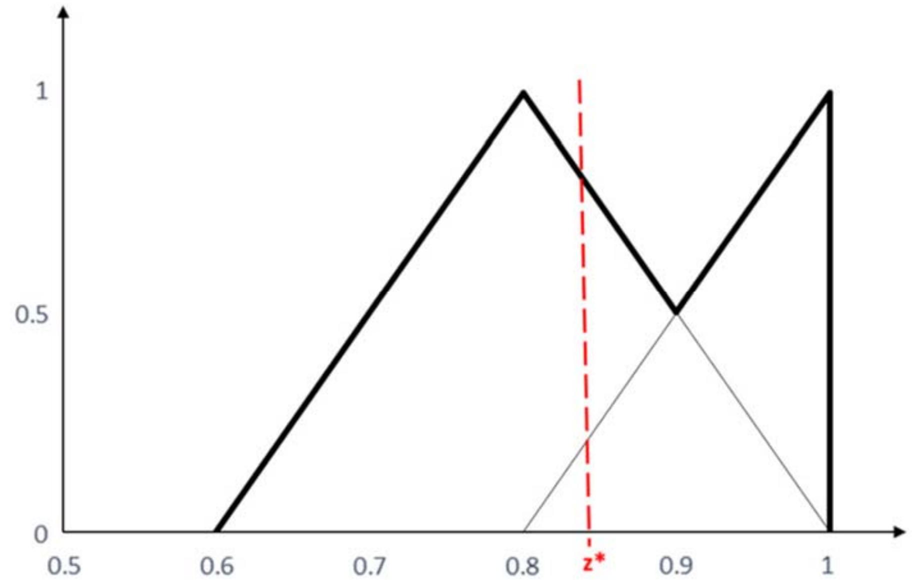

Figure 4. Illustration of CoG and MAX method (Soner et al., 2015).

3.3.3. Step 3: Identification of direct relationships

To find potential causes (i.e. initial causes in a causal map), the role of each concept in the map needs to be carefully evaluated. The outdegree (od) and indegree (id) of each variable are used to characterise it.

$$od(i) = \sum_{j=1}^{n} \left| W_{ji} \right| \tag{3}$$

$$id(i) = \sum_{j=1}^{n} \left| W_{ij} \right| \tag{4}$$

$$od(i) \geq \bar{x}_{od} \tag{5a}$$

$$|P|_i \geq 2 \tag{5b}$$

$$|P|_i = \frac{od(i)}{id(i)} \tag{6}$$

3.3.4. Step 4: Identification of indirect relationships

Examining the adjacency matrix only reveals potential causes, based on direct relationships between ideas and represented by causal chains of length one. Unfortunately, this is insufficient to identify the hidden potential causes, which can have a significant impact on the situation under investigation. As a result, the spread of causal effects via reaction routes and loops must also be considered (Asan et al., 2011). The original normalisation produced in this research may be represented as follows:

$$Nod(i)^q = \frac{max_{i=1\ldots n}\{od(i)\}.od(i)^q}{max_{i=1\ldots n}\{od(i)^q\}} \qquad (7)$$

$$Rod(i) = (od(i) + Nod(i)^2 + \cdots + Nod(i)^{n-1})/Q = \left(\sum_{q=1}^{Q} Nod(i)^q\right)\Big/Q \qquad (8)$$

The resulting indications are utilised to show potential causes that were previously believed to be inconsequential but now play a leading role due to indirect relationships. The ideas are analysed for this purpose using the same principles as mentioned in Step 3.

3.3.5. Step 5: Qualitative simulations

The steady state computation gives us an indication of the ordering and hence the overall priority of the variables with respect to each other. (Papageorgiou and Kontogianni, 2012).

The simulation process is started by giving a number in the range [0, 1] to the activation level of each idea based on expert opinion regarding a certain state. A value of zero implies that a given notion is not present in the system at that iteration, whereas a value of one shows that a given concept is present to the greatest extent possible.

The greater the number of concepts impacted (i.e. activated) by a single concept in the early iterations, the more probable the concept is a potential cause.

4. CASE STUDY

4.1. SIRE 2.0 deficiency sample database

In the study, a total of 52 SIRE 2.0 deficiency cases are first examined to create the dataset. In order to classify the examined deficiency cases using the IMO classification scheme, maritime experts have then reduced the number of deficiency cases to 12. Then the opinions of maritime experts have been taken into account to detect deficiency causes. A total of six maritime experts have taken part in this study. Three of the experts have been working on risk assessment, tanker safety, and SIRE inspections for more than five years. The other three experts are chief engineers and masters working in different departments of tanker companies, such as operations and training. After the deficiency cause determination process, the questionnaire format shown in Figure 3 has been used in order to prioritise. In this context, assistance has been received from the opinions of 24 maritime experts in total. Experts consist of experienced people, such as chief engineers, port state controllers, flag state controllers, academicians, and training superintendents. As a result of the study, interviews have been held with the six maritime experts mentioned above in the proposal and preparation of preventive actions.

4.2. Deficiency cases

In Deficiency Case #1, the inspector has detected that the new bridge equipment had several electrical wires connected loosely and unsecured, as well as in a scattered manner. The units have been operational, but the inspection covers for their electrical junction boxes have been left open, with the deck officers having to put in and remove the pen drives for the passage plans to transfer through these wires. It has been noticed that the operator’s response to this finding was left open to insert the USB pen drive for updating and loading charts, conducting corrections and synchronisations when necessary. In addition, they have found some wires untied inside the cabinet. Therefore the potential causes of this case have been primarily determined as C1, C4, C5, C6, C8, D3, D10, and E1.

In Deficiency Case #2, the inspector has determined that the vessel's daylight signal lamp was fitted with a weight of more than 7.5 kg and was not convenient according to resolution MSC.95(72) 7.3.2. It has been observed that the operator's response to this finding was that their vessel's approved complete kit consisted of the battery in the case, battery charger, transformer unit, etc. It has been consequently found that when the accessories are excluded, the bag weighs 6.5 kg. Therefore the potential causes of this case have been primarily determined as C1, C2, C5, C7, D2, D9, D10, and E2.

In Deficiency Case #3, the inspector has observed that the company form did not contain spaces for personnel entering enclosed spaces to sign the permit. Also, the inspector has determined that the attachment to the permit does not affect the crew's understanding of the safety procedures listed in the permit, as stated in the OCIMF Guidelines on Safety Management Systems for both hot work and entry into enclosed spaces (according to IMO Resolution A.1050(27)). It has been noticed that the operator's response to this finding was that the master had taken this opportunity to refresh the crew members on the enclosed space procedures and relevant documentation. Therefore the potential causes of this case have been primarily identified as C3, C6, C7, D3, D5, and E4.

In Deficiency Case #4, the inspector has indicated that there was no detector fitted to the forepeak stores by the fixed fire detection system fitted on the navigation bridge. It has been was seen that the operator's response to this finding was that they provided the paint store with a smoke detector, water sprinkler, and manually operated call point, also providing the Boatswain store with portable extinguishers. As per their class society interpretation, the Boatswain store is defined in SOLAS as a service space without any substantial fire risk. The potential causes of this case have therefore been primarily identified as A1, A4, A6, B1, B3, B4, C4, C7, and E1.

In Deficiency Case #5, the inspector has detected that the vessel was not fitted with additional life-saving equipment with buoyancy for persons weighing up to 140 kg as per SOLAS III Reg. 7 Para. 2.1.5, LSA Code 2.2.1.3, Chapter II, and MSC. 201(81). It has been observed that the operator's comment to this finding was that their total of 90 life jackets were in compliance with regulations; however, six pieces of life jackets with buoyancy were not in compliance with the MSC, LSA Code, and SOLAS III. Consequently, the potential causes of this case have been primarily detected as C1, C2, C5, C7, D2, D9, D10, and E2.

In Deficiency Case #6, the inspector has determined that there is no fitted equipment underneath the hydraulic pressure parts of both pre-provision cranes on the aft deck. Also provided were drain holes and pipes in the vicinity leading to the lower accommodation decks, which in turn were draining to the poop deck. It has been noticed that the operator's comment to this finding was that the arrangement came from the original design of the vessel. In addition, the operator responded that, as mitigating operational measures, the drain hole and pipe in the vicinity would be plugged while the provision cranes were in operation. Therefore, the potential causes of this case have been primarily detected as A4, A5, A7, B1, B3, B4, C1, C3, C6, C7, D3, D5, and E4.

In Deficiency Case #7, the inspector has observed that the fitted equipment underneath the hydraulic systems of both the port-side mooring winches was not completely enclosed and each had one. The operator's comment to this finding was that they aimed to contribute to the prevention of pollution, the height of triangular barrier plates at those two locations is being increased by cold work. Therefore, the potential causes of this case have been primarily identified as C3, C6, C7, D3, D5, and E4.

In Deficiency Case #8, the inspector has indicated that in the cargo control room several valve open-close positions were not correctly reading. The operator's response to this finding was that the vessel had properly carried out zero and span adjustments as per specific job descriptions described in PMS. However, the reason for the incorrect readings was noted to be a slight electronic calibration difference for those valves. The potential causes of this case have therefore been primarily detected as C1, C2, C5, C7, D2, D9, D10, and E2.

In Deficiency Case #9, the inspector has detected that the ventilation fan was not operational during the inspection. The operator's response to this finding was that their ventilation fan was in working condition just one day ago, and it was noticed that the electric motor was tripping upon start attempt on the next day. They have confirmed that all the vent fans were being operated as required and tested and maintained in accordance with the vessel's PMS. Therefore the potential causes of this case have been primarily detected as C1, C4, C5, C6, C8, D3, D10, and E1.

In Deficiency Case #10, the inspector has observed that all the main switchboards in the engine control room were not suitable or approved. In addition, the mats did not carry any markings on the underside, and the provided certificate on board did not have any data to be able to correlate to the mats in place. The operator's response to this finding was that they investigated and found that the last certified mats had been inadvertently used. The potential causes of this case have therefore been primarily detected as A4, A5, A7, B1, B3, B4, C1, C3, C6, C7, D3, D5, and E4.

In Deficiency Case #11, the inspector has indicated that the boiler forward glass was out of service and did not work properly during inspection. The operator's response to this finding was that the valves were closed to remove the gland joint; however, there was not sufficient time to complete this job, and the chief engineer was informed of this pending job. Consequently, the potential causes of this case have been primarily detected as C1, C4, C5, C6, C8, D3, D10, and E1.

In Deficiency Case #12, the inspector has detected that no spare life jackets were stowed within the hospital for emergency use by any patients living within the hospital in an abandon ship situation. The operator's response to this finding was that one life jacket and one immersion suit had been placed in the hospital after the inspection, and their stowage location was properly marked with relevant IMO signs in the hospital. Therefore the potential causes of this case have been primarily detected as A4, A5, A7, B1, B3, B4, C1, C3, C6, C7, D3, D5, and E4.

4.3. Analysis & Results

The language scale shown in Fig. 3 is used by experts to represent the degree of the causal relationship (weights) between two concepts. Because the number of causes examined in our FCM model is relatively large (44 different causes), it becomes a tough and time-consuming task for experts to answer all paired questions (44 * (44-1) = 1892) and the chance of experts introducing erroneous data grows (Asan and Soyer, 2009). To address this issue and make administering the questionnaire easier, the adjacency matrix is separated into ten discrete zones. These groups consist of (i) Industrial engineers (Group #1), (ii) Maritime stakeholders (Group #2), (iii) Maritime researchers (Group #3), (iv) Experienced seagoing officers/engineers (Group #4), (v) Ship management executives (Group #5), (vi) Port state control officers (Group #6).

The calculations used in the aggregate and defuzzification process in Region 10 to determine the influence of "Inadequate knowledge of ship operations (C4)" on "Inadequate knowledge of ship procedures (C6)" are as follows:

$$Z^* = \frac{\int_{0.6}^{0.8} \frac{(z-0.6)}{0.2} zdz + \int_{0.8}^{0.9} \frac{(z-1)}{-0.2} zdz + \int_{0.9}^{1} \frac{(z-0.8)}{0.2} zdz}{\int_{0.6}^{0.8} \frac{(z-0.6)}{0.2} dz + \int_{0.8}^{0.9} \frac{(z-1)}{-0.2} dz + \int_{0.9}^{1} \frac{(z-0.8)}{0.2} dz} = 0.830$$

In this scenario, the average outdegree calculated for the full idea set is around 13.4. Concept i, if $od(i) \geq 13.2$ and $|P_i| \geq 2$. For example, C3 is a potential cause, since $od(3)=20.1$, $id(3) = 4.2$ and $|P_3| = 20.1/4.2 = 4.78$. Finally, the potential causes identified are A1, A13, B4, C6, C5, D3, D8, E3 and E1.

In the investigation of indirect relationships, a similar categorisation is used. To investigate hidden potential causes, the diffusion of causal influences along reaction routes and loops is examined as follows:

$$Nod(4)^2 = \frac{max_{i=1\dots44}\{od(i)\}.od(4)^2}{max_{i=1\dots44}\{od(i)^2\}} = \frac{29.1 * 312.1}{491.2} = 18.48$$

$$Nid(4)^2 = \frac{max_{i=1\dots44}\{id(i)\}.id(4)^2}{max_{i=1\dots44}\{id(i)^2\}} = \frac{32.5 * 46.2}{391.4} = 3.83$$

$$Rod(4) = \frac{(\sum_{q=1}^{6} Nod(4)^q}{6} = \frac{20.1 + 18.48 + 16.42 + 15.24 + 15.24 + 15.24}{6} = 16.78$$

$$Rid(4) = \frac{(\sum_{q=1}^{6} Nid(4)^q}{6} = \frac{4.2 + 3.83 + 3.12 + 3.01 + 3.01 + 3.01}{6} = 3.36$$

The same principles proposed in the direct relationships analysis are used here to determine potential causes. As a result, A15, B2, C8, D10, and E4 are indicated as potential causes. Comparing the findings of the two studies can assist to validate the relevance of particular ideas as prospective causes and also discover hidden potential causes, previously assumed to be insignificant, but playing a vital role due to indirect effects.

These simulations provide insight into the overall priority of potential causes identified in the previous two phases.

For example, Inattention $A_1^{(O)}$= [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0] represents the initial vector state. The results of the 44 different scenarios indicate that the system converges toward a steady state in no more than four repetitions, and that only 19 causes achieve an activation level of exactly one (the rest ends up between 0.98-0.99). The number of concepts impacted by a certain concept in the early iterations is a significant indication in these simulations. As a consequence, the final list of potential causes is determined by combining the findings of Steps 3, 4, and 5. Table 1 summarises the findings.

The priorities are determined by averaging the rank orders of the scenarios in iterations one and two. Inadequate situational communication/awareness (C3), for example, is the most impactful potential cause, activating 36 concepts in the first iteration and 43 concepts in the second. Lastly, the potential causes are given in priority order as C3, C6, D3, C5, C8, B4, E1, D10, A1, E3, A13, B2, A15, D8 and E4.

Table 2. Priorities and final list of potential causes

Dimension	Activated cause	# of Activated concepts		Rank order w.r.t. (I1)	Rank order w.r.t. (I2)	Priority
		Iteration 1 (I1)	Iteration 2 (I2)			
Safety administration	C3	36	43	1	2	1
Mental action	E4	8	16	15	16.5	15
Safety administration	C6	33	40	2	2.5	2
Management	D8	9	19	14.5	16	14
Management	D3	31	39	2	4	3
Diminished human performance	A15	10	20	13	14.5	13
Safety administration	C5	30	36	4	5	4
Marine environment	B2	11	21	12.5	14	12
Safety administration	C8	26	35	6	5.5	5
Diminished human performance	A13	14	22	11	12.5	11
Marine environment	B4	25	34	6	7	6
Mental action	E3	17	23	10	12.5	10
Mental action	E1	24	30	7	9	7
Diminished human performance	A1	20	25	9.5	9	9
Management	D10	22	26	7	9.5	8

4.4. Integrated Preventive Actions

As a result of comprehensive analysis, inadequate situational communication/awareness, inadequate knowledge of ship procedures, regulations/standards, inadequate supervision, lack of unawareness of role/task responsibility and poor maintenance etc. are revealed as the potential causes that might lead to the occurrence of deficiency items. Considering the priorities and dimensions of the causes, integrated preventive actions are recommended as follows:

i) Applying process improvement techniques to the targeted operations (i.e. Inert Gas (IG) operation, Single Point Mooring (SPM) operation, cargo operation, etc.) in accordance with the inspection findings.

ii) Conducting a Failure Mode, Effects and Criticality Analysis (FMECA) to the systems/equipment (compressed air system, oil-fired boiler, IG system, mooring system) that frequently have problems on the fleet level

iii) The existing Planned Maintenance System (PMS) programme should be strengthened with additional functions, such as workload balance and smart job scheduling.

iv) A task-based talent assessment and development programme should be improved to support the awareness of shipboard personnel on responsibility allocation.

v) Adopting emerging information and communication technologies enabling synchronous communication and effective knowledge transfer to increase the existing potential of supervisory support to fleet.

Since the proposed methodology simulates the effect of identified causes and derives the priorities, the recommended preventive actions have great potential to produce integrated solutions to the analysed deficiency cluster. The next issue is to coordinate the recommendations and to monitor the possible improvements on fleet level.

5. CONCLUSIONS AND FUTURE STUDIES

SIRE 2.0 is a relatively new inspection regime to support the transformation of the tanker shipping industry in a sustainable manner. It requires a great effort from ship operators to manage higher compliance with SIRE 2.0 requirements. This paper proposes a novel proactive modelling approach, intended to prevent reoccurrence of the SIRE 2.0 related deficiencies. It combines IMO classification scheme and FCM model to identify causes of focused deficiencies. The model under consideration comprises a total of four distinct phases. During the initial stage, an analysis is conducted to identify any shortcomings in SIRE 2.0. This study analyses ship information, risk categorisation, operator response, and deficiency details within the given context. Consequently, a dataset is generated for preliminary analysis.

Once the requisite data has been gathered, it is imperative to group and categorise the inadequacies. The cause identification process in this particular context involves the utilisation of the IMO classification scheme, specifically the HTW 8/INF.3 scheme. The data pertaining to deficiencies has been scrutinised and categorised based on several dimensions, including but not limited to, reduced human performance, marine environment, safety administration, management, and mental procedures. The utilisation of expert opinions in the maritime domain is employed in the finalisation of this procedure. Subsequently, symbols including A1, B2, C3, and D10 are employed to denote each instance of a SIRE 2.0 deficiency case, following which the analysis phase is initiated. During the analysis phase, the FCM technique is employed to conduct prioritisation, simulation, and verification stages. This involves identifying causal relationships, aggregating weights from multiple maritime experts, and defuzzification, among other processes.

Herein, integrated preventive action recommendations specific to the causes clustering with higher priorities are suggested in detail. Process improvement techniques, FMECA, enhanced PMS, task-based talent assessment, and ICTC solutions are addressed as key enablers for the analysed deficiencies. Besides the use of IMO classification scheme, the proposed methodology managing an industrial contribution addressed in this paper is to provide a novel proactive safety measures towards SIRE 2.0 related deficiencies onboard tanker ships. As a further study, the extended database might be structured to build a predictive analytic function in the developed model.

CONFLICT OF INTEREST: Authors declare no conflict of interest.

REFERENCES

Akpan, A. W., & Ogunsola, T. M., 2015. Budget Based Optimization of Preventive Maintenance in Maritime Industry. American Journal of Engineering Research (AJER), 4, 13-20.

Akyuz, E., 2015. A hybrid accident analysis method to assess potential navigational contingencies: The case of ship grounding. Safety science, 79, 268-276. Available at: https://doi.org/10.1016/j.ssci.2015.06.019.

Akyuz, E., & Celik, M., 2014. Utilisation of cognitive map in modelling human error in marine accident analysis and prevention. Safety science, 70, 19-28. Available at: https://doi.org/10.1016/j.ssci.2014.05.004.

Arslan O, Aydemir B, Kececi T., 2016. Review of Tanker Ship SIRE Inspection Findings in Turkey. International Conference on Maritime Safety and Human Factors, At Glasgow, Scotland, U.K.

Arslan, O., Aydemir, B., & Kececi, T., 2016, September. Review of Tanker Ship SIRE Inspection Findings in Turkey. In International Conference on Maritime Safety and Human Factors, At Glasgow, Scotland, UK.

Asan, U., Kutlu, A.C., Kadaifci, Ç., 2011. Analysis of critical factors in energy service contracting using fuzzy cognitive mapping. In: Proceedings of the 41st International Conference on Computers and Industrial Engineering, October 23–26, 2011, Los Angeles, USA.

Asan, U., Soyer, A., 2009. Identifying strategic management concepts: an analytic network process approach. Comput. Ind. Eng. 56, 600–615. Available at: https://doi.org/10.1016/j.cie.2007.11.003.

Aydin, O., Celik, M., Bicen, S., & Bayer, D., 2022. Systematic Analysis of Multi-Source Inspection Database via Ship Smart Audit System. Transactions on Maritime Science, 11(2). Available at: https://doi.org/10.7225/toms.v11.n02.w01.

Bakhtavar, E., Valipour, M., Yousefi, S., Sadiq, R., & Hewage, K., 2021. Fuzzy cognitive maps in systems risk analysis: a comprehensive review. Complex & Intelligent Systems, 7, 621-637. Available at: https://doi.org/10.1007/s40747-020-00228-2.

Başhan, V., Demirel, H., & Gul, M., 2020. An FMEA-based TOPSIS approach under single valued neutrosophic sets for maritime risk evaluation: the case of ship navigation safety. Soft Computing, 24(24), 18749-18764. Available at: https://doi.org/10.1007/s00500-020-05108-y.

Cang, T., Dung, V. A., Thien, D. M., & Bich, V. N. (2010). Implementation of the Computerized Maintenance Management Systems(CMMS) for the Maritime Industry. In World Congress on Engineering 2012. July 4-6, 2012. London, UK. (Vol. 2189, pp. 1103-1106). International Association of Engineers.

Cebi, S., Celik, M., & Cicek, K., 2009. Prioritization of the VIQ items within SIRE program for an oil tanker ship. In 2009 International Conference on Computers & Industrial Engineering (pp. 449-452). IEEE. Available at: https://doi.org/10.1109/ICCIE.2009.5223890.

Celik, M., Lavasani, S. M., & Wang, J., 2010. A risk-based modelling approach to enhance shipping accident investigation. Safety Science, 48(1), 18-27. Available at: https://doi.org/10.1016/j.ssci.2009.04.007.

Christensen M., 2013. A qualitative study of the review and verification process of the Safety Management System within companies servicing the Norwegian Continental Shelf [Master's thesis]. Høgskolen i Vestfold.

Christensen, M., 2013. A qualitative study of the review and verification process of the Safety Management System within companies servicing the Norwegian Continental Shelf (Master's thesis, Høgskolen i Vestfold).

Corovic, B. M., & Djurovic, P., 2013. Research of marine accidents through the prism of human factors. Promet-Traffic & Transportation, 25, 369-377.

Dimitrios, G., 2012. Engine control simulator as a tool for preventive maintenance. Journal of Maritime Research, 9(1), 39-44.

Grbić L, Čulin J, and Perković T., 2018. SIRE inspections on Oil tankers. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 12:359–362. Available at: https://doi.org/10.12716/1001.12.02.17.

Grbić, L., Čulin, J. & Perković, T. 2018. SIRE inspections on Oil tankers. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 12(2). Available at: https://doi.org/10.12716/1001.12.02.17.

Gurbuz, S. C. & Celik, M. 2022. A preliminary design of a 3D maritime gamified mentoring platform to support tanker pre-vetting inspection training: 'Maritime Gamentor'. Ships and Offshore Structures, 1-11. Available at: https://doi.org/10.1080/17445302.2022.2133878.

Gurbuz, S. C. & Celik, M., 2022. A preliminary design of a 3D maritime gamified mentoring platform to support tanker pre-vetting inspection training:'Maritime Gamentor'. Ships and Offshore Structures, 1-11. Available at: https://doi.org/10.1080/17445302.2022.2133878.

Han, P., Ellefsen, A. L., Li, G., Holmeset, F. T. & Zhang, H., 2021. Fault detection with LSTM-based variational autoencoder for maritime components. IEEE Sensors Journal, 21(19), 21903-21912. Avaialble at: https://doi.org/10.1109/JSEN.2021.3105226.

Hasanspahić, N., Frančić, V., Vujičić, S., & Maglić, L. 2020. Reporting as a key element of an effective near-miss management system in shipping. Safety, 6(4), 53. Available at: https://doi.org/10.3390/safety6040053.

Heij C, Bijwaard GE, Knapp S., 2011. Ship inspection strategies: effects on maritime safety and environmental protection. Transp Res Part D: Transp Environ. 16(1):42–48. Available at: https://doi.org/10.1016/j.trd.2010.07.006.

IMO, 2021. Available at: https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/HTW-Default.aspx, accessed on Feb 10, 2023.

Kacmaz, E., Kara, G., & Yıldız, M., 2016. Evaluation of marine pollution caused by tanker ships and preventing under focus of the international regulations. Proceedings book, 318.

Kartsimadakis, A., 2023. Remote inspections scheme on tanker vessels during Covid-19 pandemic. In Smart Ports and Robotic Systems: Navigating the Waves of Techno-Regulation and Governance (pp. 293-303). Cham: Springer International Publishing.

Kosko, B., 1986. Fuzzy cognitive maps. Int. J. Man Mach. Stud. 24, 65–75. Available at: https://doi.org/10.1016/S0020-7373(86)80040-2.

Kum, S., & Sahin, B., 2015. A root cause analysis for Arctic Marine accidents from 1993 to 2011. Safety science, 74, 206-220. Available at: https://doi.org/10.1016/j.ssci.2014.12.010.

Lazakis, I., & Ölçer, A., 2016. Selection of the best maintenance approach in the maritime industry under fuzzy multiple attributive group decision-making environment. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 230(2), 297-309. Available at: https://doi.org/10.1177/1475090215569819.

Li, Y., Chu, F., Zheng, F., & Liu, M., 2020. A bi-objective optimization for integrated berth allocation and quay crane assignment with preventive maintenance activities. IEEE Transactions on Intelligent Transportation Systems, 23(4), 2938-2955. Available at: https://doi.org/10.1109/TITS.2020.3023701.

Mullai, A., & Paulsson, U., 2011. A grounded theory model for analysis of marine accidents. Accident Analysis & Prevention, 43(4), 1590-1603. Available at: https://doi.org/10.1016/j.aap.2011.03.022.

Navas de Maya, B., Kurt, R. E., & Turan, O., 2018. Application of fuzzy cognitive maps to investigate the contributors of maritime collision accidents. Transport Research Arena (TRA) 2018. Available at: https://strathprints.strath.ac.uk/63613/

Obiedat, M., & Samarasinghe, S., 2013. Fuzzy representation and aggregation of fuzzy cognitive maps. In Piantadosi, J., Anderssen, R.S. and Boland J. (eds) MODSIM2013, 20th International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2013, pp. 684-690.

OCIMF, 2022. Available at: https://www.ocimf.org/programmes/sire-2-0, accessed on: Feb 25, 2023.

Papageorgiou, E., Kontogianni, A., 2012. Using fuzzy cognitive mapping in environmental decision making and management: a methodological primer and an application. In: Young, S. (Ed.), International Perspectives on Global Environmental Change. InTech, Croatia, pp. 427–450.

Papageorgiou, E.I., Markinos, A., Gemptos, T., 2009. Application of fuzzy cognitive maps for cotton yield management in precision farming. Expert Systems with Applications 36, 12399–12413. Available at: https://doi.org/10.1016/j.eswa.2009.04.046.

Papakostas, G.A., Boutalis, Y.S., Koulouriotis, D.E., Mertzios, B.G., 2008. Fuzzy cognitive maps for pattern recognition applications. Int. J. Pattern Recognit. Artif. Intell. 22, 1461–1486. Available at: https://doi.org/10.1142/S0218001408006910

Raman RS, Shankaranarayanan G., 2018. Prioritization of the VIQ things inside SIRE program for an oil tanker transport. International Journal of Mechanical and Production Engineering Research and Development. 8(1):857–862.

Ross, T.J., 2004. Fuzzy Logic with Engineering Applications, second ed. McGraw- Hill, New York.

Soner, O., Asan, U., & Celik, M.l 2015. Use of HFACS–FCM in fire prevention modelling on board ships. Safety Science, 77, 25-41. Available at: https://doi.org/10.1016/j.ssci.2015.03.007.

Song, T., Tan, T., & Han, G., 2022. Research on preventive maintenance strategies and systems for in-service ship equipment. Polish Maritime Research, 29(1), 85-96. Available at: https://doi.org/10.2478/pomr-2022-0009.

Tsadiras, A.K., 2008. Comparing the inference capabilities of binary. Trivalent and Sigmoid Fuzzy Cognitive Maps, Information Sciences 178, 3880–3894. Available at: https://doi.org/10.1016/j.ins.2008.05.015

Turker, F., & Er, I. D., 2008. Enhancing quality and safety management in shipping: tanker management and self assessment. Lex et Scientia No. XV, 1.

Wang, H., Liu, Z., Wang, X., Graham, T., & Wang, J., 2021. An analysis of factors affecting the severity of marine accidents. Reliability Engineering & System Safety, 210, 107513. Available at: https://doi.org/10.1016/j.ress.2021.107513.

Wang, L., Liu, Q., Dong, S., & Soares, C. G., 2019. Effectiveness assessment of ship navigation safety countermeasures using fuzzy cognitive maps. Safety science, 117, 352-364. Available at: https://doi.org/10.1016/j.ssci.2019.04.027.

Wu, B., Yip, T. L., Yan, X., & Soares, C. G., 2022. Review of techniques and challenges of human and organizational factors analysis in maritime transportation. Reliability Engineering & System Safety, 219, 108249. Available at: https://doi.org/10.1016/j.ress.2021.108249.