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Navigating Human Factors in Maritime Safety: A Review of Risks and Improvements in Engine Rooms of Ocean-Going Vessels

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ABSTRACT

This study systematically examines the critical issue of human error within ship operations and maintenance, focusing on the challenges in fully integrating technology to enhance maritime safety on merchant vessels. The investigation into the root causes of human errors, alongside an understanding of accident causation, forms the basis of this research. This work aims to identify effective mitigation strategies to improve ship management and safety by scrutinizing marine accidents attributable to human negligence or unsafe technology use. An analysis of marine human factor literature from 2010 to 2022, employing traditional and Integrative Literature Review Analysis methods, highlights the vital role of collaboration among seafarers and the necessity of comprehensive training. The findings reveal that categories related to human factors significantly contribute to marine accidents. It is posited that focused attention on these categories and the enhancement of seafarers' competencies could lead to a notable reduction in incidents, thereby bolstering overall shipping and maritime safety.

1. INTRODUCTION

Maritime transportation is essential to international trade and global wealth, with approximately 80% of world commerce by volume and over 70% of international exchange by value conducted through the oceans and managed by seaports globally [1]. The international shipping industry plays a crucial role in the global economy and growth. Seafarers, integral to shipping operations, bear primary responsibility for safe navigation and ship maintenance [2]. While seafaring is recognized as one of the most perilous professions, its significance to world trade remains indispensable.

The competency of seafarers has been deemed a crucial factor in ensuring the safety of ships and their crews. Recognizing this, the International Maritime Organization (IMO) has acknowledged it as one of the key elements in addressing maritime accidents caused by human factors. Consequently, the IMO has dedicated considerable efforts to establish and revise the International Convention on Standards of Training, Certification, and Watchkeeping (STCW) 2010 for seafarers. The STCW establishment aims to diminish the rate of maritime accidents, primarily attributed to human error [3].

Seafaring is a physically demanding profession in a hazardous environment, characterized by unique job-related health risks not encountered in other occupations. Seafarers face both physical and psychosocial stressors, along with specific mental health challenges [4]. When on board, they contend with challenging working conditions [5]. Prolonged periods away from home can adversely affect their health [6]. Factors like exposure to chemicals and sunlight, as well as lifestyle behaviors including diet and smoking, pose risks to their safety and health. Consequently, these concerns are a significant consideration for both companies and individuals' occupational health and safety in the maritime industry [7].

Despite the significance of seafarers, seafaring is considered one of the most perilous occupations, given the high casualty rate of maritime hazards and occupational accidents. The rate of fatal accidents in the shipping industry was 21 times higher than that of the general workforce and 4.7 times higher than that of the construction industry [8]. Seafarers encounter numerous hazardous situations as they not only navigate the ship but also perform additional duties such as cargo handling, ballast operation, bunker operation, planned and unplanned maintenance work, hot work, and enclosed space work, often independently and far from dry land [9].

Despite stringent ship inspections and the detention or prohibition of non-compliant ships from continuing their operations, the rate of maritime accidents remains high [10]. Slipping, stumbling, colliding with or being struck by items, falling on board, and falling from a height are the most common causes of injuries and deaths in the workplace [2]. Accidents are typically triggered by a series of errors or when all defenses, barriers, and safeguards are breached. To avoid future disasters, reduce the number of maritime accidents, and improve maritime safety, shipping stakeholders must identify the root causes of accidents and implement appropriate and effective corrective and preventive measures [8].

A total of 65.8% of the 4104 accident incidents investigated throughout the investigations were attributed to human activities, while 20% were attributed to system or equipment failure [11].

The objective of this paper is to review human-related errors and their underlying causes in ships, leading to various hazards such as fire, explosions, electric shocks, and more. The study aims to address the identified research gap by identifying the primary causes of human errors, comprehending these errors, understanding the reasons for accidents, and proposing recommendations to mitigate accidents, ultimately contributing to effective ship management and a safer working environment. Articles from 2010-2022 were reviewed to capture the practical scenario and the latest ideas concerning human errors, their reasons, and preventive measures in the context of maritime safety. The paper discusses commonly occurring inaccuracies caused by humans, explores the reasons behind them, and reviews preventive measures. Furthermore, the research outcomes aim to provide guidelines to enhance seafarers' safety awareness, particularly in the context of maritime safety in vessel engine room operations.

Figure 1 shows the category that represents a potential cause or factor contributing to maritime accidents. The figure is showing how many accidents fall into each category for each year from 2011 to 2018. By looking at the distribution it can be understood which factors contribute more or less to maritime accidents over the specified time period. Here, in Figure 1 human actions cause the highest leading to maritime accidents and followed by system/ equipment failure.

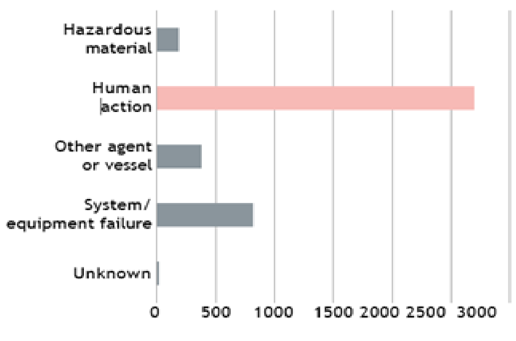

Figure 1. Distribution of accident events for 2011-2018 [11]

2. LITERATURE REVIEW ON HUMAN FACTOR

Ensuring safety remains a paramount concern within the marine industry. However, accurately predicting and preventing accidents proves challenging due to their diverse and complex causes. A major contributor to these incidents is the human factor in ship operation during maritime activities. Past incidents have consistently linked human error to accidents, estimating the range to be between 65 and 90 percent [12]. Ironically, the terms "human factors" and "human mistake" are frequently used without a clear understanding. The UK's Health and Safety Executive (HSE) sheds light on this, defining human factors as elements that impact behavior at work, spanning environmental, organizational, and occupational aspects, as well as individual qualities affecting health and safety. In contrast, human error refers to actions deviating from plans, rules, or established boundaries [13].

Major shipboard incidents, including fires, often find their roots in the human factor [14]. A recent study by the European Maritime Safety Agency delved into 4104 marine accidents, revealing that 65.8% were caused by crew errors. Specifically, during shipboard operations, crew errors contributed to 65% of 2666 incidents, with an even higher percentage of 68.6% observed in cargo-carrying vessels [15]. The crew's erroneous actions are attributed to the social environment, encompassing safety awareness, personal and manning factors, poor work practices, and crew resource management, as highlighted in incidents involving cargo-carrying vessels [11].

Controlling factors such as crew age, ranks, vessel types, and work environment play pivotal roles in determining safety practices and occupational hazards [16]. Literature in northern Europe explores the impact of safety culture on identifying marine dangers [17], with research suggesting that the majority of maritime mishaps result from human attribution and organizational factors [18]. Human mistakes shoulder responsibility for a substantial 80-85% of all maritime accidents [19]. The recent introduction of new technologies in the maritime transport system raises concerns about technology complacency and over-reliance, both contributing to human error [20]. Acknowledged as contributing elements in marine accidents, human factors encompass all aspects of the intricate relationship between machines and humans [21].

The literature on human error in maritime safety lacks a comprehensive review of the causal factors in shipping accidents [22]. Thus, further research is required to delve into the pivotal role of the human aspect in shipping [23]. Within the realm of marine engineering, a profound revelation surfaces: the primary causes of maritime accidents often stem from the behavioral factors exhibited by seafarers. The culprits, as highlighted in this research, encompass a spectrum of challenges. Inadequate training emerges as a significant concern, encompassing physical constraints, poor communication, flawed judgement, exhaustion, and weariness. Negligence, with its facets of ignorance, carelessness, delusion, foolishness, and anxiety, stands as another contributing factor. Furthermore, issues related to self-esteem, including indolence, acquisitiveness, alcoholism, misconduct, and disobedience, compound the risks [24].

Other studies [14], focused on investigating human variables in seafaring, similarly find that most maritime mishaps are attributable to onboard human errors. Elements such as attention, alertness, flexibility, self-awareness, cooperation, and collaboration among group members are identified as crucial for enhancing safety. Investigations into the impact of human variables on shipping welfare are also actively conducted [22].

In the intricate domain of engine rooms (ER), characterized as a hostile environment during operation, crews face an array of challenges. Negative characteristics such as noise, vibration, and high temperatures impact their work significantly. Primary risk issues include fire, explosion, failure of main or auxiliary engines, electrocution, oil spillage, inadequate lighting and/or ventilation, and the pervasive elements of noise and vibration. These challenges contribute substantially to the human errors observed in a ship's engine. Human variables, ranging from a lack of knowledge and disregard for safety to miscommunication, heat stress, psychological stress, fatigue, and the use of psychotropic medicines, are identified as additional risk factors [24].

In contemporary literature, there exists a notable gap in comprehending the significance of human error in ensuring maritime safety. Despite the consistent recognition of human error as a significant catalyst in maritime accidents, the management literature lacks in-depth exploration of this phenomenon [25]. Various elements contribute to human error within the maritime sector, such as fatigue, insufficient communication, inadequate technical expertise, deficient situational awareness, and complacency. It is imperative for future research to propel the understanding of human error within the maritime industry, proposing theoretical frameworks and hypotheses aimed at mitigating maritime accidents stemming from human error [26-28]. There is a need for a more in-depth understanding of the role of human error in these accidents, particularly in the context of marine engine maintenance [29]. This comprehension should be enriched by considering various theoretical perspectives, incorporating insights from the field of organizational science [26].

The exploration of the human element in shipping has become a focal point for researchers [23]. Within the domain of marine engineering, an illuminating revelation surfaces - maritime accidents are significantly influenced by the behavioral factors exhibited by seafarers. The culprits, as underscored in this research, encompass a range of challenges. Inadequate training emerges as a significant concern, entailing physical constraints, poor communication, flawed judgment, exhaustion, and weariness. Negligence, with facets of ignorance, carelessness, delusion, foolishness, and anxiety, stands as another contributing factor. Furthermore, issues related to self-esteem, including indolence, acquisitiveness, alcoholism, misconduct, and disobedience, compound the risks [24].

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A comprehensive analysis of marine accident literature, involving 572 papers from 127 journals published between 1965 and 2014 [16], indicates a notable shift in the causes of accidents from less naval architectural reasons to an increasing prevalence of human errors. Conclusions drawn suggest that future marine accident research will be multidisciplinary, structured around diverse statistical derivations, and employ modern investigative techniques. Inseparable aspects include the complex interplay among the natural maritime environment, maritime technologies, human behaviors, and the state of the maritime industry. Analytical studies of marine accidents validate previous conclusions regarding the significance of the human factor [15].

In the context of this study, a closer examination reveals the eight most crucial risk variables: explosions, engine failure, electric shock, oil spillage, ventilation and heat stress, noise and vibration, fatigue, and others per indicated in Figure 2. These variables stand at the forefront, demanding thorough scrutiny to comprehend their intricate interplay and implications [24].

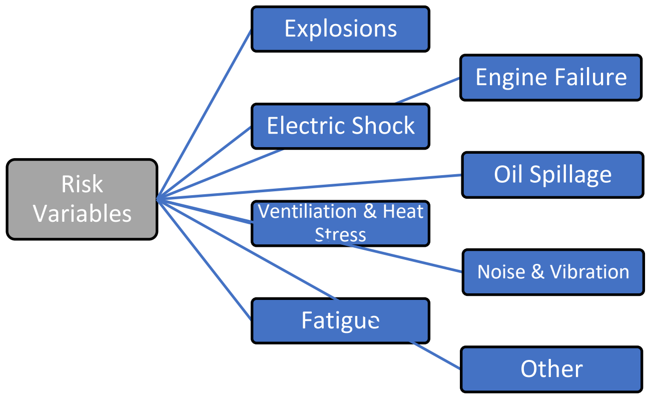

Figure 2. Risk variables on human factors

2.1 Engine room fire

An established reality within the maritime domain is that onboard fires rank among the most common mishaps, leading to both fatalities and property losses. The (engine room) ER, in particular, stands out as a frequent site for fires, with the human element often at the core of these incidents, sharing striking similarities across scenarios. The safety of the ER onboard ships, crucial for minimizing fire incidents, heavily relies on the crew's actions, especially their adherence to safety culture. Any neglect or omission of necessary measures can potentially result in a fire outbreak. Take, for instance, the delayed identification of fuel leakage or the degradation of insulating materials on hot outer surfaces - both scenarios pose a significant risk of igniting a fire [30].

The ER serves as the epicenter for most onboard fires. In perilous situations, these fires can rapidly spread to other parts of the vessel, leading to human casualties, and even jeopardizing the entire ship. The ER, with its compact, confined, and hot environment, concentrates hazardous components, including numerous fire sources and combustible objects. The threats of fire and explosion vary based on the type of fuel used, presenting inconsistent risks for merchant vessels and battleships [31]. The potential for gas leaks heightens the risk of fires in ER, particularly in ships with dual fuel engines like Marine Diesel Oil (MDO) and Liquid Natural Gas (LNG). The occurrence of a fire or explosion not only inflicts substantial damage on the environment but also poses severe risks to equipment and personnel [32]. Various types of ships have reported severe and extremely severe fire incidents between 2000 and 2014 per indicated Table 1 [24].

ER fires are typically caused by fuel or oil seeping onto a heated surface [33]. According to statistics, 60-70 percent of engine room fires follow the same pattern: a combustible liquid escapes and comes into contact with a hot surface [34].

Fires on ships are different from fires on land, and they are considerably more harmful to the crew and passengers. Due to the complexities of fire, along with additional inherent risks, if onboard fire issues cannot be extinguished, it might result in tragedy, significant damage, and catastrophic accidents. Not only is there a far smaller likelihood of discovering an evacuation path, but escaping via a life raft, lifeboat, or maritime evacuation system is also much more difficult than escaping on land. The chances of surviving outside the ship are dependent on several unforeseen elements such as weather and the risk of hypothermia; therefore, abandoning the ship is no guarantee of survival [30].

Table 1. Fire casualties in various kind of ships occurred between 2000-2014

Type of Ship	Number of Accidents	Percentage
Tanker	52	19.1
RoRo/Ferry/Passenger	52	19.1
General cargo	40	14.7
Fishing vessel	37	13.6
Bulk/Ore carrier	32	11.8
Others	28	10.3
Container	24	8.8
Tug/Supply vessel	7	2.6

In summary, onboard fires pose a significant risk in maritime, particularly in engine rooms due to fuel leakage or degraded materials. Crew adherence to safety culture is crucial, and fires can spread rapidly. Between 2000 and 2014, incidents occurred across different ship types. Escape is challenging due to weather and hypothermia risks.

2.1.1 Explosions in crankcase

A crankcase explosion in a marine diesel engine is an operational failure that can damage the ship's structure and endanger the onboard crew. To prevent or reduce the likelihood of a crankcase explosion, various procedures should be implemented. Liquid fuels and lubricating oils do not cause fires, but their vapors can. Evaporation, requiring energy, can be triggered by sources like the main machine/motor compressing propellant, a scorching hot area, or a fire. High-pressure fuel delivery to the injector may lead to leakage, reaching a hot region and vaporizing. The expanding vapor cools, forming a haze of tiny droplets. In this mist, the section closest to the hot area may reach ignition temperature, igniting the entire vapor cloud. When hydraulic oil from a high-pressure pipe contacts a hot point, it generates a flammable mist, similar to gasoline. A similar process occurs when interacting engine components locally overheat. In the 1950s, during prevalent crankcase bursts, and in the 1970s, during outbursts in reduction gearwheels in the ship industry, this phenomenon was described and explained [35].

To sum up, crankcase explosion in a marine diesel engine can damage the ship's structure and endanger the crew. To prevent or reduce the likelihood, various procedures should be implemented. Liquid fuels and lubricating oils can cause fires, but vapors can. High-pressure fuel delivery can lead to leakage, vaporization, and flammable mist. This phenomenon was described in the 1950s and 1970s.

2.1.2 Explosions in auxiliary boiler

Marine auxiliary boiler operation, or steam generation, entails a vast array of potential hazards and failures, all of which pose significant risks. These risks can lead to fatal accidents and incur high costs, including human casualties, machinery damage, disruptions to the smooth operation of the ship, and other financial losses. The following hazardous scenarios within the boiler have been identified based on years of experience with boiler plant operations. Examples include the failure of auto combustion control (ACC), explosions on the fireside, loss of power sources, water leakage due to tube bends or cracks, abnormal increases in pressure, and overheating. Overheating, often the primary cause of boiler damage or explosions, results from low water levels, typically caused by the failure of automatic controls [36].

One critical issue known as 'Melt Down' occurs when the auxiliary boiler continues running despite a very low water level. This situation causes the metal surface receiving heat to reach its melting point. While it may not trigger a boiler explosion, it inflicts substantial damage to the boiler, creating a dangerous scenario that could potentially lead to an explosion.

Another concern is Thermal Shock, defined as a sudden temperature increase. When there is a water shortage, the heating surfaces on the pressure side become overheated. Introducing more cool water in such a situation causes the water to flash to steam. Insufficient space for the steam to expand (given that steam expands 1600 times its volume compared to water) results in excess steam pressure building up. This pressure exceeds the vessel's design limits and can lead to an explosion.

Combustion explosions are also possible when gases accumulate and are ignited by an ignition source, both inside and outside the boiler [37]. Therefore, it is crucial to address and mitigate these potential dangers through proper maintenance, monitoring, and adherence to safety protocols.

To recapitulate, marine auxiliary boiler operation poses risks like auto combustion control failure, fire-side explosions, power loss, water leakage, abnormal pressure increases, and overheating. Proper maintenance, monitoring, and safety protocols are crucial to mitigate these risks and prevent damage or explosions.

2.2 Engine failure

The main propulsion engine and auxiliary engines of a vessel must operate under adverse environmental circumstances, including extremely rough seas and weather conditions. The failure of the main engine unit(s) or one or more subsystems of the main engine or auxiliary engines can have severe repercussions. These repercussions may include damage to the ship's machinery, injury or death to onboard workers, and contamination of the ocean. When the primary engine operates under extreme climatic conditions, the durability and safety of both the main engine and auxiliary engines must be considered holistically. For operation, engines are connected to a variety of subsystems, including the lubrication system, fuel oil system, fresh water and sea water cooling systems, and the scavenge air system [38].

In brief, the durability and safety of vessel engines, which operate under harsh environmental conditions, must be considered holistically, considering subsystems like lubrication, fuel oil, cooling, and scavenge air systems.

2.3 Electric shock

Maritime transportation necessitates the usage of nearly all forms of electrical equipment found in industrial facilities. For example, generators, electric motors, switching and distribution equipment, protective devices, semiconductor converters, voltage transformers and power converters, electrochemical converters - batteries, electrical protection, automatic control and diagnostics, reactive power filters, device power restrictions, drivers, couplings, bushings, various distribution boxes, lighting, heater installations, and so on [39].

Both on board and at the shipyard, the rate of exposure to electric shock occurrence is nearly the same. During welding operations in enclosed spaces, the human body sweats and becomes conductive. This may result in a severe accident of electric shock if this perspiration comes in contact with an electric current. Electric shock mishaps are more likely to occur when there are strewn cables, an open arc jump, cables with broken insulation, uncovered electrical distribution panels, and no earthing or grounding systems. The use of high voltage for portable lighting equipment is one of the leading causes of electrical accidents [36].

To conclude maritime transportation uses industrial electrical equipment, causing electrical shocks on board and shipyards. Welding operations, strewn cables, and high voltage portable lighting equipment increase risk of accidents.

2.4 Oil spillage

The unwanted accumulation of used oil after maintenance work is another source of oil spillage in the engine room, which may occur in bad weather conditions. Avoiding the use of double-wall injection pipes due to human negligence plays a vital role and can lead to this type of situation [40]. Oil spillage in the engine room can result in pollution or even fire. The leakage of fuel oil under pressure from damaged engine joints has the ability to self-ignite, based on the likelihood of a 'hot spot' forming in the area of high concentration within the range of combustibility [41].

Most of the time, onboard spillage occurs due to miscalculation or a lack of proper monitoring during bunker operations. As a result, bunker tanks overflow and spill overboard, causing immense environmental pollution. During bunkering operations, oil spills remain a major source of oil pollution. A large oil leak could spread hundreds of nautical miles from the point of origin, causing catastrophic damage to the maritime ecosystem. Because the effects of an oil spill are severe on the maritime environment, the performance of the ship's crew becomes a major concern during bunkering operations. At this time, the performance of the ship's crew is a critical concern. When attending a bunkering operation, the ship's crew must be extra cautious. In this context, predicting the probability of human error is a critical challenge for the marine industry to maintain a high degree of safety [42].

To sum up, oil spillage in engine rooms, onboard, and during bunker operations can cause pollution, fire, and environmental damage. Predicting human error probability is crucial for the marine industry, as crew performance is critical.

2.5 Ventilation and heat stress

The performance of engines, diesel generators, and electric motors in ship engine rooms is influenced by ventilation. The supply of air for combustion, heat transfer through convection, airflow for heat recovery, and the removal of undesirable heat, all within a specific temperature range for crew comfort and to protect electrical appliances from excessive thermal exposure, are key objectives of engine room ventilation [43].

Vessel concepts have evolved based on modern technologies for design and construction, allowing for more efficient space utilization. However, as ships become more compact with increased space allocated to cargo or working areas and reduced space for engine rooms, ventilation concerns arise [44].

Onboard ships, the atmosphere in the engine room is a typical example of a harsh environment, with extreme temperature and relative humidity conditions. International Hazard Datasheets on Occupation - Ship-Engineer (Machinist) highlight various risks to which ship engineers (machinists) may be exposed. The continuous movement between cold and hot areas exposes engineers to cold stress and/or heat stress. It's important to note that most ship engineers are often unaware of the required observation frequency. In fact, the datasheet [45], the ILO, and standards [46] do not provide clear information about the proper atmosphere and thermal conditions of the engine room, its design, and the behavior adopted by marine engineers to mitigate work-related risks. Work-related risk refers to the likelihood of a worker being exposed to a specific negative event as a result of their work [47].

The engine room is considered significant when assessing the indoor work environment conditions onboard a ship due to its unique qualities, making it one of the harshest locations onboard [48]. Consequently, comfort and heat stress indices were calculated using temperature and relative humidity data collected from the engine room and other areas. Through the analysis of these real-world situations, it was possible to determine the time limit for a person to operate without heat stress, following the ISO standard [25].

In brief, ventilation is crucial for engine performance in ship engine rooms, where extreme temperature and humidity conditions pose risks from cold and heat stress. Engineers calculate comfort and heat stress indices using temperature and relative humidity data.

2.6 Noise and vibration

The workforce in the engine department is exposed to operational sounds in the engine rooms of ships. Staff exposed to extreme noise levels for an extended period may develop deafness. In noisy work environments, the mental demand also increases. Engineers have been proven to be both fatigued and less precise when working in a noisy setting, as scientifically demonstrated [49].

Noise issues are a predominant concern in ship design, affecting human well-being, health, habits, and the overall ambiance. Additionally, individuals on board may experience human error due to an unpleasant noise level, believed to be a significant cause of maritime mishaps. Noise-related hazards significantly impact workplace health and safety, and loud sounds at work can lead to temporary or permanent hearing loss. Noise has a wide range of effects, from short-term annoyance and discomfort to long-term problems, including hearing loss. Beyond its negative health impacts, noise has a significant effect on crew performance. Due to the continual reduction in worker sizes in recent years, fatigue issues have become the primary contributor to human error, necessitating additional research into human factors [45].

To put it briefly, noise exposure in ship engine rooms can cause deafness, mental strain, fatigue, and reduced precision in engineers, impacting well-being, health, habits, and ambiance, and contributing to maritime mishaps.

2.7 Fatigue

The International Confederation of Free Trade Unions (ICFTU) presented the results of a survey on working hours prepared by members of the National Union of the United Kingdom (National Union of Marine, Aviation, and Shipping Transport Officers) (NUMAST) during the sixty-eighth period of MSC sessions, with some of the results listed here: The ship's crew faces a higher workload on board, leading to increased individual workloads and fatigue. Fatigue issues were more prevalent in countries with a less developed marine culture. Crew members identified a lack of manpower as the main cause of fatigue on board [50].

Familiarity with the work may reduce the difficulty of a task, enabling workers to complete it more efficiently. However, long-term familiarity with the work can make it monotonous, leading to decreased attention and potential risky behavior by the worker [51].

Instead of repeatedly performing monotonous activities, a break can be included in the working schedule as an alternative approach, considering the diverse types of engines and machines running together or separately in the engine room. Depending on the operational situation, each engineer in the engine room may take a separate break [52]. To conclude, CFTU reports ship crews experience fatigue due to increased workloads, lack of manpower, and monotonous tasks, particularly in less developed marine countries.

2.8 Others

For the designs that do not support operational processes, crew members are compelled to find alternative ways to carry out their responsibilities, leading to tasks being completed with a risk of promoting inappropriate conduct. This type of behavior can increase the risk of exposure to hazardous substances and injury for engine crew members [29]. Thus, automated technology in the maritime industry, particularly in the context of ship operations, is a significant development that is changing the nature of seafaring. This technology, often referred to as maritime autonomous surface ships (MASSs), leverages advanced technologies such as artificial intelligence, sensors, and machine learning algorithms to reduce human error and enhance maritime safety [53]. It includes features such as advanced autopilot systems, automated mooring systems, and enhanced monitoring and data collection capabilities [54]. The implementation of automated ships is expected to lead to reduced human input in ship operations, potentially impacting the jobs of seafarers. The development and implementation of automated ships are not without obstacles, including regulatory hurdles, technology limitations, and industry acceptance [54].

The use of automated technology in the maritime industry, particularly in ship operations, has been a topic of interest for several decades. This technology is seen as a means to enhance safety and environmental protection, with the potential for fully autonomous ships and the use of AI in navigation [55]. The inland waterway transport sector has already seen significant changes due to automation, with the potential for fully automated and unmanned vessels [56]. However, the impact of automation on maritime technology is not without its challenges, including the potential loss of situation awareness [57]. It is quite challenging for a seafarer to keep pace with the rapid growth of new and more complex automated technologies continually being introduced on board vessels [49].

Furthermore, there is no standardization in equipment configuration, and it can even differ on vessels managed by the same business. Consequently, seafarers are frequently required to familiarize themselves with the technologies and devices of every vessel they join, which they may not have used before, shortly after embarkation. This must be done promptly while also becoming familiar with or refreshing their knowledge of corporate regulations and procedures [58]. Moreover, operating manuals are often lengthy and occasionally created without a thorough understanding of user requirements, making it challenging to identify essential instructions quickly. Additionally, there are times when certain equipment is fully replaced, but previous operating instructions and maintenance manuals are not updated. This can be hazardous, especially if the equipment fails and requires rapid servicing for safe operation. These issues contribute to tension and exhaustion, which are factors in marine accidents [59].

With increased onboard computerization and automation, the role of the seafarer has shifted significantly from primary system controller to near-mere observer. As traditional knowledge and abilities are not required for passive control actions, there is a risk that they may be lost [60]. Simultaneously, people's reliance on and faith in automation technology are expanding, creating new sources of error and risk [61].

Seafarers face challenges in navigating automated technologies, lack of standardization, and outdated operating manuals. The shift from primary system controller to near-mere observer has led to loss of traditional knowledge and increased error and risk.

3. DISCUSSION

3.1 Improvement and prevention

Owing to systematic developed effect of human factor on safety issues, immediate steps must be taken to remove human errors, such mistakes in shipping is the safety culture on ships. To identify applicable preventive actions, an integrated and systematic perspective towards safety is obligatory [62]. They attempted to sort out the matter to shuffle the safety culture thing in both hypothesis theory and practical in the level of work environment, also determination of the role of restrain/preventive nature at a national stage.

The importance of nationality, sector, and the organizational model of safety culture in relation to safety behaviors were Due to the systematically developed impact of the human factor on safety issues, immediate steps must be taken to eliminate human errors, as these errors pose significant risks in shipping, emphasizing the importance of cultivating a safety culture on ships. The need for an integrated and systematic perspective on safety is emphasized, as discussed in reference [62].

Efforts have been made to address safety culture both theoretically and practically within the work environment, with considerations for its implications at a national level. An examination of the significance of nationality, sector, and organizational safety culture models reveals their impact on safety behaviors, emphasizing the need for a holistic approach at different analytical levels [63]. The study proposes a novel safety culture evaluation and improvement methodology to enhance maritime safety, including initial findings from a company's safety climate assessment. Additionally, to enhance fire safety in engine rooms, establishing a safety culture is recommended, underscoring the importance of safety-security training for engine room personnel. The development of a safety culture involves the implementation of safety management practices, with a call for labor rule changes based on a crew-wide safety culture [64].

A study of 100 maritime incidents revealed that a significant percentage of fatalities resulted from various errors made by multiple individuals. The study demonstrated that each human error played a crucial role in the occurrence of disasters, indicating that the accident could have been averted if any faults in the chain of events had been avoided. Therefore, the primary challenge in improving maritime safety lies in understanding the role of the human factor [58]. The literature emphasizes the need for methods spanning both physical and virtual environments to enhance the expertise of maritime teams, particularly focusing on the youth entering the field, to reduce human errors arising from a lack of familiarity with processes and contexts, a major contributor to maritime incidents [65].

In complex socio-technical systems like maritime transportation, all components can contribute to errors and accidents, creating a chain of mistakes [66]. The scope of examination should extend beyond seafarers to include ship-owning companies, shipbuilders, classification societies, and government regulatory authorities - entities making safety-critical decisions. The implementation of user-centered design is proposed to address ergonomic issues, ensuring that equipment is designed to collaborate effectively with human operators under various conditions. Designers are urged to have intimate knowledge of all tasks performed by sailors in different circumstances that may arise on or related to the ship [61].

In addition to basic technology acceptance characteristics, it is essential to study the influence of technology on decision performance, including aspects like situation awareness, monitoring, voyage plan monitoring, and threat avoidance, as well as the decision process, encompassing factors such as confidence, satisfaction, vigilance, mental and physical effort, stress, and fatigue. This research aims to enhance safety and improve human decision-making [67]. Therefore, encouraging all seafarers to promptly report any faults or difficulties with technology is crucial, considering the varied technological impacts experienced by users with different roles over time.

All instruction manuals, processes, and safety management system guidelines should align with verified equipment on board and adhere to shipping firms' standards. Seafarers are urged to address problems and prompt the corporation or equipment makers for specific instructions or suitable manuals. Standardizing equipment is emphasized to reduce the risk of manufacturing flaws and minimize the need for operator cross-training between different ship types. Effective teamwork is deemed essential for optimal safety on board vessels, helping to prevent accidents caused by design defects, inadequate knowledge of systems, and excessive reliance on technology through productive interactions among crew members [68].

According to [69], the master plays the most critical role in ensuring effective communication among crew members. Establishing and maintaining a healthy safety culture hinge on the master's ability to balance command with crew initiative. The master should consider practical suggestions from crew members, acknowledge and explain decisions favorably during on-board safety meetings to encourage open communication. It is crucial to refrain from assigning blame, fostering an environment where crew members feel comfortable reporting equipment problems, safety flaws, or near-misses. Emphasizing the importance of providing safety-related information as a preventive strategy is key [60].

To mitigate the risk of engine room fires, rigorous work standards and an understanding of the importance of safety practices are essential. Ensuring ergonomics criteria for various working positions is also vital. Fire safety management in the ship's engine room should be a crucial aspect of the daily routine and duties of the engine room crew. Tasks such as controls, audits, maintenance, assessments, and maintaining cleanliness and orderliness contribute to maintaining an acceptable fire safety level in the machinery space. Crew members must undergo maritime education and training to operate equipment safely in diverse situations, requiring a thorough understanding of the device's operation, capabilities, and limitations to avoid disasters [15].

Human–machine interaction is a crucial part of marine safety that must be nurtured and converted into the most vital safety connection; it must not be labeled as a weak link. A lot of work has gone into minimizing the impact of human factors in maritime accidents. Several international organizations, for example, the International Maritime Organization (IMO), the International Labor Organization (ILO), and the International Association of Ship Classification Societies (IASCS), all work hard to eliminate human error in their respective work domains. It is worth noting that the International Safety Management (ISM) code is one of the most effective strategies for preventing human error in the shipping industry [70]. Thus, a literature study was conducted on the topic of shipping accidents, the impact of human errors, and actions to make shipping safer.

Hetherington et al. [22] published a monograph for chief engineers and others to use in assessing the possibility of human mistakes in marine operations, and the authors proposed an assessment instrument for the likelihood of human error. The need for appropriate English communication in improving marine safety was emphasized. The criteria that define the level of safety in an engine room include adherence to the inspection regime, inspections, technical condition, adequate maintenance, provision of acceptable conditions and materials for exploitation, and cleanliness [71]. Thus, the classification of the human factors and defining the dominant and implicit factors that cause accidents in the engine room of ocean-going vessels is crucial in the risk management implementation on board the merchant vessels.

3.2 Findings

After the above thorough discussion, in Table 2, we can classify human factors in two major groups, one group containing all factors that can be overcome with increased awareness, proper training and adequate knowledge. On the other hand, some human factors are inherent, in course of time these factors will gradually increase and deteriorate work efficiency and ability, resulting in accidents. Table 3 demonstrates these two categories of human factor:

Table 2. Risk factors improvement or preventive measures

<table>
<tr><th>Causes</th><th>Improvement/ Prevention</th><th>References</th></tr>
<tr><td>Fire</td><td>• Port States should check the issuer of seafarers' certificates and training more frequently and thoroughly. As a result, the capability and dependability of sailors will improve in a favorable way.
• The active participation of ship owners is critical to avoid accidents related to fire on-board, as well as in identifying and enhancing safety factors. The seafarers should be guided, supervised and provided with effective safety training.
• Protective activities and inspections are carried out on a continuous basis.
• Improve crew safety knowledge.
• Attaining safety culture.
• Strengthen supervision and remodeling of safety management policy are essential.
• Controls, overhauls, inspections, repairs, measurements, and keeping spaces tidy and in order performed by the ship's ER crew using due and correct procedures supported by experience and care may substantially assist in effectively maintaining an adequate fire safety level in the machinery space.</td><td>[32, 33]</td></tr>
<tr><td>Explosion</td><td>• Training based on simulations to examine various hazardous situations.
• Continuous monitoring of the equipment while it is in operation.
• Following the company's Planned Maintenance System (PMS) and the International Safety Management (ISM) code to the letter.</td><td>[36]</td></tr>
<tr><td>Ventilation problem</td><td>• Fresh air inlets should be as low as possible and as far away from the source of heat as possible.
• Exhaust should be as high as possible (preferably above the engine).
• Supply and exhaust grilles should be as far apart as possible to avoid recirculation.
• Cold combustion air should be led as close to the air filter as possible.</td><td>[72]</td></tr>
<tr><td>Fatigue</td><td>• Reducing weariness among sailors necessitates external and corporate regulation and control, as well as individual preventive intervention and human resilience.
• Among the fatigue-reducing elements are alertness management measures, the most important of which are effective work-rest timing and adequate sleep hygiene.
• Whereas countermeasures (scheduling, education, naps, caffeine, and so on) — ideally in combination — may help to mitigate the detrimental effects of shift work on nighttime drowsiness and daytime insomnia.</td><td>[73, 74]</td></tr>
<tr><td>Machine Failure</td><td>A safety check list has been developed that will be useful to perform a safe voyage of the vessel under a harsh environment.
<table>
<tr><th colspan="2">Sample check list for harsh environment</th></tr>
<tr><td>Main engine lube oil system</td><td>Lubricating oil system.
Filters to be cleaned irrespective of PMS hours.</td></tr>
<tr><td>Main engine fuel oil system</td><td>Check functioning of quick closing valve, temperature control valve irrespective of PMS hours.</td></tr>
<tr><td>Main engines scavenge system</td><td>Clean air inlet filters, replenish oil in the lube oil sump both on turbine and blower side.</td></tr>
<tr><td>Main engine cooling water system</td><td>Check function of temperature control and continuously monitor expansion tank level.</td></tr>
<tr><td>Steering gear system</td><td>Standby pump to be running, replenish oil in the system tank.</td></tr>
<tr><td>Auxiliary engine</td><td>Additional diesel generator to be running and sharing load of the plant.</td></tr>
<tr><td>Engine room gear</td><td>Overhead crane to be lashed and no loose gears.</td></tr>
</table></td><td>[75]</td></tr>
<tr><td>Noise</td><td>• Bring into legislation to codes for noise levels.
• Noise-reduction rules that are effective and meet the health needs of those who work in these environments.
• Noise may get reduced in the design phase other than attempting of mitigating after building up, IMO noise code might be upgraded to impose low level of noise in ships, as awareness of the contrary impacts of noise are grown in recent years and myriads of design has been shown for solutions to obtain the low level of noise are now available.</td><td>[48, 49]</td></tr>
<tr><td>Electric shock</td><td>• The areas with potential electrical hazards should be well warning-signed.
• By touching metallic conductive objects that may come under voltage due to the isolation fault, the following procedures can be utilized to safeguard employees from the effects of electrical shock.
- protective grounding;
- potential equalization;
- unlocking protection;</td><td>[39, 40]</td></tr>
</table>

	- isolation of conductive parts; - electric separation of networks; - use of small voltages; - ground-current power compensation; - individual protection methods, etc.	
Oil spillage	• Double-wall injection pipes with a drain space and a leakage signaling system are recommended for engine supply systems. • Machinery areas with internal combustion engines, oil-fired boilers, or oil-fuel units must have one of the fixed fire-extinguishing systems and one portable foam applicator unit that meets the Fire Safety Systems Code.	[41, 71]

Table 3. Classification of human factors

Avoidable Human Factors		**Inevitable Human Factors**	
Factors	Probable driving component	Factors	Probable driving component
Fire	Negligence to safety and tidiness	Noise and vibration	Excessive noise and continuous vibration
Explosion	Reluctance to follow PMS	Heat and cold stress	Rapid change in both atmospheric and workspace temperature
Failure of main or auxiliary engines	Improper monitoring	Psychological stress	Working in confined area for prolong time
Electrocution	Lack of knowledge, inadequate safety precaution	Workload	Emergency work or duty in addition to the regular work
Oil spillage	Miscommunication, inadequate safety precaution	Monotonous routine	No variation in work schedule
Personal injury	Avoiding personal protective equipment (PPE)	Use of psychotropic drugs	Limitation of entertainment
		Rough weather	Sleep deprivation and loss of appetite

In maritime safety, various causes and preventive measures have been identified for potential hazards. Fire incidents often result from a lack of thorough checking of seafarers' certificates and training. To address this, it is recommended that Port States enhance the frequency and thoroughness of checks and encourage active participation from ship owners in accident prevention and safety enhancement, including continuous protective activities, inspections, and safety training for crew members. Similarly, strategies to prevent explosions involve training through simulations, continuous equipment monitoring, and strict adherence to safety codes like the Planned Maintenance System (PMS) and International Safety Management (ISM). Inadequate ventilation system design can lead to problems, and optimal positioning of air inlets and exhaust outlets, along with proper routing of combustion air, is essential for prevention. Fatigue among sailors necessitates external regulation, alertness management, and effective work-rest timing. Machine failures in harsh environments can be prevented by following a safety checklist. Legislation on noise levels and effective noise-reduction rules are crucial, with suggestions to upgrade the IMO noise code. Electric shock risks require warning signage and various protective procedures. Lastly, oil spillage prevention involves using recommended equipment and fixed fire-extinguishing systems. These strategies aim to enhance overall maritime safety and reduce the risk of accidents [32, 33, 36, 39-41, 48, 49, 71-75].

The above table highlights factors contributing to avoidable and inevitable human factors in maritime incidents. Negligence to safety and tidiness drives avoidable fire incidents, while reluctance to follow the Planned Maintenance System (PMS) plays a role in explosions [76]. Failure of main or auxiliary engines is often due to improper monitoring, and electrocution risks arise from a lack of knowledge and inadequate safety precautions. Oil spillage is linked to miscommunication and insufficient safety measures, while personal injuries result from avoiding personal protective equipment (PPE). Inevitable human factors, such as noise and vibration, contribute to fire incidents, and heat and cold stress are driving components in explosions. Psychological stress, working in confined areas for prolonged periods, and excessive workload are linked to engine failures. Monotonous routines, use of psychotropic drugs, limitations in entertainment, rough weather, and sleep deprivation contribute to personal injuries. Recognizing these factors is crucial for implementing effective preventive measures in maritime safety.

In the broader context of maritime safety research, the findings underscore the multifaceted nature of potential hazards at sea and emphasize the need for comprehensive strategies to mitigate risks. The identified causes and preventive measures span various aspects of maritime operations, addressing issues from human factors to technical and environmental considerations. Notably, the recommendations emphasize the importance of rigorous checks on seafarers' certificates and training to prevent fire incidents, urging active involvement from ship owners in accident prevention initiatives. Strategies for explosion prevention involve simulations, equipment monitoring, and adherence to safety codes, highlighting the significance of a proactive approach. The importance of well-designed ventilation systems and adherence to safety protocols is underscored as a crucial element in preventing hazards. Addressing human factors, including fatigue management, external regulation, and adherence to safety checklists, is recognized as essential in averting machine failures and accidents. The link between negligence, reluctance to follow maintenance systems, and avoidable incidents is highlighted, reinforcing the need for a culture of safety and adherence to established protocols. The identified human factors contributing to inevitable incidents emphasize the importance of recognizing and addressing psychological stress, workload issues, and environmental conditions. Overall, these findings provide a comprehensive framework for enhancing maritime safety, emphasizing the interconnectedness of human and technical elements in preventing accidents at sea.

4. PRACTICAL IMPLICATIONS

The summary delineates factors contributing to both avoidable and inevitable human factors in maritime incidents. Neglecting safety protocols and maintaining untidiness drive avoidable fire incidents, while a reluctance to adhere to the Planned Maintenance System (PMS) plays a role in explosions. Engine failures, whether in main or auxiliary systems, often stem from improper monitoring, and the risk of electrocution arises due to a lack of knowledge and inadequate safety precautions. Oil spillage is linked to miscommunication and insufficient safety measures, while personal injuries occur when individuals avoid using personal protective equipment (PPE). Inevitable human factors, such as noise and vibration, contribute to fire incidents, while heat and cold stress are significant components in explosions. Psychological stress, prolonged work in confined areas, and excessive workload are linked to engine failures. Monotonous routines, the use of psychotropic drugs, limitations in entertainment, rough weather, and sleep deprivation contribute to personal injuries. Recognizing these factors is crucial for implementing effective preventive measures in maritime safety.

Implementing the above findings in the maritime industry requires a comprehensive approach, integrating policies, procedures, and cultural shifts to bolster safety. For instance, numerous IMO conventions include clauses empowering local governments to inspect foreign vessels upon port visits, ensuring compliance with IMO standards specified in instruments to which the port State is a Party [1]. Key practical steps involve enhanced certification checks, urging port states to conduct regular and thorough assessments of seafarers' certificates and training through standardized checklists and protocols based on procedures for Port State Control 2019's handbook. Strengthening inspection teams, leveraging technology, and enforcing penalties for non-compliance are crucial actions. Active ship owner participation is encouraged through mechanisms such as incentives for safety compliance, collaboration with industry associations, and recognition of exemplary safety records. Explosion prevention strategies entail regular training, equipment monitoring, and strict adherence to safety codes, with actions including safety drills, simulation training, and audits. Ensuring optimal ventilation system design and maintenance involves routine inspections, training programs, and incentives for compliance. This is in-aligned with IMO's maritime regulations and compliance to crucially ensure a safe and healthy working environment at sea [1].

Fatigue management necessitates external regulation, alertness management, and strict work-rest timing, with actions including setting limits on working hours and implementing fatigue-monitoring technology. Machine failure prevention requires adherence to safety checklists, comprehensive training, safety audits, and incentives for protocol adherence. Noise reduction and electric shock prevention involve enforcing legislation, upgrading codes, conducting regular assessments, implementing measures, and providing training. Oil spillage prevention entails equipment inspections, training, and enforcement of safety protocols. Human factors awareness should be further fostered through training programs on adherence to PMS, educational awareness materials and the use of PPE to promote a safety workplace culture. Continuous improvement involves establishing a culture of learning from incidents, conducting post-incident reviews, sharing lessons across the industry, and incorporating feedback into safety protocols. Overall, practical implementation necessitates a combination of regulatory measures, industry collaboration, technological integration, and a steadfast commitment to instilling a safety-first culture throughout the maritime sector.

This research holds considerable potential impact for companies, owners, and top management in shipping offices or aboard merchant ships. It provides valuable insights into evaluating and understanding safety culture, its significance, and the hazards prevalent in the ship and maritime sectors. The suggested preventive measures can serve as safety improvement guidelines, offering a checklist for regular monitoring and implementation. Following these measures has the potential to significantly reduce the number of maritime accidents. Moreover, enhancing the capability of seafarers to perform their required tasks further contributes to overall safety improvement in the maritime industry.

5. LIMITATIONS

The study's findings are valuable, but they may not apply universally due to specific situations or geographical limitations. Inaccurate data on incidents, cultural differences, technological advancements, and unpredictable weather conditions could affect the effectiveness of the recommendations. Additionally, the study may not cover all aspects of maritime safety, and the resources required to implement these recommendations may not be accessible to everyone.

6. DIRECTIONS FOR FUTURE RESEARCH

More detailed literature review of the other factors for example navigation error, Lack of passage planning and monitoring, inadequate communication, insufficient knowledge and lack of general technical knowledge, Faulty managerial decisions, Lack of maintenance of standards and others which are related to human mistake or reasons might be investigated associated with any theory in the future with statistical analysis. Some research questions can be addressed in the future studies for instance, how can training programs be improved to enhance the competency of maritime crew members, especially in emergency situations? How do different work/rest schedules impact the fatigue levels of maritime personnel, and what are the implications for decision-making and performance? How do communication breakdowns contribute to maritime accidents, and what communication protocols can be implemented to reduce the risk of misunderstandings? To what extent does the integration of advanced navigation technologies contribute to or mitigate human errors in maritime operations?, How can lessons learned from maritime accidents be effectively disseminated throughout the industry to prevent similar incidents in the future?, and others. Inevitable human factors which have been discussed above also require further research to provide proper insight and preventive measures in order to enhance the safety work environment in the engine room. If future researchers successfully answer the questions and test the hypotheses related to human errors and accidents in the maritime industry, the potential implications could be substantial. This research could lead to the development of targeted training programs and technologies, improving the competency of maritime personnel and reducing the occurrence of accidents at sea. Insights into emergency response procedures, human-machine interaction, and organizational cultures could result in more effective crisis management, user-friendly shipboard equipment, and a shift towards safety-focused industry cultures. Additionally, research findings may inform adjustments to regulatory frameworks, promoting compliance and preventing accidents. Addressing the impact of work/rest schedules on fatigue levels could lead to evidence-based guidelines, enhancing crew well-being and reducing fatigue-related errors. Overall, successful research outcomes could contribute to a safer, more efficient, and environmentally responsible maritime industry, with positive implications for public safety, resource efficiency, and international collaboration on safety standards.

7. CONCLUSION

This study emphasizes the importance of addressing human factors in the maritime industry to improve safety. It suggests a systematic approach to safety, considering factors like nationality, sector, and organizational model. The study also highlights the interconnectedness of seafarers, ship-owning companies, shipbuilders, and regulatory authorities. It proposes user-centered design to improve ergonomics and human-machine interaction. The study also calls for a shift in labor rules based on a crew-wide safety culture. It also emphasizes the role of the master in ensuring effective communication and a healthy safety culture. The findings provide a comprehensive framework for enhancing maritime safety.

The profession of seafaring is a crucial component of the international shipping industry. Seafarers are the driving force of ocean-going vessels. They must be well educated and have sound knowledge of their work and duties to ensure smooth operation of ships. Lack of knowledge regarding their responsibilities may lead to grave danger like damage of properties or serious personal injury. Seafarers have the tendency to become reluctant over time as they get familiarized with a vessel. They start avoiding safety gear and proper PPE while carrying daily routine work. By doing so, they put themselves as well as their fellow colleagues at risk. These unsafe actions frequently result in serious injuries.

The study highlights the need to address human factors in the maritime industry to improve safety, advocating for a user-centered design, labor rule changes, continuous education, and safety protocols to enhance resilience.

8. RECOMMENDATIONS

The recommendations for enhancing maritime safety encompass a multifaceted approach aimed at minimizing human errors, improving safety practices, and preventing accidents at sea. Some recommendation can be suggested based on above review and findings. Safety-related information should be provided by all crew members. It is vital to abandon the use of age-old ships in organization practices in order to build and sustain an efficient safety culture. Enhancing daily safety procedure monitoring as well as training program by the chief engineer and master as group in-charge is highly necessary when considering the entire crew as a team.

Special and regular safety training programs must be provided to every member with practical implementation. The new ship builders might keep in mind to plan to design the vessel according to the safety maintenance updated and upgraded guidelines. Use of age-old vessels/ships must be prohibited as it is dangerously threatening to the lives of the seafarers as well as for the companies. Key strategies include the development and promotion of a robust safety culture through continuous training and awareness programs, with active involvement from ship owners. An integrated and systematic safety perspective is advocated, emphasizing the identification of applicable preventive actions and restraints at a national level. The impact of nationality, sector, and organizational models on safety behaviors is recognized, urging evaluation at different analytical levels.

Special attention is given to youth training and expertise development, with methods spanning physical and virtual environments to minimize errors. Safety examinations are extended beyond seafarers to include various stakeholders, and technology's influence on decision-making is studied for continuous improvement. Effective teamwork and communication are emphasized, along with rigorous work standards and ergonomics to prevent accidents. Adherence to safety manuals and standardization is encouraged, and the master's role in fostering a healthy safety culture is highlighted. Specific measures are proposed for preventing engine room fires, addressing human factors, and implementing risk management strategies. Overall, these recommendations aim to establish a comprehensive framework for maritime safety by addressing individual, organizational, and technological aspects, ultimately enhancing safety practices and reducing the risk of maritime accidents. It is recommended that based on the findings of this study, the classification of human factors should be included in the risk management system to improve working condition in the vessel’s engine room.

The practicality of enhancing maritime safety through the provided recommendations hinges on industry commitment, regulatory alignment, and adaptability. Establishing a robust safety culture, incorporating an integrated safety perspective, and considering factors like nationality and organizational models are feasible but require industry-wide collaboration. Initiatives such as youth training, technology-influenced decision-making studies, and effective teamwork are practical with proper investment and a cultural shift. Rigorous work standards, adherence to safety manuals, and addressing human factors rely on enforcement, standardization, and ongoing efforts. While the recommendations align with best practices, their success depends on a collective commitment to fostering a safety-oriented maritime environment.

The recommendations are directed at a diverse range of stakeholders in the maritime industry, including ship owners, national authorities, training institutions, industry professionals (seafarers and crew members), ship designers, masters and captains, educational and training institutions, and technology providers. The overarching goal is to foster a comprehensive and collaborative approach to maritime safety. Key areas of focus include promoting a strong safety culture, implementing integrated safety perspectives, addressing human factors through training and expertise development, emphasizing effective teamwork and communication, ensuring rigorous work standards and ergonomics, and encouraging the adherence to safety manuals and standardization. The recommendations aim to minimize human errors, enhance safety practices, and prevent accidents across various facets of maritime operations.

Implementing the recommendations can significantly improve maritime safety by fostering a safety culture, integrating safety perspectives, and addressing human factors. This includes extending safety examinations, promoting teamwork, and ensuring rigorous work standards. Standardizing equipment and adhering to safety manuals can reduce technical risks, leading to improved safety performance.

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