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Mental wellbeing; Human reliability assessment of seafarers during the COVID-19 era

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ABSTRACT
The COVID-19 pandemic took the world by storm and disrupted global trade and maritime activities. Seafarers suffered immensely as most of their activities were affected due to the lockdown and travel restrictions placed by most governments to protect their borders. This had an impact on mostly their mental health as most of their routine became disrupted, travel plans were cancelled, and some fear of losing their jobs due to uncertainty. This research focuses on the impact the lockdown had on the mental health of seafarers and how it affects their human error probability value during COVID-19 by utilizing the HEART methodology. The conventional HEART technique is not precisely developed to be applied in the marine and offshore sector, so it was imperative to modify it to capture the key factors this research would be measuring which include fatigue, poor communication, depression, sleep deprivation, and how they influence the Human Error Probability (HEP) value of seafarers. To properly factor in these influencing factors, a questionnaire was developed and distributed to expert seafarers to weigh each factor in other to develop the Error Influencing Factor (EIF) table to further boost the accuracy of this research. For this research, the scenario used is a pre-mooring task carried out by seafarers. The result shows that the HEP value changes by over 55% from 6.1676E–2 before covid-19, to 6.1960E–1 during covid-19. Event Tree analysis was also carried out using the individual HEP values to calculate the probability of failure of the mooring ropes. The result shows that the probability of failure during COVID-19 is higher when compared. The application of this modified HEART technique confirms that COVID-19 lockdown had a negative impact on these factors that influence the mental well-being of seafarers.

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Introduction

Background study

The life of seafarers is depicted by some unique features that set them apart from other engineering sectors. Marine operations globally are highly significant in the safe movement of goods, essential commodities, and deep-sea explorations around the world. According to United Nations (2021), this sector alone is responsible for about 80% of global trade volume, and is an important source of revenue and transportation for most coastal nations. Due to its scale of importance and challenging environment, seafarers are tasked to carry out rigorous daily maintenance procedures which are greatly significant for the consistent and safe movement of offshore equipment for various reasons. Also, due to the unique terrain, seafarers carry out these operations under demanding physical and mental working conditions such as; sleep deprivation as a result of long hours of work, no or poor communication with family and friends, depression, and a high level of fatigue and stress (Mansyur et al., 2021; Salyga & Kušleikaite, 2011; Wadsworth et al., 2008).

During the COVID-19 pandemic of 2020, global trade and transportation were affected significantly including the marine sector (Athanasios & Shamika, 2020). The movement of people was halted as governments of different nations around the world closed their borders due to the fear of rising cases of the virus. At its pick, this had an immense impact on the lives of seafarers already working with the aforementioned unique circumstances due to their job and were either trapped at sea and unable to go home or stuck at home with no source of income to provide for their families (International Maritime Organization, 2021; Okeleke & Aponjolosun, 2020). This new challenge had an enormous effect on the physical health, mental wellness, and human reliability of seafarers who were unable to properly carry out their already potentially high risk tasks now coupled with the fear of the unknown and the safety of their families onshore (Baygi et al., 2021; Qin et al., 2021; Xiong et al., 2020).

Human error is a leading element that affects the possibility of an accident occurring when carrying out maintenance operations by seafarers during marine operations and even in other industrial sectors (Calixto, 2016a). According to Hasanspahić et al.

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(2021), p. 135 marine accident reports recorded by the Marine Accident Investigation Branch (MAIB) UK from 2010 to 2019, regarded human error as the primary cause of 80–85% of accidents in the marine sector. The International Maritime Organisation (IMO) is centred on increasing the safety of operations onboard ships through various sets of requirements, rules, and regulations. Even while ship inspections are carried out regularly and physical checks have been made, the number of accidents in the marine sector is still on the high side (Baniela & Ríos, 2011).

Research problem

The human factor in most engineering sectors is estimated to be the reason for about 80% of the accidents being recorded (Kletz, 2001). The dynamic nature of human behaviour, influencing factors both physical and psychological, and human response to its environment are some of the reasons for this high percentage. The human reliability of seafarers conducting crucial activities at sea was further placed in a declining phase because of the COVID-19 which distorted an already tasking life at sea making it even more difficult to operate properly (Marine network, 2021). The reliability of seafarers during this period declined due to the impact of the lockdown on their mental health as the change of crew who desperately need the time off had no choice but to stay back to continue those demanding activities.

According to Seafarers Health Information Programme (2020), the mental well-being of seafarers determines their morale to carry out a task. It could be easily correlated that the lockdown would cause a negative impact on the life of seafarers. As a result of this their productivity, response to activities onboard, and human reliability are expected to drop leading to a significant negative impact on the global shipping sector. The influence it has on the mental and physical health of the crew cannot be over emphasized. Crew members who are averagely separated from their family over a minimum period of 3 months would have their time extended by months and would only be allowed to go offshore for serious medical issues that cannot be handled onboard. This would increase the stress on seafarers thereby making them more susceptible to errors leading to major accidents.

This research focuses on how the pandemic affects the operational reliability of seafarers by influencing several factors that determine their state of mental well-being while carrying out operations onboard. Due to the lockdown, several accidents occurred during the COVID-19 pandemic such as operational failure, grounding, suicide, total loss, and fatalities owing to the poor human cognitive response being influenced by stressors because of the panic and fear of the unknown (Doumbia-Henry & Se, 2020; Makara-Studzińska et al., 2021). This also influenced the human error levels of seafarers due to mental stress on them during the COVID-19 pandemic. The human reliability during both periods must be studied as much research has not been carried out because the pandemic started two years ago. However, the effects it comes with are eminent and research needs to be carried out to further investigate the impact it has on the lifestyle of seafarers.

Scope, aim, and objectives

The scope of this research is to evaluate the effect of COVID-19 lockdown on the mental health of seafarers and how it influences psychological factors such as fatigue, depression, poor communication, sleep deprivation, and the Human Error Probability (HEP) of seafarers during the COVID-19 pandemic using a mooring operation scenario onboard to examine the effect. How did the human error probability change before COVID-19 and during covid-19. The study would focus on two scenarios, before and during COVID-19 to analyse how it affects the mental health of seafarers and the human reliability changes due to covid-19.

This research aims to investigate the influence of COVID-19 lockdown on the Human Error Probability (HEP) of seafarers while performing maintenance operations onboard. Therefore the objectives of this research are;

1) To evaluate the impact of COVID-19 on the factors that influence the mental health of seafarers.

The influencing factors that would be assessed for this research include: fatigue on seafarers, depression, no or poor communication with family and friends, and sleep deprivation.

2) Revising the Human Error Assessment Reduction Technique (HEART) to assess and measure the potential human error in the marine sector during the COVID-19 pandemic.
3) To develop a comprehensive Error Influencing Factor (EIF) table to fit into the marine operations during the COVID-19 pandemic lockdown.

This is done by using a questionnaire that would be sent to experts to quantify and weigh the effects of those influencing factors on seafarers.

4) Show the application of the revised methodology on a marine maintenance operation before and during the pandemic lockdown to study the differences in HEP values.

Research significance

This research study would contribute to the body of knowledge on the effect of the COVID-19 lockdown on the influencing factors that affect the mental well-being of seafarers and its effects on the level of reliability during the pandemic period. By evaluating the

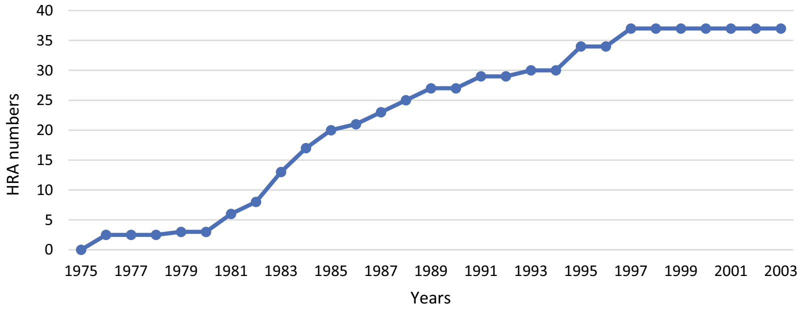


Figure 1. Cumulative number of HRA methods according to the year of publication (Hollnagel, 2005).

effects the COVID-19 lockdown had on the HEP value of seafarers, it would be of great importance to the marine industry generally to further mitigate the challenges of the ever-demanding life of seafarers in this changing world and post-pandemic era. This would also help address the current shortage of research on the impacts of the COVID-19 pandemic on seafarers and most importantly, shine a light on the significance of mental health to outstanding operational performance in the marine environment.

Literature review

Human error has always been one of the main causes of accidents in marine operations, nuclear power plants, the rail industry, and the aerospace sector (Kletz, 2001). As the world becomes more connected and industrialized, human error implications have resulted in significant capital loss and environmental damage. The topic of Human Reliability Assessment (HRA) has always been at the forefront of any operational assessment to achieve optimal safety and effectiveness while carrying out tasks.

Human Reliability Assessments (HRA) development

In the aim of trying to understand what HRA is and more importantly, trying to determine what it ought to be; it is important to investigate how HRA has developed over the past decades. Since the beginning of industrialization, researchers have been developing several human reliability assessment methods. HRA has three main functions, which include the prediction of error likelihood, recognition of human errors, and the decrease of those probabilities if achievable (Kirwan, 1996).

Hollnagel (2005), summarized the growth and development of HRA over the years from 1980 to 2005 noting its strong connection, and origin of development and research from the Three-Mile Island (TMI) major accident on the 28th of March 1979 and the growth in various HRA methods. While the Three-Mile Island (TMI) accident was significantly classified as a case of human error, it also fitted into the mounting concern of system failure and helped push forward the awareness that it was inevitable. Most of the HRA methods being used currently first appeared in the 1980s with a surge in growth taking place in 1984. Figure 1 shows below the cumulative numbers of HRA methods according to the year of publication, as this development was followed by another growth period around 1996, which brought into light the second generational phase of human reliability assessment methods (Hollnagel, 2005).

Although, as technology advances most industries such as aviation, marine sector, medical, railway, and nuclear plants use human reliability assessment to identify errors that could potentially lead to accidents or incidents on various levels. Therefore, the development of more advanced human reliability assessment methods is still ongoing to foresee and reduce the Human Error Potential (HEP) even more. Due to a large number of Human Reliability Assessment (HRA) methodologies and the recent development of newer ways of assessing accidents, the human reliability assessment techniques are grouped by the disparities in problem-solving methods, as first and second generations.

First generation

The early development of the first generation of human reliability assessment took place in the 1980s. These human reliability assessments were first created to help risk evaluators and accident analysts to evaluate and predict the possibility of a human error occurring during operations. These first-generation human reliability assessment methods concentrate on rule base level of the human action, and the skill of the operator, and are frequently condemned for failure to factor in aspects such as organizational factors, errors of commission, and the impact of context (Julie & Justin, 2009). Some of the methodologies which are categorized under the first generation of human reliability assessment are as follows:

- HEART (Human Error Assessment and Reduction Technique) is easy to understand and apply this method by human factor specialists and engineers with generic applications in various sectors.

- ASEP (Accident Sequence Evaluation Program) is a shortened version of THERP (Technique for Human Error Rate Prediction) methodology developed for the USNRC (United States Nuclear Regulatory Commission).
- SPAR-H (Simplified Plant Analysis Risk Human Reliability Assessment) is a helpful methodology in circumstances where thorough evaluation is not required.

Second generation

Further advanced techniques began development in the 1990s and are still ongoing. This is to make up for the shortcoming and omissions of the first generational methodologies for human reliability assessment. However, due to the lack of acceptance in the UK the advantages of the second-generation methods over the first-generational methods are yet to be fully recognized, and they are also yet to be through empirical observation validated (Julie & Justin, 2009). The second-generation HRA was carefully examined and modelled to study the impact of context on the error, organizational factors, and error of commission.

In the research by Kirwan and Gibson (2007), it was discovered that the most notable of the second-generational human reliability assessment techniques are as follows;

- CREAM (Cognitive Reliability and Error Analysis Method) with main domain in the nuclear sector but also has a wider range of applications.
- ATHEANA (A Technique for Human Event Analysis) developed by the USNRC, this method is resource demanding and further development is still in progress.
- CAHR (Connectionism Assessment of Human Reliability) is a data-based approach that is useful with generic applications.

Expert judgement based

The human reliability assessment methods using expert judgment became popular in the 1980s, these are mostly adopted in less safety-crucial settings than in key hazard-prone industries. These methods require a defined process for experts to understand how probable an error is likely to occur in a particular scenario (Julie & Justin, 2009). The most common is the SLIM (Success Likelihood Index Method) and PC (Paired comparisons) which both has generic application. However, these methods have been questioned for their mode of approach but are still being used to inform the creation of new tools (Scott, 1997; Tu et al., 2015).

Application of human reliability assessment in the marine sector

Human reliability assessment requires utilizing quantitative and qualitative analysis techniques to evaluate the human impact when performing a given task. There are a variety of methods available for HRA as mentioned above with most of them applied in high-hazard industries. To increase the operation of machine and human systems to reduce the possibility of human errors during maintenance operations, it is of the essence to assess and measure human productivity in maintenance processes. Scholars like (Atiyah, 2018; Bowo et al., 2017; Deacon et al., 2013; Martín et al., 2019; Noroozi et al., 2013; Tu et al., 2015) and many more have implemented various HRA methods in several industries to analyse several human error probabilities.

DiMattia et al. (2005) utilized human reliability evaluation by investigating the prediction of human error probability when performing urgent musters procedures on offshore production platforms. In the research, the Success Likelihood Index Methodology (SLIM) was implemented due to a lack of a sufficient human error database for offshore platform musters, so the expert judgment method was adopted to predict the human error probabilities of the operations. A committee of 24 experts who are involved in offshore oil and gas industries presented the data for ranking the performance shaping factors that were considered which include stress, training complexity, experience, atmospheric factors, and event factors. The muster scenarios that were taken into consideration include gas release, fire and explosion, and man overboard which were broken down in detail. The study result shows that stress has the highest effect on seafarers while conducting muster operations compared to the other factors.

Deacon et al. (2013) employed the HRA method for the evaluation of human functioning in offshore evacuation procedures, also the evolution of tools that would help assess the risk of human error and the efficacy of various safety measures. A framework was presented for enhanced identification and evaluation of the risks of human error utilized for crucial processes in the Escape Evacuation and Rescue (EER) procedure on offshore installations. The report uses major incident investigations from industries and various combinations of expert judgment methods to evaluate the risk of evacuation using three tasks which include the escape from danger (escape or muster phase), evacuate installation (evacuation phase), and the rescue phase. The HEART technique was applied to evaluate the probability of occurrence and the use of historic data for the evaluation of the severity of each consequence. Additional methods employed were the HAZOP methodology, ALARP method, Risk matrix, the

Bow-tie analysis integrating together the fault tree and event tree as well as mitigation and prevention barriers, and the Accident Risk Assessment Methodology for Industries (ARAMIS). The results show that the HEP value differs due to the view of various experts assessing the processes however, more comprehensive decisions would combine the conclusion of the various HEPs with all consequence severities to properly evaluate the complete risk tolerance and the risk mitigating measures needed.

Noroozi et al. (2013) studied the human reliability in maintenance procedures on facilities offshore, using the pump maintenance operation as a case study. A pump maintenance process was broken down into stages to critically study the possibility of human error during the maintenance operation. The technique of removing equipment from service and re-installing them back is studied for potential failure. The study sought to emphasize the significance of taking into account human error in risk analysis. The SLIM method was implemented to calculate the HEP for each scenario, with their various consequences also assessed. The result of the study showed that although currently most operational activities are done by computerized systems, the possibility of human error during the process cannot be fully eliminated. The result demonstrated that most maintenance processes even with the goal of reducing accidents and enhancing the reliability of a given system can end up increasing the overall system risk due to the occurrence of human error at the various stages of maintenance.

Abbassi et al. (2015) presented a unique method for the assessment of HEP while conducting offshore maintenance operations in the marine environment by incorporating the Technique for Human Error Rate Prediction (THERP) with SLIM methodology. Both methodologies THERP and SLIM were combined to produce the nominal human error probability (HEP). The developed approach was utilized on the maintenance task of an offshore condensate pump. In the study two steps were considered, the first HEP was calculated using all the standard procedures while in the second step a further safety measure of Radio Frequency Identification (RFID) based tools was integrated into the system and the HEP value is then re-evaluated. From the result of the study, excluding the implementation of RFID tools, the HEP value was calculated as 5.72% but with the inclusion of the RFID equipment, the HEP value was estimated as 4.63% producing a net HEP decrease of 1.09%. The RFID aided the manager with the maintenance techniques so that the right processes are readily available where and when required by the operator.

Calixto (2016b) presented several human reliability assessments to describe human errors throughout the life cycle of various assets which include design, manufacturing, operation, maintenance, and transportation. Various human performance factors were considered to reduce any factor that affects human error like social, physical, mental, ergonomic, and technological. In this study, different HRA methods such as Operator Action Tree (OAT), THERP, Accident Sequence Evaluation Program (ASEP), HEART, Success Likelihood Index Methodology implemented through Multi-Attribute Utility Decomposition (SLIM-MAUD), Sociotechnical Analysis of Human Reliability (STAH-R), Standardized Plant Analysis Risk Human Reliability (SPAR-H), Systematic Human Error Reduction and Prediction Approach (SHERPA) and The Bayesian Network method were applied to various case studies to show the suitable industries for the various methods, how to correctly apply them to demonstrate the influence of human error to asset performance and various operations.

Islam et al. (2016) researched the various mistakes made by humans throughout the maintenance operation of marine prime movers as many errors occur during the maintenance process. The research was conducted to assess the HEP for the maintenance process of marine engines to lessen the rate of human error and prevent accidents in the shipping sector. The SLIM methodology was used due to the absence of human error data for marine engine maintenance processes. The study revealed that out of 43 activities taken into account, the lowest HEP was from the inspection and overhaul of the piston and piston rings, which means it has the lowest consequence for an accident during a maintenance operation on the marine engine. While on the contrary, the lubrication and fuel filters pressure difference inspection and filter renewal task has the highest HEP value, indicating the process has the highest probability of an accident during maintenance operations.

Okaro and Tao (2016) assessed human error probability for gas compression systems in subsea facing operational stresses in West Africa to predict the reliability index. The mechanical failure of the system was demonstrated by developing a failure model to measure the endurance strength of the system under additional environmental stresses such as temperature and pressure. Modified Fusell-Vesely formulation and Block diagram was used to further break down the system into sub-systems for the critical study of each component and to improve them. From the results, the study revealed that due to the accumulative marine stresses applied to the subsea system the system mechanisms fail faster than the estimated time of failure indicated by the offshore reliability database. Therefore, the reliability of a subsea system should be enhanced by designing the system to have higher stress tolerance and redundancy.

Islam et al. (2017) employed the HEART methodology to evaluate the human error probability of seafarers. The study focused on the maintenance duties conducted by seafarers offshore to investigate how they are often susceptible to different errors that lead to accidents. The research reviewed and developed a modified HEART method to evaluate the potential human error in different operational and environmental circumstances. The study proposed the application of this method of human reliability assessment to enhance the reliability and safety of current maintenance operations in the marine and offshore sectors to reduce the probability of accidents. The influencing factors concentrated on high ship motion, severe weather, workload and stress, severe degree of noise, and ship motion on the performance of seafarers during maintenance operations. The questionnaire created was used to formulate the error influencing factors (EIF) for both the deck and engine crew considering the answers from expert seafarers around the world with at least 5 years of experience. The modified methodology was utilized in the maintenance operation of a condensate marine pump and a marine engine exhaust turbocharger on an offshore facility. From the study, the results showed that the sub-activity of clearance checking after a renovation has the highest level of human error probability of 1.25E–01 for the maintenance operation of an exhaust turbocharger. While for a condensate pump maintenance operation, the filling pump, testing for leaks, and opening valves have the highest human error probability value of 2.35E–02.

Ade and Peres (2022) reviewed several human reliability methods utilized in risk assessment and analysis on offshore platforms and drilling operations. The study indicates that the conventional method applied for data collection and the calculation of the risk is quantitative risk analysis. The research reviewed recent literature, and the methodology and techniques used to achieve their results. The study investigated the techniques utilized in the offshore industries along with different QRA techniques that accelerate human reliability assessment incorporation into the marine sector. The research result shows that the offshore territory mainly makes use of the first-generation HRA methodologies for quantitative risk assessment of marine emergency and maintenance scenarios, and the second-generational human reliability assessment for operational process and nominal design. It was also noted from the study that specific types of quantitative risk assessment techniques were more consistent with certain human reliability methods depending on the nature of the methodology being used in the research.

HRA methodologies have also been applied in sectors like medicine, nuclear, electrical, and mechanical. Hasibuan et al. (2020) researched work-related accidents that occur at boiling stations because of human error, using XYZ company which processes palm oil as a case study. From the study, most of the accidents are a result of errors from work operators such as lorry going off track, boiling over time, entering wrong boiling pressure standards, not using the necessary personal protective equipment, and low discipline standards which are all as an upshot of the human factor. HEART technique was used to assess the human error probability of the operators. Based on calculation from the results of the human error probability (HEP), the highest value for potential error was on setting the boiler time task with a HEP value of 0.5324. The study also examined preventive measures to be taken for the prevention of such high-level risk using the Fishbone diagram.

The reviewed studies are some demonstrated proofs of the significance of measuring human errors in risk measurement of several industrial and scientific maintenance tasks. Assessing human error helps to lessen the likelihood of human mistakes in maintenance processes and adds to decreasing accident occurrence.

Accidents characteristics

The awareness of how accidents occur and the suitable mitigations to prevent their recurrences is an essential part of human reliability assessment (Hollnagel, 2005). One of the reasons for continuous increases in the number of human reliability assessment methods is the ever-increasing complexity of technology, its dependence on human operators, and the resulting changes in accident causation mechanisms (Underwood & Waterson, 2013b).

According to Underwood and Waterson (2013a), in most highly hazardous sectors just like the marine industry, the evolution of accident assessment can be identified by using three major methods of analysis which include: sequential, epidemiological, and systemic techniques. The differences between the three techniques of analysis are further explained below.

Sequential techniques

This technique is easy and like a linear cause-and-consequence style, this model defines mishaps as the aftermath of an undesired event (root cause), that begins a chain of events resulting in an accident (consequences) and the process is linear. This indicates that an accident is an upshot of a root cause therefore if properly discovered and eliminated would avert the accident from happening in the future. The technique is often demonstrated by a series of falling dominos. In this technique, accidents are avoided by removing a domino, eliminating the vulnerable link, or putting a barrier between two dominoes to stop the series of events (Department of Energy, 2012). The Domino Theory of Accident Causation created by H.W. Heinrich in 1931 is a typical model of a sequential technique in accident analysis (Manuele, 2012;

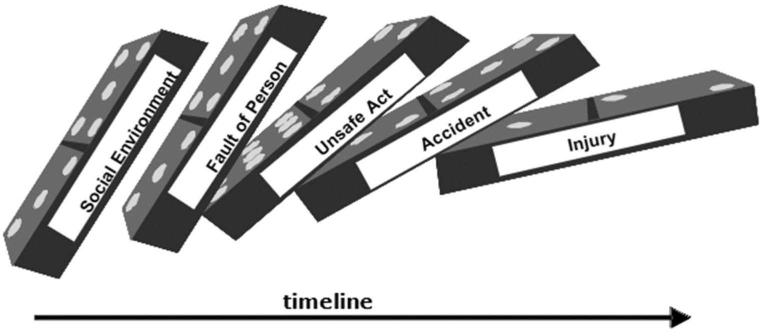


Figure 2. Domino model of accident (Qureshi, 2007).

Marsden, 2017). Figure 2 shows a vivid illustration of the domino theory of accident analysis.

This method works well with accidents resulting from the actions of operators in simple systems or accidents caused by physical component failure. Nevertheless, this technique poorly describes the relationship between human factors, and organizational and management factors in the cause-effect leading to an accident (Rathnayaka et al., 2011). As technology improves, it turned out that the sequential methods were not able to effectively describe some main accidents (Underwood & Waterson, 2013b). The role of human factors, environmental influence, management, and organizational influence is now important in better understanding and analysis of accidents because of this, epidemiological techniques were generated.

Epidemiological techniques

This is a more complex effect failure model where accidents are identified because of the combination of unsafe acts and unsafe conditions. This technique is often likened to medical interpretation that likens the unsafe condition to pathogens in the body lying inactive until triggered by an unsafe act (Qureshi, 2007). In this technique, accidents are avoided by reinforcing defences and barriers. The most famous example of an epidemiological tool is the Swiss Cheese model as shown below in Figure 3, developed by James Reason (Reason, 2000).

The epidemiological techniques better demonstrate the influence of management factors, human factors, and organizational influences on accidents. These techniques demand that the accident be studied beyond the immediate cause to examine the impact of surrounding conditions that may have had an impact on different factors resulting in an accident (Underwood & Waterson, 2013b). As the nature of accidents becomes complex due to technological advances, researchers like (Leveson, 2001; Svedung & Rasmussen, 2002) debate the application of these epidemiological techniques and their efficacy in large-scale accidents and suggest the application of systemic techniques as a preferred solution.

Systemic techniques

These techniques are complex multi-dimensional models, the system theory is built to recognize the behaviours and structures of any given system. It describes accidents as the unanticipated conduct of a system rising from unchecked interactions amongst its essential parts instead of considering accidents as a linear sequence of cause and effect (Underwood & Waterson, 2013b). In these techniques, accidents are caused by an unexpected sequence of nominal activities which combine with another nominal variability in the process to generate the required conditions for an accident to happen (Department of Energy, 2012). Simply eliminating the root cause of an accident does not guarantee the accident from not recurring, an intensive historic investigative approach must be conducted to identify the safety flaws throughout the complete system. Figure 4 shows an illustration of the systemic technique.

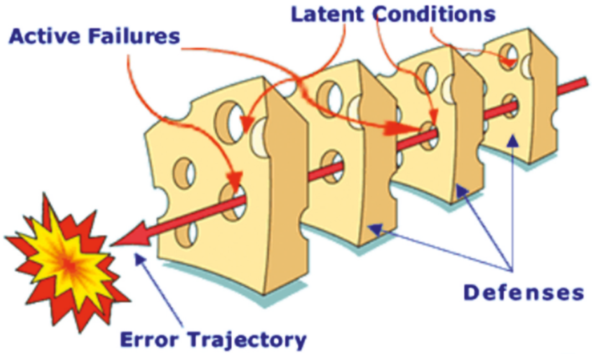


Figure 3. Swiss cheese model for accident causation (Reason, 2000).

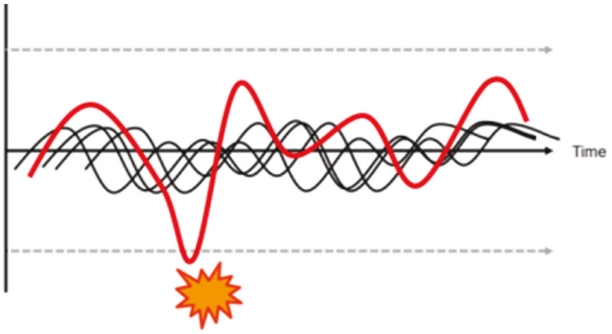


Figure 4. Illustration of systemic accident model (Department of Energy, 2012).

Table 1. Human reliability assessment methods for sequential, epidemiological, and systematic techniques (Underwood & Waterson, 2013a).

Techniques	HRA Methodologies
Sequential	Domino Model, Event Tree Analysis, Fault Tree Analysis, Five Whys Method, Critical Path Models.
Epidemiological	Human Factors Analysis & Classification System (HFACS), Swiss Cheese Model.
Systemic	Functional Resonance Analysis Method (FRAM), Systems Theoretic Analysis Model and Process model (STAMP), Accimap.

Although these systemic techniques aim to deliver a greater awareness of the various aspects that may have contributed to an accident, various studies argue that they are resource consuming and demand a vast amount of knowledge to understand and successfully apply them (Ferjencik, 2011; Johansson & Lindgren, 2008). Table 1 shows below some human reliability assessment methods that have already been categorized under the three assessment techniques.

Most marine and offshore maintenance is performed in demanding working environments. Due to this, the marine industry is safety-conscious, and maintenance operations are conducted by operators who are vulnerable to errors. Unfortunately, errors in the offshore and marine sector are inevitable when conducting offshore operations (Ung, 2019). For this reason, many methodologies and research have been conducted and examined to develop various solutions to reduce operational error of seafarers and simplify the assessment process (Kirwan, 1996).

The HEART methodology is easy to understand and implement, trustworthy, and fast (Casamirra et al., 2009). It is a trustworthy method for comparative study of HEP value of different scenarios during maintenance operations. For this reason, this methodology is best suitable for this study. The application of this technique shows that the HEART methodology has a general application and can be utilized in the analysis of maintenance processes in marine operations. Additionally, a guideline published by the International Maritime Organisation (IMO) proposed the HEART methodology for analysing human error probability in the marine sector (IMO, 2002). In this research, the suggested method will help the marine sector in better examining the probability of human mistakes and the risks involved when the mental well-being of seafarers is influenced by psychological factors.

Influencing factors

In the study of human reliability assessment, there are several factors both environmental, physical, and mental influencing factors that have an impact on the reliability of an operator. Noroozi et al. (2014) researched the effect of a cold environment, low visibility due to fog, freezing conditions, and stress on seafarers and how it affects their human error probability while conducting operations on offshore oil and gas platforms. DiMattia et al. (2005) focused on the impact of stress, training complexity, experience, atmospheric factors, and event factors on the reliability of seafarers while conducting muster evacuation operations on board. Other factors like not using the necessary personal protective equipment and low discipline standards which are all an upshot of the human factor were also covered by (Hasibuan et al., 2020).

Maclachlan et al. (2012) conducted an extensive review of papers in the international maritime database from 2000 to 2010 to show the scope of research into maritime health. The report revealed that the group of psychology and mental well-being concerns of seafarers had a small amount of research conducted. This section covers documents concerning fatigue, stress, attentiveness levels, and psychological problems such as depression. Consequently, studies that focus on the well-being and mental health of seafarers such as (Mcveigh et al., 2017), social life (Wang et al., 2020), burn-out syndrome (Kerkamm et al., 2022a; Makara-Studzińska et al., 2021; Oldenburg et al., 2012), and quality of life (Sliškovíc & Penezíc, 2017) should be supported and given more attention by stakeholders in the marine sector, especially those that aim to establish the influence of working conditions on the wellbeing of the seafarer. This research would focus on the effect of the COVID-19 lockdown on four main influencing factors which are fatigue, depression, poor communication, and sleep deprivation, and how they affect operational performance of seafarers during the lockdown.

Fatigue

The level of stress faced by anyone physically or mentally can lead to various signs of disorderliness, dissatisfaction, and discomfort. There is no universal definition for fatigue but it is the state of being tired, sleepy, or exhausted due to prolonged levels of psychological or physical stress, long periods of exposure to tough environments, or prolonged levels of anxiety that results in the dilapidation of human performance. According to IMO (2001), fatigue can be said to be a state of incapability both physically and mentally because of mental, emotional, or physical labour which can influence mostly all physical and mental abilities which include strength, decision-making, time of response, or speed.

Fatigue is a huge concern in most high-hazard prone industries including the marine industry, as it impacts the capacity of the operator to carry out tasks with a high level of efficiency and clear cognitive thinking ability (Baygi et al., 2021). Seafarers averagely spend six months at sea living and working under harsh environmental and physical conditions in a constantly moving vessel which includes weather conditions, ship motion, and loud noise from ship machinery (Jonglertmontree et al., 2022). The COVID-19 pandemic lockdown by far played a major role in increasing the already high levels of fatigue on seafarers, as seafarers were subjected to mental stress due to anxiety and fear for their families and loved ones, also the physical exhaustion of carrying out more tasks with little or no support or changes as no one was allowed to go on board to work or time off (Doumbia-Henry, 2020).

Depression

Depression at work is another major factor lowering the performance of seafarers in marine operations at sea. According to Gotlib and Hammen (2008), depression is a combination of experiences involving mood, mental, physical, and behavioural experiences that reflect prolonged damaging and detrimental conditions that may be clinically identified as a set of symptoms of depression. These symptoms can cause a lot of damage physically and mentally to individuals if not identified and treated accordingly. Depression increases the likelihood of seafarers being susceptible to error as it affects the cognitive response when allowed to thrive (Bjorn, 2020). Research conducted by Lefkowitz et al. (2019)shows that seafarers are subjected to multiple events over time that could lead to bad mental health. Even though the causes of depression may differ, some similar characteristics show negative working conditions which in turn leads to depression. Overtime the mood of seafarers could change because of different conditions such as supervisor demand, length of stay at sea, food quality, rough sea, working conditions, and cultural differences which would have an enormous negative effect on their operational performance on board (Ettman et al., 2020; Sampson & Ellis, 2019). Longer isolation from family and friends increased contract length with no added financial benefits, poor food quality due to shortage in the food supply, fatigue as a result of trouble sleeping due to worry and anxiety, and supervisor demands all had a negative mental effect on the performance of seafarers during the lockdown (Millefiori et al., 2021; Slišković, 2020; Stannard, 2020).

Poor communication

Humans are social beings and communication with loved ones and friends is a crucial part of our life, as social beings we use different modes of communication to interact, exchange knowledge, and develop relationships with each other and our environment (Tulsky et al., 2005). The separation from home with no viable means of communication with the family has been discovered to be one of the substantial factors impacting the stress levels experienced among seafarers working onboard during the pandemic (Lefkowitz et al., 2019). When seafarers cannot communicate properly, this increases the level of stress and worry as regards their wellbeing and how they are coping onshore, as the entire world faces this unknown challenge for the first time in modern history. For this reason, this influencing factor is seen as an important factor to be assessed in this research. For most seafarers keeping steady and good communication with family and friends is an important aspect of maintaining a sound and healthy mind while at sea. Most married seafarers find it almost impossible to undergo lengthy contracts as this creates a huge communication gap between them and their families (Thomas et al., 2003). No or poor communication with loved ones for a long period has a psychological effect on the performance of seafarers as it could be directly linked to fatigue, depression, and a sense of loneliness which all has a diverse effect on the reliability of the operator to carry out his activity effectively. Although there have been advances in communication technology, the impact is rarely felt at sea as severe weather condition and poor internet frequency constantly affect the communication systems at sea

(Jensen, 2021). Previous studies before the pandemic show evidence of a direct influence of the internet on the lives of seafarers on board (Pauksztat et al., 2022). This shows that the quality of internet access has a direct impact on the operational performance of seafarers.

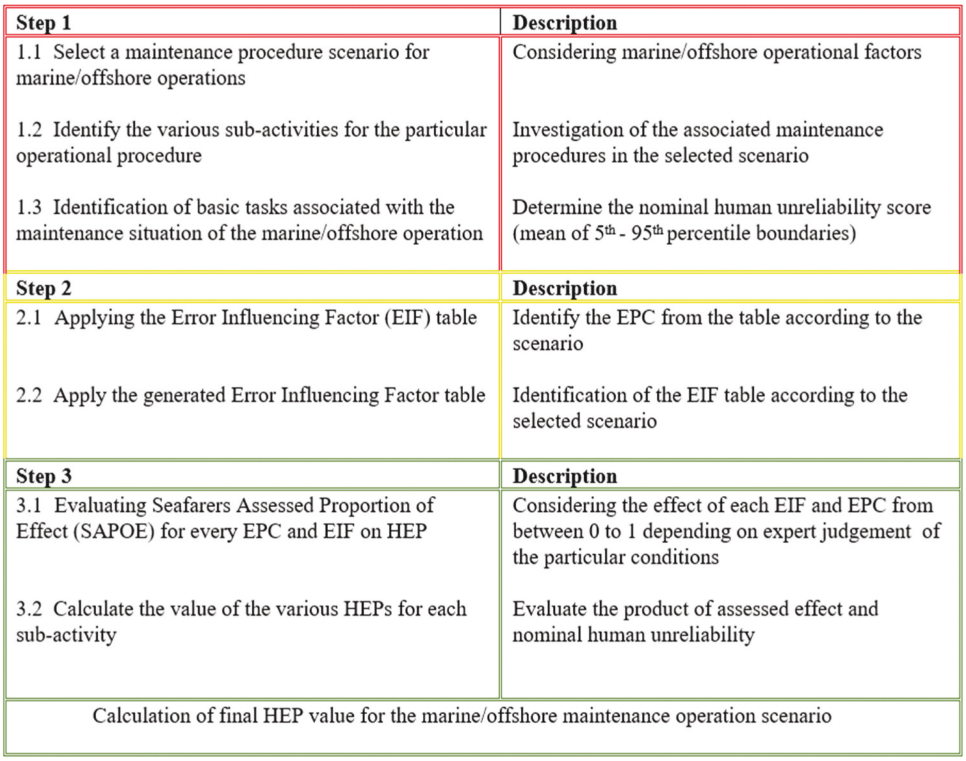
Sleep deprivation

Sleep deprivation among seafarers has a strong correlation with high stress and fatigue levels (Carotenuto et al., 2012). Enough sleep duration and quality are important for the mental well-being of seafarers in other to conduct operations seamlessly. Sleep deprivation can disrupt the thinking pattern and ability to carry out activities properly as it affects the mind and body, this is another reason as to why this factor is seen to be very important to look into. In a research carried out on seafarers by Härmä et al. (2008), the investigation was conducted on seafarers who work on a 6-on and 6-off watch schedule and those who work on a 4-on and 8-off watch schedule. The results show that seafarers who operate on the 6-on and 6-off watch schedule complain of higher levels of fatigue, stress, and increased levels of sleepiness during shifts compared to those on 4-on and 8-off which have a high level of unreliability while performing activities onboard. Environmental factors such as weather conditions, ship motion, and noise on board also result in some levels of sleep disturbance. However, one of the most important factors that result in sleep deprivation among seafarers is the workload seafarers have to carry out while onboard and the limited time to perform given tasks (Kerkamm et al., 2022b). During the lockdown, the levels of stress on seafarers increased as no workers were going onboard to change the crew at the end of their contract and some were sick or experiencing other symptoms of physical and psychological stress (Pauksztat et al., 2022).

Methodology

The conventional Human Error Assessment and Reduction Technique (HEART) was created by Williams (1988) for use in engineering operations. However, this methodology requires some level of modification to be fully usable in the HRA of maintenance procedures in marine operations. In this research, one of the objectives is to revise the heart methodology. The technique is revised by generating Error Influencing Factors (EIFs) using developed questionnaires distributed to marine experts, and generation of the weight of each factor by using expert judgment to analyse the effect of COVID-19 lockdown on factors that impact the operational performance of seafarers to make it applicable in the marine sector.

For the successful evaluation of human reliability in the marine sector, the HEART technique is applied to pre-mooring maintenance scenarios to calculate the HEP value of seafarers conducting maintenance operations before the COVID-19 lockdown and during the COVID-19 lockdown to demonstrate the potential differences in the HEP value of both cases. Using the



Step 1	**Description**
1.1 Select a maintenance procedure scenario for marine/offshore operations	Considering marine/offshore operational factors
1.2 Identify the various sub-activities for the particular operational procedure	Investigation of the associated maintenance procedures in the selected scenario
1.3 Identification of basic tasks associated with the maintenance situation of the marine/offshore operation	Determine the nominal human unreliability score (mean of 5th - 95th percentile boundaries)
Step 2	**Description**
2.1 Applying the Error Influencing Factor (EIF) table	Identify the EPC from the table according to the scenario
2.2 Apply the generated Error Influencing Factor table	Identification of the EIF table according to the selected scenario
Step 3	**Description**
3.1 Evaluating Seafarers Assessed Proportion of Effect (SAPOE) for every EPC and EIF on HEP	Considering the effect of each EIF and EPC from between 0 to 1 depending on expert judgement of the particular conditions
3.2 Calculate the value of the various HEPs for each sub-activity	Evaluate the product of assessed effect and nominal human unreliability
Calculation of final HEP value for the marine/offshore maintenance operation scenario	

Figure 5. Developed methodology for the estimation of HEP value for marine and offshore maintenance operations.

refined HEART methodology, Figure 5 shows the steps for estimating the HEP value for the maintenance operation in this research.

Step one of the HEART technique

In the first step, the selection of an operational scenario that would be focused on is carried out. The scenario is either maintenance or operational task that would be conducted by the operator while considering various marine operational factors that may influence the task. For the case of this research, the mooring equipment maintenance task is conducted by an operator. Likewise, the selection of sub-activities for the selected marine operation maintenance scenario is conducted. The mooring maintenance activity is further broken down into smaller sub-activity to identify every task conducted by the maintenance operator at every given time when carrying out the operation. The next phase is the identification of the basic task associated with each sub-activity for the maintenance operation to ascertain the nominal human unpredictability score. The basic task is the kind of task being conducted by the seafarer in the scenario and it could be classified as either a routine task, unfamiliar, or complex task. In the HEART methodology, the nominal human unreliability score takes the mean of the 5th to 95th percentile limits for each activity and it is generated by Williams (1988) as shown below in Table 2.

Step two of the HEART technique

In step two the EPC table developed by Williams (1988) is used to select the multiplier of each nominal likelihood for various sub-activity following the maintenance operational procedure in the scenario. The multiplier of nominal likelihood is the sum of EPC whereby the nominal human unreliability arises. The formation of the EIF table for the maintenance processes of marine activities is reviewed further below in section 3.4. The EIF table was generated utilizing an online Google Form questionnaire survey distributed to experts in the marine and offshore sector. Table 3 shows the attribute attached to weigh each factor in the questionnaire from 1–5 below.

There are a total of 38 EPCs in the EPC table used in the technique, and the selection of the appropriate EPC depends on the conditions for the sub-activities being considered, also each EPC selected has a multiplier as shown in Table 4, which should be inserted into equation (1). Also under this step of this research, it is essential to include the EIFs to accurately calculate the HEP as the EPC table is insufficient in covering all factors involved in marine maintenance activities. The EIFs are the important psychological influencing issues this research focuses on (fatigue, depression, poor communication, and sleep deprivation) that affect the operational performance of seafarers during the COVID-19 lockdown and increase the likelihood of mistakes.

Finally, the developed EIF multiplier table was developed using expert judgment as shown in Table 5. Utilization of the EIFs table demands the identification of the multiplier number of each nominal probability for the operation being conducted. The EIF table is made up of 14 EIFs which all have an individual effect on the final HEP value. A correct choice of the suitable EIF among the 14 options depends on the chosen scenario task for the activity being considered. Every EIF has a nominal probability inputted into Equation (1) replacing the EPC.

Step three of the HEART technique

For the final step, Seafarers Assessed Proportion of Effect (SAPOE) is allocated to accurately calculate the final HEP. The SAPOE is the effect of a particular EPC or EIF on the performance of seafarers. Each SAPOE is the assigned weight of either EPC/EIF depending on the case being focused on and its importance based on expert judgment. Every EIF/EPC is evaluated separately from 0 to 1 depending on expert judgment onz how

Table 2. HEART generic task (Williams, 1988).

Code	Generic task	Recommended human nominal unreliability	5th to 95th percentile boundaries
A	Inexperienced, executed quickly without actual idea of the possible outcomes	0.55	0.35–0.97
B	Shift or recovery equipment to new or initial state on one try without oversight or procedures	0.26	0.14–0.42
C	Complex task requiring elevated level of comprehension and skill	0.16	0.12–0.28
D	Fairly simple task performed rapidly or given scant attention	0.09	0.06–0.13
E	Routine, highly practiced, rapid task involving low level of skill	0.02	0.007–0.045
F	Fix or change a system to original or new state following processes, with some verification	0.003	0.0008–0.0035
G	Totally familiar, well-designed, highly practiced, routine task happening numerous times per hour, performed to highest standards by initiative-taking, highly trained and experienced personnel, with time to correct potential error, but without the benefit of significant job aids	0.0004	0.00008–0.009
H	Responding properly to system command even when an enhanced or automated monitoring system for providing precise interpretation of system state	0.00002	0.000006–0.0009

Table 3. Attributes attached to each weight from the questionnaire.

	Weights	Description
Extreme	5	The influencing factor has severe effect on seafarers operational performance.
High	4	The influencing factor high effect on seafarers operational performance.
Moderate	3	The influencing factor has moderate effect on seafarers operational performance.
Mild	2	The influencing factor has little effect on seafarers operational performance.
Negligible	1	The influencing factor has no effect on seafarers operational performance.

Table 4. Modified error producing conditions in HEART methodology.

	Error-Producing Condition	Highest predicted nominal value by which unreliability changes from good to bad
1	Inexperience with an important situation but does not occurs frequently	17
2	Lack of time on hand for error recognition and correction	11
3	A weak signal-to-noise ratio	10
4	Not following controlling information or features that is easily available	9
5	No way of transmitting critical information to operators in a form they can easily understand	8
6	Differences between an operator's model and that of the designer	8
7	No clear means of overturning mistakes	8
8	Channel overload triggered by simultaneous display of information	6
9	Unlearning a method and applying another that involves the use of an opposite method	6
10	Seafarers need to transfer knowledge from task to task without loss	5.5
11	Uncertainty in the required working standards	5
12	Discrepancy between seeming and real risk	4
13	Unclear, poor, or ill-matched system response	4
14	No clear timely confirmation of an intended action from system	3
15	Inexperienced seafarer (recently qualified crew, although not expert)	3
16	Inadequate standard of information provided by the normal procedures and crew on-board	3
17	Poor or no separate testing or checking of result	3
18	Disagreement between long and short-term goals	2.5
19	Inadequate information for validity check	2.5
20	A gap between the education level of the seafarer and the obligations of the operation	2
21	Encouragement to use unsafe techniques by supervisor	2
22	Little chance to exercise body and mind outside the direct boundaries of the task	1.8
23	Unreliable tools	1.6
24	A need to make decisions that are above the knowledge of the seafarer	1.6
25	Improper distribution of function and task	1.6
26	Improper way to keep track of advances during task	1.4
27	A danger that limited physical capacity will be surpassed	1.4
28	Less importance given to a task	1.4
29	High-level of emotional stress on operator	1.3
30	Indications of sickness among seafarer, especially fever	1.2
31	Low crew morale	1.2
32	Discrepancy of meaning of procedures and displays	1.2
33	A poor or harsh environment (below 75% of health or life-threatening severity)	1.15
34	Lengthy very repetitive cycling of a low mental work tasks	×1.1 for first half hour ×1.05 for each hour thereafter
35	Interruption of seafarer routine work sleep schedule	1.1
36	Change in task pace due to intervention by others	1.06
37	Additional or fewer crew necessary to execute task normally	×1.03 per extra man
38	Age of seafarer carry out maintenance duty	1.02

severely it impacts the unreliability of the operator on the task.

$$\text{Assessed effect} = \text{SAPOE} \times (\text{Maximum predicted nominal amount} - 1) + 1 \qquad (1)$$

Table 5. Error influencing factor for seafarers.

	EIFs	Multiplier of nominal probability
1	Extreme level of fatigue	×2.8
2	High level of fatigue	×2.52
3	Moderate level of fatigue	×1.4
4	Mild level of fatigue	×0.14
5	Extreme level of depression	×2.57
6	High level of depression	×2.43
7	Moderate level of depression	×1.76
8	Extreme level of poor communication	×2.35
9	High level of poor communication	×2.18
10	Moderate level of poor communication	×1.53
11	Mild level of poor communication	×0.12
12	Extreme level of sleep deprivation	×2.97
13	High level of sleep deprivation	×2.02
13	Moderate level of sleep deprivation	×1.39
14	Mild level of sleep deprivation	×1.2

From Equation (1), the HEP value for all sub-activity is estimated by the multiplication of all selected nominal human unreliability with the assessed effect amount from either the EIF or EPC table depending on the sub-activity being evaluated. The final HEP is generated by the summation of all HEP values from the sub-activities.

Development of the EIF table

The EPC table developed by Williams (1988) for maintenance procedures mostly did not cover important aspects of marine operational factors, especially during COVID-19 such as fatigue, depression, poor communication with family, and sleep deprivation. These factors have a significant influence on the reliability of seafarers during operations which could lead to an error during a maintenance operation. Consequently, the EIF table was developed for this research to supplement the omissions in the EPC table considering the mental health of seafarers for the accurate calculation of HEP value of seafarers. This research conducted some steps to create the EIF table, these phases involve the identification of predominant psychological factors affecting the mental health of seafarers by reviewing previous literature (Bjorn, 2020; Carotenuto et al., 2012, 2013; Kletz, 2001; Smith et al., 2006; Thomas et al., 2003) and expert opinions. Google form online questionnaire was developed for this purpose and was distributed to experts via the online link. Finally, the main aim of the questionnaire was achieved by gathering 50 expert opinions which were carefully analysed to develop the weight of each influencing factor. Figure 6 shows the various steps observed in creating the EIF table as further illustrated below.

Thereafter, the Mean and standard deviation values of the importance for each influencing factors was also developed from the questionnaire and displayed in Table 6, and the proportionate impact of every of the different influencing factors is given in Table 7.

After calculating the proportional effect of the influencing factors generated from the survey, the table for the EIFs is created by multiplying the weight of each factor from section A of the questionnaire by the weight of the influencing factor on mental health of seafarers from section B which includes extreme, high, moderate, mild, and negligible. The developed table for the EIF multiplier is shown in Table 5. The data obtained from the questionnaire proves that the COVID-19 lockdown had a significant influence on the mental health and well-being of seafarers, which can lead to a significant increase in human factor errors in the course of maintenance. Hence, it is essential to create an EIF table to complement the EPCs to accurately calculate the final HEP value while on COVID-19

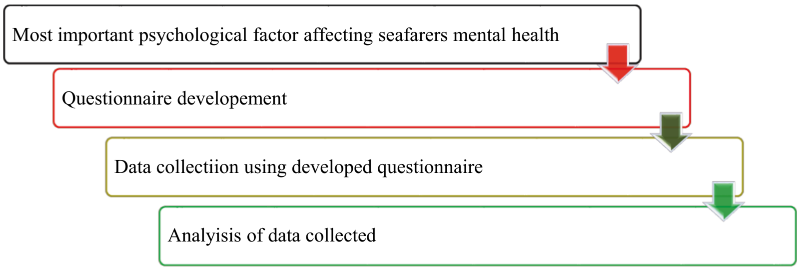


Figure 6. Process for development of EIF table.

Table 6. Mean and standard deviation values of the importance of the influencing factors generated from the questionnaire.

	Influencing factors	Mean value	Standard deviation
1	Fatigue	3.50	1.09
2	Depression	3.38	1.16
3	Poor communication	2.94	1.11
4	Sleep deprivation	3.16	1.27

Table 7. Proportional effect of the influencing factors generated from the survey (SAPOE for covid-19).

	Influencing factors	Weight of influencing factor	Proportional effect of individual influencing factors
1	Fatigue	Extreme	0.8
		High	0.72
		Moderate	0.4
		Mild	0.04
2	Depression	Extreme	0.76
		High	0.72
		Moderate	0.52
3	Poor communication	Extreme	0.8
		High	0.74
		Moderate	0.52
		Mild	0.04
4	Sleep deprivation	Extreme	0.94
		High	0.64
		Moderate	0.44
		Mild	0.06

lockdown. This developed technique is applicable and appropriate for different marine environments or case studies.

Results - application of the developed methodology

For validating the applicability of the revised HEART methodology, this research chapter focuses on the pre-mooring maintenance operation carried onboard under two different scenarios before and during the COVID-19 lockdown to compare the HEP values. Firstly, the technique is implemented on a pre-mooring maintenance operation conducted by seafarers to estimate the HEP value of the operation. The second case would be analysed using a case study during the COVID-19 lockdown and implementing the EIFs to accurately calculate the HEP value of seafarers during the lockdown.

Questionnaire data analysis and demography

The research questionnaire was created using Google Forms and distributed using online platforms to seafarers from different backgrounds and positions. The questionnaire contains seven questions, the first two

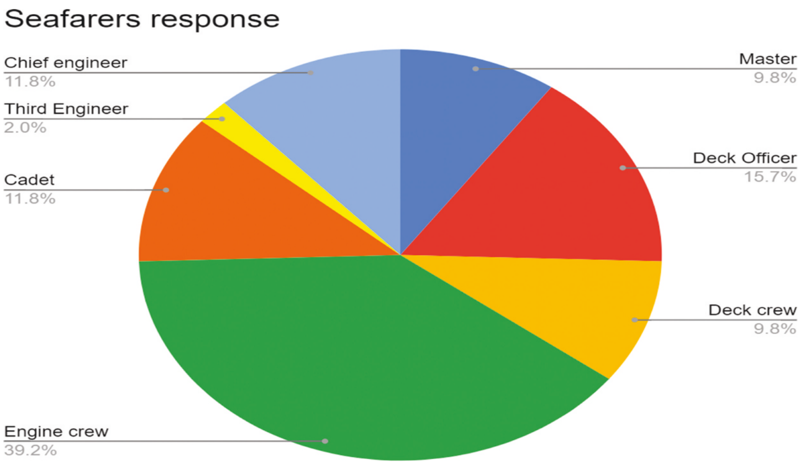


Figure 7. Demography of response.

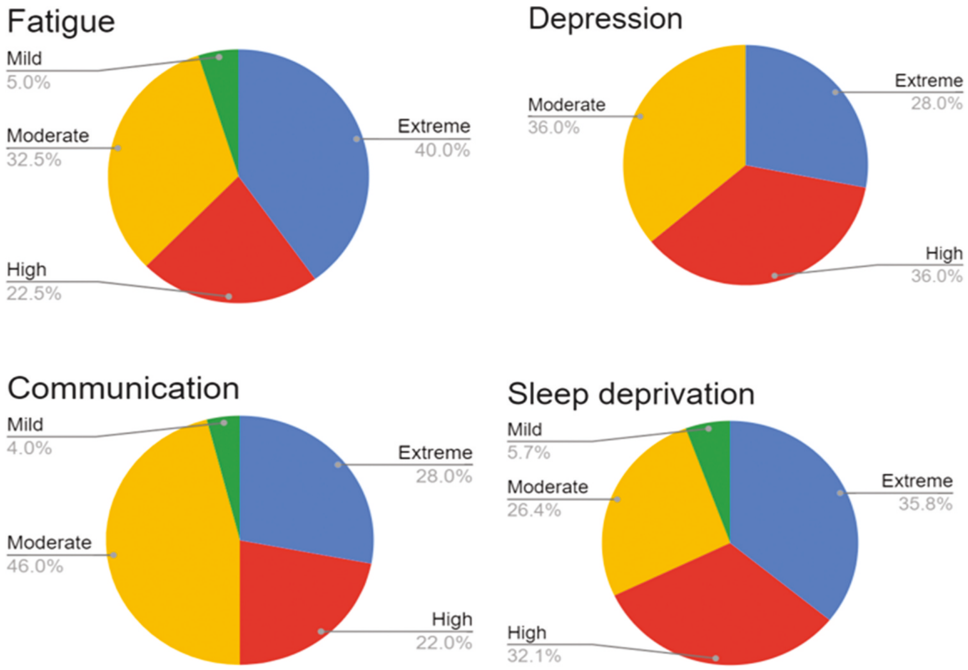


Figure 8. Response to weight of each influencing factor.

questions take into account the position/role of the seafarer taking the survey, and how they weigh each influencing factor. Figure 7 shows the response during the period of data gathering, 50 responses were collected and analysed.

Figure 8 shows the response to each question from this questionnaire section. The responses from the survey question 3 to 6, weighing each of the influencing factors were used to formulate the EIF table for seafarers as shown in Table 5, and the SAPOE as shown in Table 7, by breaking the weight down into extreme, high, moderate, mild, and negligible for all four influencing factors being studied to further analyse the scenario. The questions are as shown below;

- How important is the effect of fatigue in decreasing operational performance in seafarers?
- How important is the effect of depression in decreasing operational performance in seafarers?
- How important is the effect of poor communication with family and friends in decreasing operational performance in seafarers?
- How important is the effect of sleep deprivation in decreasing operational performance in seafarers?

Pre-mooring maintenance operation

Mooring operation is important and frequently conducted onboard vessels as they move from port to port and conduct other activities in the open sea. This being the case, maintenance operations must be conducted by experienced personnel on all mooring equipment onboard for safety. Mooring operations are conducted by the combination of various mooring equipment which includes the mooring line, winch, fender, and operating motor, the winch is the most complex with multiple components (Gaspar et al., 2001), a typical

Figure 9. Mooring winch (Aicrane, 2022).

depiction of the mooring winch is shown below in Figure 9.

Scenario 1: before covid-19

Following the steps for this methodology, as shown in Figure 5, the HEP value for pre-mooring maintenance operation would be calculated. At this stage, the next step is to develop two scenarios that would cover a normal mooring maintenance operation, and the second would factor in the effect of COVID-19 on the influencing factors affecting the operator's mental health and influence the HEP value during the operation. The selected scenario before COVID-19 is as follows;

A mooring operation is to be carried out, the master instructed the third mate to perform pre mooring inspection on the mooring equipment. The third mate is well familiar with the routine inspection operation process. While inspecting the mooring winch, he restored most of the system to its original state for maintenance operation but no proper way to keep track of advances during the activity. Moreover, while checking the brake linkage the maintenance activity does not have direct information available for accuracy and performance standards. The master has asked the third mate to carry out the operation quickly in a short period with not enough time for better error detection and correction as he is required to carry out more activity due to the sickness of the second mate, and the mooring operation would commence shortly.

The maintenance operation of mooring systems includes 4 activities and 12 sub-activities as shown below in Table 10. The sub-activities are selected due to the depth of maintenance required to be carried out by the operator in this particular scenario. Mooring ropes inspection is the first activity during this operation scenario and it is divided into two sub-activities. It requires periodic inspection for abrasion and damages due to frequent use under tension. The next activity is the inspection of the mooring winch components which are broken down into eight sub-activities because of its multiple components. Thereafter, the inspection of the mooring fittings and fenders.

Secondly, after choosing a scenario and also recognizing the various sub-activities under the task, the nominal human unreliability and generic task are chosen from Table 2. The EPCs and their multiplier of nominal probability from Table 4, the respective EIFs are also selected for the second case study at this stage to implement the effect of COVID-19 on the operator as shown in Table 5, respectively. Then SAPOE is allocated from 0–1 for all chosen EIFs and EPCs. Equation (1) is then used to estimate the assessed impact of all factors selected. To demonstrate the application of the technique, a detailed simplified calculation is shown for the mooring operation in Table 8 and illustrated below in Figure 10

The results of the first case study show the individual HEP values are in the range of 6.24E–5 to 1.2062E–2. In this case study, checking the brake linkage during the operation has the highest HEP value of 1.2062E–2, and the summation of the total HEP value is calculated as 6.1676E–2.

Scenario 2: during covid-19

The process for the calculation of the HEP value for the second scenario during COVID-19 is the same as the first as the operation is the same, the only changes are the impact of those psychological factors being affected by COVID-19 on the operator which are factored in under the EPC table and implemented in this case, unlike the first scenario. The selected scenario during COVID-19 lockdown is as follows;

A mooring operation is to be carried out, the master instructed the third mate to perform pre mooring inspection on the mooring equipment. The third mate is familiar with the routine inspection operation process. While inspecting the mooring winch, he restored most of the system to its original state for maintenance operation but no proper way to keep track of advances during the activity. Moreover, while checking the brake linkage the maintenance activity does not have direct information available for accuracy and performance standards. The third mate conducted the task under high levels of fatigue, sleep deprivation, and moderate levels of depression as he had to work extra hours. He has been instructed by the master to carry out the operation quickly in a short period with not enough time for better error detection and correction as the mooring operation would commence shortly. Moreover, the third mate is long overdue for time-off but cannot be released due to the COVID-19 restriction and has barely spoken to his family, he is extremely worried as he would not be able to see or communicate with them anytime soon. Although the procedure for calculation is similar, a detailed calculation is conducted and shown in Table 9 and illustrated as shown below in Figure 11.

The result shows that the individual HEP values are between 6.2685E–4 to 1.2117E–1. The sub-activity with the highest HEP value is checking the brake linkage. The sub-activity is complex and it requires a higher level of experience and attention to prevent risk which puts more stress on the third mate. Finally, the overall HEP value for pre-mooring maintenance operations during the COVID-19 lockdown is estimated as 6.196E–1.

Table 8. Calculation of mooring maintenance operation scenario before covid-19.

SCENARIO BEFORE COVID-19 LOCKDOWN							
Activity	Sub-activity	Nominal human unreliability	Error producing condition	Multiplier of nominal probability	SAPOE base on importance by experts judgement	Assessed Effect	Human Error Probability
Mooring ropes inspection	Check for visible indication of the snap back zone	0.00002	Less importance given to a task Lack of time on hand for error recognition and correction	×1.4 ×11	0.10 0.20	1.04 3	**0.0000624**
	Check for any heavy abrasion damages on the ropes	0.00002	Less importance given to a task Lack of time on hand for error recognition and correction	×1.4 ×11	0.10 0.20	1.04 3	**0.0000624**
Mooring winch	Check if all control, links, and levers are grease, free/easy to use	0.003	Less importance given to a task Improper way to keep track of advances during task Lack of time on hand for error recognition and correction	×1.4 ×1.4 ×11	0.10 0.13 0.20	1.04 1.052 3	**0.00984672**
	Check the load sensor on the mooring winch	0.00002	Less importance given to a task Improper way to keep track of advances during task Lack of time on hand for error recognition and correction	×1.4 ×1.4 ×11	0.10 0.13 0.20	1.04 1.052 3	**6.5644E–05**
	Inspect the winch barrel/drum for damages	0.003	Less importance given to a task Improper way to keep track of advances during task Lack of time on hand for error recognition and correction	×1.4 ×1.4 ×11	0.10 0.13 0.20	1.04 1.052 3	**0.00984672**
	Inspect the wrap for damages	0.003	Less importance given to a task Improper way to keep track of advances during task Lack of time on hand for error recognition and correction	×1.4 ×1.4 ×11	0.10 0.13 0.20	1.04 1.052 3	**0.00984672**
	Check and clean the brake drum from rust	0.003	Less importance given to a task Improper way to keep track of advances during task Lack of time on hand for error recognition and correction	×1.4 ×1.4 ×11	0.10 0.13 0.20	1.04 1.052 3	**0.00984672**
	Check brake linkage	0.003	Less importance given to a task Improper way to keep track of advances during task Lack of time on hand for error recognition and correction Inadequate information for validity check	×1.4 ×1.4 ×11 ×2.5	0.10 0.13 0.20 0.15	1.04 1.052 3 1.225	**0.012062232**
	Inspect gears for rust and grease properly	0.003	Less importance given to a task Improper way to keep track of advances during task Lack of time on hand for error recognition and correction	×1.4 ×1.4 ×11	0.10 0.13 0.20	1.04 1.052 3	**0.00984672**

(*Continued*)

Table 8. (Continued).

SCENARIO BEFORE COVID-19 LOCKDOWN							
Activity	Sub-activity	Nominal human unreliability	Error producing condition	Multiplier of nominal probability	SAPOE base on importance by experts judgement	Assessed Effect	Human Error Probability
	Carry out proper marking and labelling on equipment	0.00002	Less importance given to a task Improper way to keep track of advances during task Lack of time on hand for error recognition and correction	×1.4 ×1.4 ×11	0.10 0.13 0.20	1.04 1.052 3	**6.56448E–05**
Ship mooring fittings	Check all mooring fittings for rust or any heavy damage	0.00002	Less importance given to a task Lack of time on hand for error recognition and correction	×1.4 ×11	0.10 0.20	1.04 3	**0.0000624**
Fenders	Check all fenders for any serious damage, in the right position and tacked firmly	0.00002	Less importance given to a task Lack of time on hand for error recognition and correction	×1.4 ×11	0.10 0.20	1.04 3	**0.0000624**
	Total HEP value for pre-mooring maintenance operation						**0.061676722**

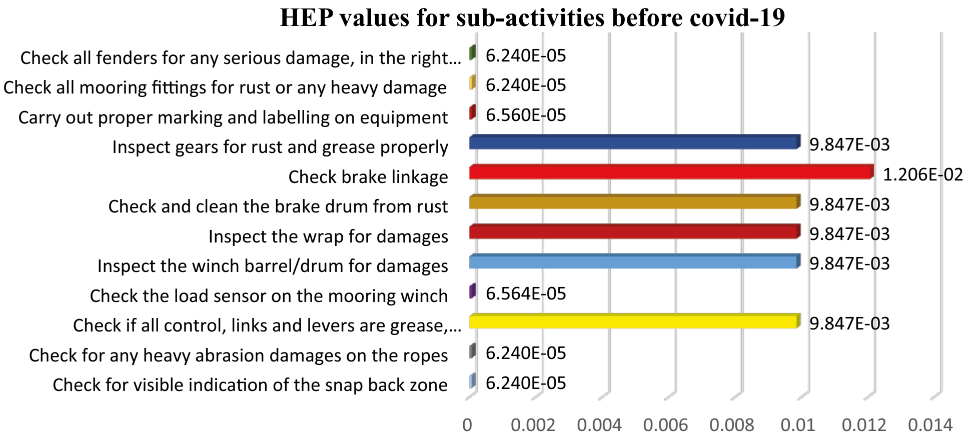


Figure 10. HEP for mooring equipment maintenance before covid-19.

Event tree for mooring operations

Event Tree Analysis (ETA) is a technique applied in the engineering sector to enable the possible measurement of outcomes in a system that may lead to an accident. It utilizes both quantitative and qualitative approaches but lags in some key areas like the assumption that all events are separate and it demands high occupational knowledge and expertise for accuracy (Rausand & Hoyland, 2004). Failure of mooring operation is usually focused on the mooring line as it is subject to much tension and environmental factors (Drori, 2015). Two separate event trees are created to accommodate the two scenarios this research focuses on with similar initiating events and the factors that might result in total or partial failure.

Developed event tree

From the above total HEP values derived from both scenarios, the event tree was generated using the HEP values as the initiating frequency for an excess strain on the mooring line resulting in various outcomes. The various events for this task are some of the activities being carried out under this type of scenario and the weight of each success or failure is given by expert judgment as there are no data to quantify each task individually. This research also assumes that other conditions are kept at the appropriate levels including weather conditions and personnel training.

According to Marine Accident Investigation Branch (MAIB) for the year (2019, 2020, 2021), the number of on-deck accidents attributed to mooring operations has always been on the high side with numbers ranging from 20–26 confirmed cases each year. For this research, the assumption is made that all accidents are a result of mooring line failure. The frequency was calculated by getting the average accident divided by the total vessels in operation per year. The frequency was calculated to be 1.834E–2 accidents/ship year. Also, according to ClydePort (2021), an average number of 5 persons are required for a mooring operation, an assumption of 5% fatality gives 0.25 fatalities per accident. Following these assumptions, a calculation of the frequency of mooring accidents is shown below in Table 10. The event tree diagrams for both cases are also shown below in Figures 12 and 13.

The analysis shows, that three event leads to “rope fail under tension” which might lead to a fatal accident or loss of cargo. Likewise, four successful events led to the successful prevention of the accident as shown in the event tree.

Furthermore, following the event tree analysis, the Potential Loss of Life (PLL) is calculated. The event frequency that cut across all the conditions but also led to failure before and during COVID-19 are given as 1.8281E–4 and 1.5304E–3 respectively. The frequency is already given as 5% for fatality with an average of 5 crew members as shown in the calculation as 0.25 fatalities per accident. A detailed calculation of the potential loss of life is shown below in Table 11.

To illustrate the events conducted leading to mooring rope failure, an event tree analysis is used. For the credibility of this analysis and to align it to the previous assessment carried out using the HEART methodology, the total HEP value of both scenarios was integrated into the event tree as the initiating frequency to further show its impact on the probability of occurrences and the outcomes. Also as seen in the analysis, the probability of occurrences for each failure of safety conditions leading to the failure of the system increases for an identical system because of the HEP value that points to the impact of lockdown on the operation. Due to a lack of data for each event, expert judgment was implemented to weigh each subsequent event on success (YES) or failure (NO). From the analysis, three outcomes lead to system failure in both scenarios but the probability of occurrences increased when the impact of COVID-19 was factored into the second scenario using the HEP value. Furthermore, the research shows the PLL as a support to the event tree analysis calculated. Using the probability frequency of the

Table 9. Calculation of mooring maintenance operation scenario during covid-19.

SCENARIO DURING COVID-19 LOCKDOWN							
Activity	Sub-activity	Nominal human unreliability	Error producing condition	Multiplier of nominal probability	SAPOE base on importance by experts	Assessed Effect	Human Error Probability
Mooring ropes inspection	Check for visible indication of the snap back zone	0.00002	Less importance given to a task	1.4	0.1	1.04	**0.000626851**
			Lack of time on hand for error recognition and correction	11	0.2	3	
			High levels of fatigue	2.52	0.72	2.0944	
			High levels of sleep deprivation	2.02	0.64	1.6528	
			Moderate levels of depression	1.76	0.52	1.3952	
			Extreme levels of poor communication	2.35	0.8	2.08	
	Check for any heavy abrasion damages on the ropes	0.00002	Less importance given to a task	1.4	0.1	1.04	**0.000626851**
			Lack of time on hand for error recognition and correction	11	0.2	3	
			High levels of fatigue	2.52	0.72	2.0944	
			High levels of sleep deprivation	2.02	0.64	1.6528	
			Moderate levels of depression	1.76	0.52	1.3952	
			Extreme levels of poor communication	2.35	0.8	2.08	
Mooring winch	Check if all control, links, and levers are grease, free/easy to use	0.003	Less importance given to a task	1.4	0.1	1.04	**0.098917088**
			Improper way to keep track of advances during task	1.4	0.13	1.052	
			Lack of time on hand for error recognition and correction	11	0.2	3	
			High levels of fatigue	2.52	0.72	2.0944	
			High levels of sleep deprivation	2.02	0.64	1.6528	
			Moderate levels of depression	1.76	0.52	1.3952	
			Extreme levels of poor communication	2.35	0.8	2.08	
	Check the load sensor on the mooring winch	0.00002	Less importance given to a task	1.4	0.1	1.04	**0.000659447**
			Improper way to keep track of advances during task	1.4	0.13	1.052	
			Lack of time on hand for error recognition and correction	11	0.2	3	
			High levels of fatigue	2.52	0.72	2.0944	
			High levels of sleep deprivation	2.02	0.64	1.6528	
			Moderate levels of depression	1.76	0.52	1.3952	
			Extreme levels of poor communication	2.35	0.8	2.08	

(*Continued*)

Table 9. (Continued).

SCENARIO DURING COVID-19 LOCKDOWN

Activity	Sub-activity	Nominal human unreliability	Error producing condition	Multiplier of nominal probability	SAPOE base on importance by experts	Assessed Effect	Human Error Probability
	Inspect the winch barrel/drum for damages	0.003	Less importance given to a task	1.4	0.1	1.04	**0.098917088**
			Improper way to keep track of advances during task	1.4	0.13	1.052	
			Lack of time on hand for error recognition and correction	11	0.2	3	
			High levels of fatigue	2.52	0.72	2.0944	
			High levels of sleep deprivation	2.02	0.64	1.6528	
			Moderate levels of depression	1.76	0.52	1.3952	
			Extreme levels of poor communication	2.35	0.8	2.08	
	Inspect the wrap for damages	0.003	Less importance given to a task	1.4	0.1	1.04	**0.098917088**
			Improper way to keep track of advances during task	1.4	0.13	1.052	
			Lack of time on hand for error recognition and correction	11	0.2	3	
			High levels of fatigue	2.52	0.72	2.0944	
			High levels of sleep deprivation	2.02	0.64	1.6528	
			Moderate levels of depression	1.76	0.52	1.3952	
			Extreme levels of poor communication	2.35	0.8	2.08	
	Check and clean the brake drum from rust	0.003	Less importance given to a task	1.4	0.1	1.04	**0.098917088**
			Improper way to keep track of advances during task	1.4	0.13	1.052	
			Lack of time on hand for error recognition and correction	11	0.2	3	
			High levels of fatigue	2.52	0.72	2.0944	
			High levels of sleep deprivation	2.02	0.64	1.6528	
			Moderate levels of depression	1.76	0.52	1.3952	
			Extreme levels of poor communication	2.35	0.8	2.08	
	Check brake linkage	0.003	Less importance given to a task	1.4	0.1	1.04	**0.121173433**
			Improper way to keep track of advances during task	1.4	0.13	1.052	
			Lack of time on hand for error recognition and correction	11	0.2	3	
			Inadequate information for validity check	2.5	0.15	1.225	
			High levels of fatigue	2.52	0.72	2.0944	
			High levels of sleep deprivation	2.02	0.64	1.6528	
			Moderate levels of depression	1.76	0.52	1.3952	
			Extreme levels of poor communication	2.35	0.8	2.08	

(*Continued*)

Table 9. (Continued).

SCENARIO DURING COVID-19 LOCKDOWN							
Activity	Sub-activity	Nominal human unreliability	Error producing condition	Multiplier of nominal probability	SAPOE base on importance by experts	Assessed Effect	Human Error Probability
	Inspect gears for rust and grease properly	0.003	Less importance given to a task	1.4	0.1	1.04	**0.098917088**
			Improper way to keep track of advances during task	1.4	0.13	1.052	
			Lack of time on hand for error recognition and correction	11	0.2	3	
			High levels of fatigue	2.52	0.72	2.0944	
			High levels of sleep deprivation	2.02	0.64	1.6528	
			Moderate levels of depression	1.76	0.52	1.3952	
			Extreme levels of poor communication	2.35	0.8	2.08	
	Carry out proper marking and labelling on equipment	0.00002	Less importance given to a task	1.4	0.1	1.04	**0.000659447**
			Improper way to keep track of advances during task	1.4	0.13	1.052	
			Lack of time on hand for error recognition and correction	11	0.2	3	
			High levels of fatigue	2.52	0.72	2.0944	
			High levels of sleep deprivation	2.02	0.64	1.6528	
			Moderate levels of depression	1.76	0.52	1.3952	
			Extreme levels of poor communication	2.35	0.8	2.08	
Ship mooring fittings	Check all mooring fittings for rust or any heavy damage	0.00002	Less importance given to a task	1.4	0.1	1.04	**0.000626851**
			Lack of time on hand for error recognition and correction	11	0.2	3	
			High levels of fatigue	2.52	0.72	2.0944	
			High levels of sleep deprivation	2.02	0.64	1.6528	
			Moderate levels of depression	1.76	0.52	1.3952	
			Extreme levels of poor communication	2.35	0.8	2.08	
Fenders	Check all fenders for any serious damage, in the right position and tacked firmly	0.00002	Less importance given to a task	1.4	0.1	1.04	**0.000626851**
			Lack of time on hand for error recognition and correction	11	0.2	3	
			High levels of fatigue	2.52	0.72	2.0944	
			High levels of sleep deprivation	2.02	0.64	1.6528	
			Moderate levels of depression	1.76	0.52	1.3952	
			Extreme levels of poor communication	2.35	0.8	2.08	
Total HEP value for pre-mooring maintenance operation during COVID-19 lockdown							**0.619585174**

event that cut across all the safety conditions but also resulted in system failure before and during COVID-19 as 1.8231E–4 and 1.5304E–3 respectively.

Furthermore, both analyses carried out above show a drastic change in HEP values, individual risk, and PLL. This is of great importance because it illustrates that the pandemic harmed operations at sea. HEP value increased by 55% from 6.1676E–2 before COVID-19 to 6.1960E–1 during lockdown under the influence of COVID-19 on the mental

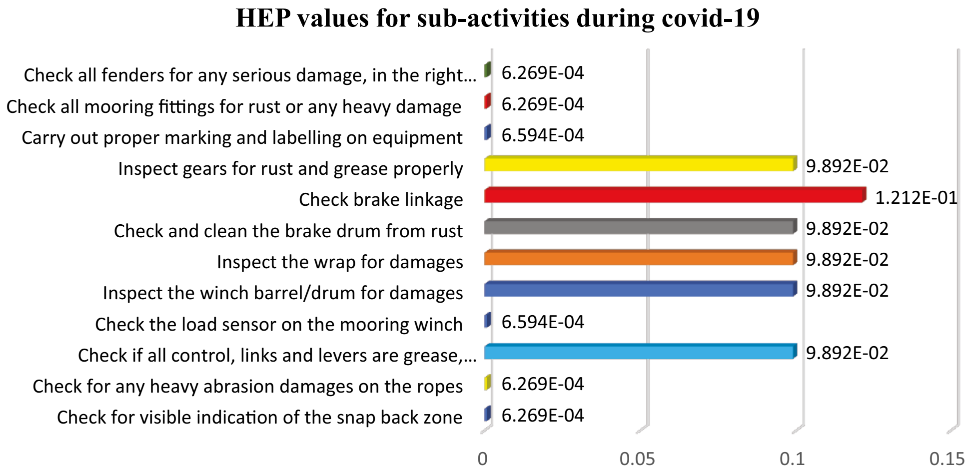


Figure 11. HEP for mooring equipment maintenance during covid-19.

Table 10. Frequency of mooring accidents.

	Frequency of mooring accidents (MAIB)			
Year	2021	2020	2019	
Number of accidents	23	20	26	23
Number of vessels	1530	900	1332	1254
Frequency				1.834E−2

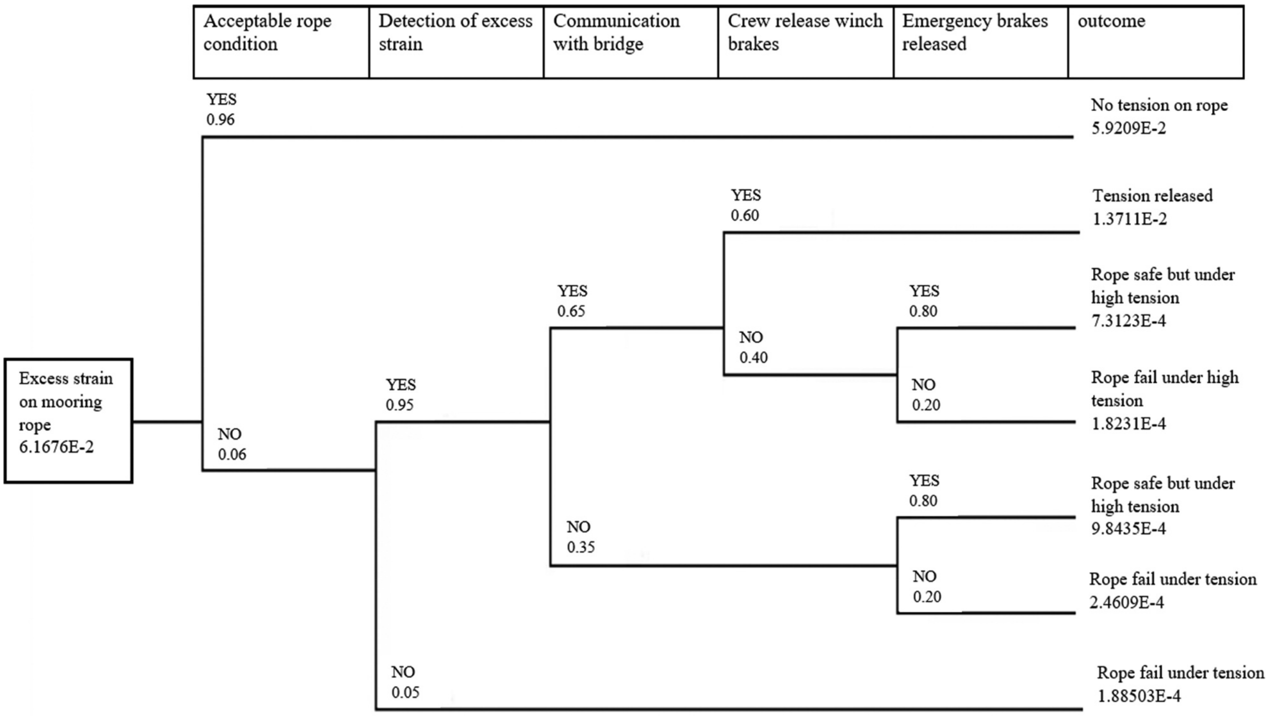


Figure 12. Event tree showing mooring operation failure before covid-19.

health of the operator, the event tree analysis outcomes, the individual risk increased from 9.1405E−6 to 7.6520E−5, and PLL from 4.5703E−5 to 3.8260E−4 all point to the impact this research aim to investigate. The various sub-activity with the highest level of failure is also shown in both cases. This is a result of the influence of psychological stressors on the operator while conducting the maintenance

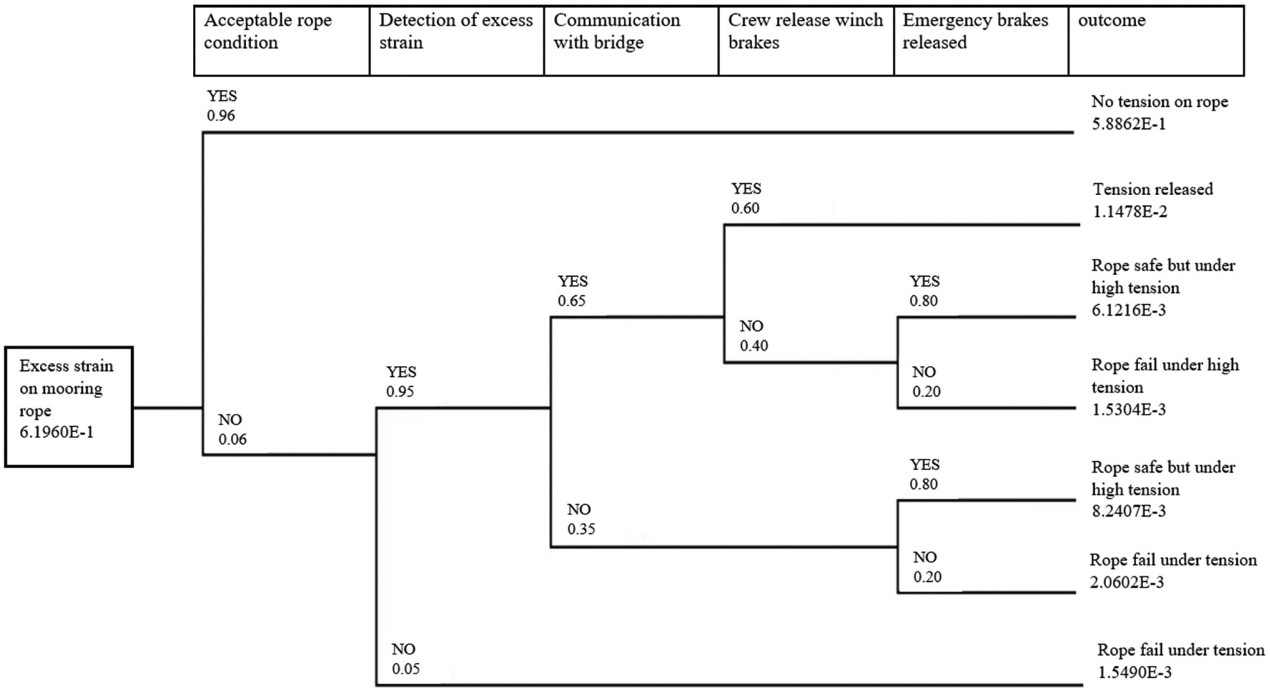


Figure 13. Event tree showing mooring operation failure during covid-19.

Table 11. PLL calculation for fatalities.

Outcome (Accidents)	Frequency	Fatality	Individual risk	Fatalities per parted mooring line	PLL
Rope snap under tension (before covid-19)	1.8281E–4	5%	9.1405E–6	0.25	4.5703E–5
Rope snap under tension (during covid-19)	1.5304E–3	5%	7.6520E–5	0.25	3.8260E–4
			8.5661E–5		4.2830E–4

task. The scenario for each case was carefully assumed to apply to a pre-mooring operation conducted at sea. The weight of influence for each influencing factor covered by this study was also weighted by expert seafarers to further boost the credibility of this research and the results. Research carried out by the European Maritime Safety Agency (2022) also supports these findings and shows a downward trend in maritime trade volume, traffic, ship-building, employment, and delay in maintenance-related activities attributed to the lockdown. This negative change is significant and worth investigating further to provide mitigative measures to prevent accident occurrence from increasing in marine space as findings point in a negative direction

Discussion

The effects and psychological impact of COVID-19 on seafarers have been extensively analysed and represented in the result chapter which achieves the main aim of this research to analyse the effect of COVID-19 on seafarers while conducting operations. This chapter further elaborates on the results to connect the dots and show reasons why these findings are important to the marine sector.

The marine sector has been known to be reactive rather than proactive in accident handling like the aviation sector. Accidents in the marine sector are huge and have both heavy financial and environmental impacts. Countless accidents that have caused loss of life, assets, and major environmental pollution could have been prevented if the sector could be more proactive and tackle issues as they arise. This research focuses on the mental health of seafarers at this time in line with a direction of problem-solving and proactiveness. These research findings give seafarers, ship owners, and the marine sector generally a sense of the current state of mental health of seafarers and possible outcomes if mitigative measures are not put in place. Noticeably, the level of accidents in the marine sector has dropped compared to 3 decades ago but much of this has only been carried out in response to accidents that have happened in the past and mostly about the ship structure alone and not the crew members onboard. From the analysis, a 55% increase in human unreliability is a massive negative impact on accident prevention. For this reason, this research is aimed at pointing to the direction of mental health of seafarers, its significance, and errors that could be avoided if taken more seriously by the maritime sector.

Focusing on the impact of COVID-19 on the influencing factors of mental health of seafarers (fatigue, depression, poor communication, and sleep deprivation) in turn shows how seafarers respond to maintenance operations when under stress. It demonstrates that more work needs to be done during this period targeting the mental rehabilitation of seafarers and giving them more opportunities to discuss how they have been impacted by the pandemic. It is also intended that the implementation of this developed technique in the marine sector will give a clear view of the changes in the HEP values of seafarers because of the COVID-19 lockdown the world recently experienced, and any factor that could affect mode of seafarers of operation during maintenance. These findings would also help seafarers and ship operators understand how important the mental health of seafarers is and how it plays a major role while carrying out operations.

Limitations

The limitations of conducting this study are acknowledged in this paragraph to further understand the scope of this study. In this research, the HEART technique is limited to a marine mooring operation scenario and is used to analyse the various effects of COVID-19 to deduce its impacts on the human error probability of a seafarer during the COVID-19 lockdown. Although, the process can also be used to analyse other scenarios of operation by seafarers in the marine sector. This research only considered four influencing factors (fatigue, depression, poor communication, and sleep deprivation) on the mental health of seafarers but other factors could be considered for further extensive study. Also, the HEART methodology is considered an old first-generation HRA technique applied in petrochemical and nuclear industry, and more advanced techniques have been developed as shown in chapter 2. For this reason, it was modified to suit the marine field and further strengthened using questionnaires to get the judgment of experts on the research. However, by doing so expert opinions could vary in future research which could lead to disparity in some results. The questionnaire feedback had 50 expert responses which could also be factored in as a limitation as a greater number of responses would lead to higher credibility but this was used due to time constrain.

Conclusion

Summery

This chapter completes this research study by summarising the key findings regarding this research aim and objectives, as well as the recommendations and opportunities for future research in line with this study.

This study aimed at investigating the influence of COVID-19 on the HEP value of seafarers while performing maintenance operations. The approach taken was to investigate four influencing factors; fatigue, depression, poor communication, and sleep deprivation that affect mental health of seafarers and the impact COVID-19 had on them.

The HEART methodology was used for this research due to easy applicability and adoption in the marine sector. The method even though being a first generational HRA method has significant processes in producing the framework for this research. To revise the technique EIF table was formulated, a questionnaire was developed to collect responses from experts on the influencing factors to further boost the credibility of this research using this method. The questionnaire was developed and distributed to seafarers via online platforms, and used to weigh each influencing factor individually. The EIF table was developed using the data from the questionnaire before implementing it into the methodology.

Furthermore, the data was implemented into a premooring maintenance operation at sea. Two similar scenarios were adopted before and during COVID-19 to analyse the changes in HEP values of both due to the pandemic. The result shows a 55% increase in human unreliability due to the impact of COVID-19 and a significant increase in individual risk. This indicates that COVID-19 had a huge negative impact on the mental health of seafarers leading to poor performance. Event tree analysis was also conducted to further analyse the effect of the HEP values by implementing them both as the initiating frequency. The various outcome also demonstrated the effect of COVID-19 and showed higher probability values of accidents occurring during COVID-19 when compared together.

It is intended that the implementation of this developed technique in the marine sector will give a clear view of the changes in the HEP values of seafarers during lockdown, and any factor that could affect mode of operation of seafarers during maintenance. These findings would also help seafarers and ship operators understand how important the mental health of seafarers is and how it plays a major role while carrying out operations.

Recommendation and future work

As the various impacts of COVID-19 are still being understood in various sectors, more research should be conducted on how the marine sector could protect seafarers and mitigate unforeseen factors that could influence their mental health. Other factors not covered by this research should also be studied.

The modified HEART technique is easy to implement but other modern techniques of HRA such as CREAM and SLIM could also be implemented to further achieve more accurate results. Also, when questionnaire tools are being used, time should be given to allow more responses.

Finally, the negative impacts of the pandemic are still being studied as the pandemic is new. More are still being discovered as time goes on and wider research should be conducted in this direction to add to the body of knowledge as to the impact covid has on the engineering sector in general.

Disclosure statement

No potential conflict of interest was reported by the authors.

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