

## Unveiling Seafarer's Fatigue: An In-Depth Analysis of Fatigue among Singapore Bunker Tanker Seafarers and Mitigation Strategies

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### Abstract

*This study investigates the effects of crew fatigue on bunker barge employees, with a particular emphasis on the sources and causes of crew fatigue on bunker tankers operating in Singapore. The research investigates shipboard management, operations, planning, the worldwide oil market, the supply and demand for seafarers, and Singapore's maritime industry. In order to investigate the factors that lead to fatigue and the effects it has on the workplace, an anthropological approach and statistical methods are utilized. This study investigates organizational structures, the international oil and shipping sectors, as well as Singapore's shipping business. Seafarers' fatigue can be affected by a variety of factors, including the physiology of the crew as well as the architecture of the vessel. Methods of data collection and processing are analysed, including Bayesian networks and Python scripts, among other things. According to the findings of the study, fatigue among seafarers is caused by a number of different causes, including onshore management as well as physical and psychological stress, with physical stress and irregular sleeping habits being the two elements that have the most significant impact.*

*Keywords: Fatigue; Seafarers; Onshore Management; Physical Stress; Psychological Stress*

### Introduction

The maritime industry, acting as the routes of global trade and economic exchange, relies on the intricate interplay of vessels navigating vast oceans (Bommarito 2022). The size of the global bunker fuel market was estimated to be around \$120.1 billion in 2019, and it is projected to reach \$130.1 billion by the year 2027, expanding at a compound yearly growth rate of 3.1 percent over the next seven years (Ayad 2021). Within this intricate network, bunker tankers assume a vital role, serving as the carriers of the lifeblood that propels shipping vessels forward—fuel (Anantharaman 2018). This fuel sustains the movement of goods and resources, facilitating the seamless continuation of international commerce. However, beneath the surface of these operations lies a critical concern: the well-being of seafarers who bear the responsibility of steering these bunker tankers through often treacherous waters (Kamis et al., 2022).

In the heart of this maritime saga, Singapore emerges as a pivotal player, boasting one of the world's most bustling ports and serving as a strategic nexus for international shipping activities (Fong & D. Meyer, 2015). The maritime landscape of Singapore encompasses not only its economic

vitality but also its cultural diversity and historical significance (Rochwulaningsih et al. 2019). Amidst this bustling backdrop, seafarers operating on Singaporean bunker tankers shoulder a unique set of challenges, from the demanding nature of their work to the prolonged hours of operation and the unpredictable environmental conditions they face (Wu & Liang, 2011).

Bunker fuel is a type of fuel oil that is utilized on board ships. It is used as a source of fuel for the ship's engines in the bunkers (Ait Allal et al. 2019). Fuel oil with high Sulphur content, fuel oil with low Sulphur content, and diesel oil are the three primary forms of marine fuel that are utilized by ships (Chu Van et al. 2019). As of right now, there is a growing awareness toward reducing environmental pollution, and rigorous government policies are anticipated to offer prospects for fuels such as LNG, gasoil, LPG, and others as a replacement for bunker fuels (Al-Enazi et al., 2021). For example, on March 24, 1989, the oil spill caused by the Exxon Valdez occurred in Prince William Sound in the state of Alaska (Barron et al., 2020). The Exxon Valdez is a massive oil supertanker that is operated by Exxon Shipping Company and is heading in the direction of Long Beach. The Exxon Valdez ran aground on Bligh Reef in Prince William

Sound in 1989, approximately 2.5 kilometers west of Tatitlek, Alaska. As a result of the collision, nearly 11 million US gallons of crude oil were released into the environment over the course of the following few days (Schaefer & Bishop 2022). Exxon found itself in an extraordinarily difficult financial position because of this accident, having shelled out nearly \$2 billion to clean up the leak and an additional \$1 billion to pay related civil and criminal incriminations (Fourcade, 2011). The incompetent management of the ship by the third officer on deck, which may have been caused by exhaustion or an excessive amount of work, was one of the factors that contributed to the accident (Schaefer & Bishop, 2022).

When sailors are overworked and exhausted, they are more likely to make significant errors in their decision-making processes, which can result in incidents that have repercussions for the entire world (Johansen 2022). In order to reduce the likelihood of accidents of this kind, save the environment, and ensure that the global economy continues to function normally, an investigation of the effects of weariness on seafarers working on Singaporean bunker tanker vessels is required.

With all of these complex interrelationships in mind, this study sets out on a mission to investigate one of Singapore's most pressing problems: the problem of fatigued seafarers working on bunker tanker crews. This study aims to improve the well-being of seafarers, strengthen maritime safety, and contribute to the sustainable evolution of the global maritime industry by delving into the factors that contribute to fatigue, evaluating its far-reaching impacts, and proposing strategies to mitigate its effects. The main purpose of this research is broken down into three distinct stages as it is carried out. To begin, the purpose of this study is to determine the primary contributors to the weariness experienced by crew members working on tanker vessels. Specifically, the objective is to untangle the complex web of factors that interact in such a way as to exacerbate the problem. Second, the purpose of this study is to determine the relative significance and weight of each of the factors that contribute to the levels of weariness that are experienced by the crew of the bunker barge. This quantification is

essential for constructing a hierarchy of treatments as well as comprehending the proportionate influence that each component has. In the end, the purpose of the research is to provide actionable recommendations that are aimed at lessening the incidence of fatigue and its negative effects among maritime workers. The purpose of this research is not only to decode the underlying intricacies of seafarer weariness but also to uncover effective pathways for its reduction and eventual removal. This will be accomplished through three stages that are interconnected with each other.

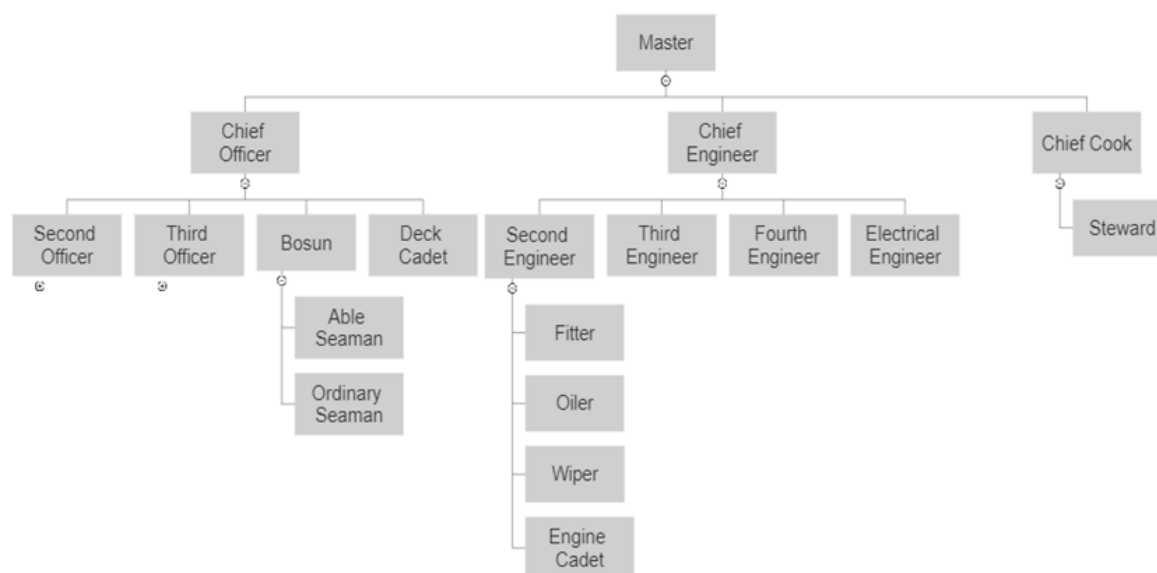
The paper is divided into several important chapters to give readers a thorough comprehension of the topic. The literature review, which is covered in depth in the second chapter, explores many subjects. The organization of shipboard and shore management is also examined, offering insight into their unique structures and roles. The chapter also examines the intricate nature of shore management organizations and their critical function in marine operations. Additionally, a comprehensive analysis of fatigue is provided, including its causes, signs, and the substantial effects it has on both shipboard and shore workers. The third chapter describes the methodology used in the study and clarifies the methods and tactics used to collect pertinent data. A thorough description of the results, supported by statistical analysis and visual aids, is given in the fourth chapter. The final chapter conducts a thorough analysis of the findings and establishes links between them and the body of prior research. The study's findings are also included in this section, along with insightful suggestions that can help port management practices and shipboard management practices generally improve.

### **Literature Review**

**Organization of shipboard and shore management**  
A fundamental pillar of global trade, the marine sector links economies and connects countries through the movement of people and goods (Bommarito 2022). For maritime businesses to be safe, effective, and profitable, ships must operate without a hitch both at sea and on land (Ringer, 2010). The coordination of these operations, which involves a complex interaction of personnel, technology, rules, and logistics, is largely

dependent on the structure of shipboard and shore management (Steven 2022). This section will describe the terms regarding the organization of shipboard and shore management. The term "seafarer" refers to any person working on a ship for a specific period, including temporary workers like pilots, stevedores, loading masters, cargo surveyors, and repair technicians. Shipboard organization depends on the requirements of shipping companies, with the main objective of maximising efficiency (Kasiska & Jendryczka, 2022). The organizational structure includes the "master" as the sovereign authority, with other officers responsible for their individual functions (Stathakis 2022). The chief engineer is responsible for the ship's machinery, while the chief officer handles

deck maintenance and catering (Narayanan et al. 2023). The deck cadet is a trainee under the supervision of the chief officer (Rex A. Abella et al. 2022). The chief engineer is responsible for maintaining the engine facility, while the electrical engineer handles electrical equipment and refrigeration devices (Islam et al. 2018). Seafarers are required to have competency certifications according to STCW 1978 standards, and they participate in training, drills, and security tasks (Kim & Mallam 2020). The chief cook oversees the catering department, with the steward assisting in cooking, inventory, and galley maintenance (Karindosk et al. 2023). The organizational structure for a shipboard organization is shown in Figure 1.



**FIGURE 1. The organizational structure for a shipboard organization**

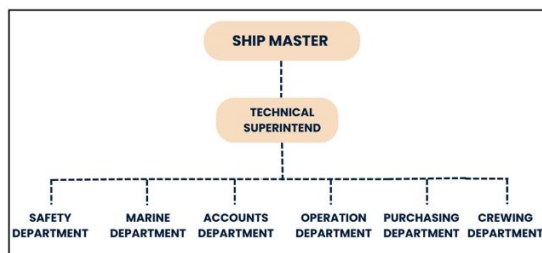
#### Shore Management Organization

Each ship has an individual managing board that oversees the management of the ship within its prescribed scope and limits (Hays & V. A. Tidwell 2022). There are several types of organizational structures in order to meet the goals of the organization (Pinjala et al. 2006). The way the organization is structured depends on several factors: type of industry, type of skill sets needed in the organization, product life cycle of products in the industry, experience level required in the organization, age group of employees required in the organization, location, need for mobility, blue-collar or white-collar first organization (Döring et al.

2022). The below section focuses on the organizational structure in the shipping industry.

The shipping industry has an organizational structure that is both on and offshore (Hessevik 2022). The shipboard management structure reports to the shore-based superintendent, who can have a number of ships under him ranging from 2 to 5. Qualification-wise, most likely he will be a former marine engineer with rich on-board and ashore experience or a highly qualified and decorated marine superintendent (Marion 2009). The ideal candidate for the role is likely to have rich expertise in cross-functional

domains like technical, commercial, operational, and administrative functions.



**FIGURE 2. Organization Structure of Shore Management**

Figure 2 illustrates a ship's organization structure, consisting of several departments such as safety, marine, operations, purchasing, crewing, and accounts. Each department has its own head of department responsible for smooth functioning. The Technical Superintendent serves as a bridge between the ships on the sea and onshore organization functions (Choi et al. 2022). The organizational structure includes departments such as safety, marine, technical, operation, crewing, and accounts (Ringer 2010). The safety department ensures safe operations by shipboard personnel and maintains the company safety management manual. The marine department ensures compliance with national and international rules and regulations, ensuring the vessel is safe and complies with local navigation regulations (Dinwoodie et al. 2012). The operation department ensures the vessel is fixed for commercial voyages and operates optimally, ensuring efficient operation and vessel engagement without off-hire or profit loss. The purchasing department devises organizational policies and mechanisms for the ship's storage areas, bunkering areas, and approved suppliers (Moshiul et al. 2023). It is crucial to maintain profitability by monitoring the changing global landscape and maintaining good relationships with vendors (Nguyen & Mutum 2012). The crewing department ensures adequate manning levels for safe operation, while the human resources department handles crew issues such as pay, motivation, fatigue, training, service conditions, and industrial relations (Saini 2011). The finance department handles the settlement of accounts, creates accounting procedures, manages credit, and maintains the overall financial results of the company. It also prepares reports with

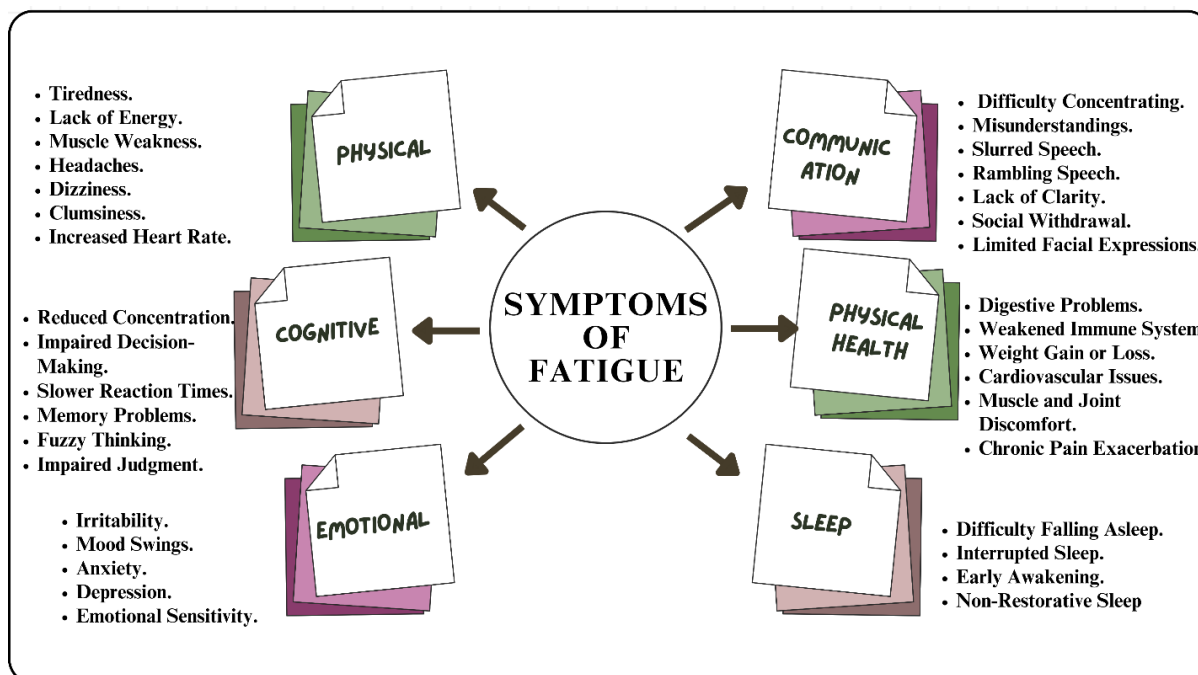
investment bankers and other organizations to envision the long-term financial vision of the ship (Bacry et al. 2015). The Chief Financial Officer works closely with the Chief Executive Officer to ensure the organization's health and ensure optimum decision-making (Shadman et al. 2023). A description of fatigue is elaborated in the following section.

### Fatigue

There is no universally accepted technical definition for fatigue. However, some terms appear in all definitions, such as the decline of human performance and the reduction of awareness or human reliability (Dincer 2000). It is generally described as a state of feeling tired, weary, or sleepy that results from prolonged physical or mental work, extended periods of anxiety, exposure to harsh environments, or loss of sleep (Palomba et al. 2022). In other words, fatigue generally includes the inability or disinclination to continue an activity that has been going on for too long (Ltzhöft et al. 2007). Fatigue is also defined by IMO as "a reduction in physical and/or mental capability as the result of physical, mental, or emotional exertion that may impair nearly all physical abilities, including strength, speed, reaction time, coordination, decision-making, and balance" (Lefkowitz et al. 2019). Furthermore, it is a nonspecific symptom as it is most of the time an indicator of other causes and conditions that include physiological conditions such as sleep disorders and strenuous muscular tasks; medical situations such as chronic inflammatory statuses, bacterial or viral infections, or autoimmune illnesses; and psychiatric conditions such as depression, anxiety attacks, and somatoform disorders (Dohrmann & Leppin 2017). Fatigue may be afflicted by prescription medicines, including antihistamines, drugs prescribed for sleeplessness, or chemotherapy medicines (Golding & Gresty 2015). It may also be a result of erratic lifestyles, such as frequent interruptions in the wake-sleep cycle, excessive alcohol or caffeine consumption, psychosocial factors, or the delayed effects of traumatic episodes (Wang 2012). There are a variety of signs of fatigue (figure 3), such as overall lethargy in an individual's activity, the inability to do a specific task within the scope of one's natural

talents or experiencing muscle fatigue because of a specific task. These symptoms can include chronic fatigue and sluggishness, which can impair judgement and attention span even after adequate rest (Rowe et al. 2017). Memory lapses and trouble remembering things start to show up, which affects how well the engineer can handle technical jobs. Physical signs may include impaired reflexes,

impaired motor coordination, and a higher risk of accidents. In addition, persistent weariness frequently results in irritability, mood changes, and increased tension and anxiety. These symptoms can build up over time, possibly causing a reduction in overall job performance, safety issues, and detrimental impacts on mental health (Moshawrab et al. 2022).



**FIGURE 3. Symptoms of fatigue**

Fatigue is caused (Figure 4) by various factors in the maritime industry, including long working hours, inadequate rest, a high workload, repetitive tasks, environmental conditions, time zone changes, responsibility, pressure, isolation, a lack of physical activity, inadequate nutrition, and cumulative fatigue. These factors disrupt natural sleep patterns, cause mental and physical exhaustion, and contribute to the overall stress experienced by marine engineers (Abrahamsen et al. 2022). Additionally, time zone changes disrupt circadian rhythms, and the critical role of marine engineers in vessel safety and operational integrity can further exacerbate fatigue (US Government Accountability Office 2021). Fatigue among seafarers has a significant impact (Figure 5) on both individual professionals and overall maritime operations. On a personal level, weariness impairs cognitive capacities, resulting in reduced focus, compromised judgement, and sluggish reaction times. Marine engineers are crucial to guaranteeing the vessel's

smooth operation and quick emergency response; therefore, their diminished mental acuity poses a serious safety risk. Reduced motor coordination, an increased risk of accidents, and increased discomfort from insufficient sleep are some of the physical effects (Lee et al. 2020). Over time, the ongoing fatigue and physical stress may cause chronic health problems. The emotional effects of exhaustion include increased stress, irritability, mood changes, and a general deterioration of mental health. Fatigue can worsen the isolation felt over extended periods at sea, heightening loneliness sensations and perhaps resulting in mental health issues (Brooks & Greenberg 2022). All these factors have an impact on marine engineers' quality of life, interpersonal connections, and job satisfaction. Fatigue often jeopardizes the effectiveness and security of maritime activities. Fatigued maritime engineers may overlook crucial information during equipment inspections or interpret data incorrectly, potentially

resulting in equipment failure or accidents (Li et al. 2022). Reduced awareness makes it more difficult to recognize and react quickly to navigational dangers, bad weather, and technical problems. The safety of the ship, the crew, and the environment may be compromised as weariness spreads across the crew, impairing team coordination,

communication, and decision-making. In order to protect the safety, health, and productivity of maritime professionals as well as the overall integrity of maritime operations, it is crucial to address the effects of marine engineer fatigue.

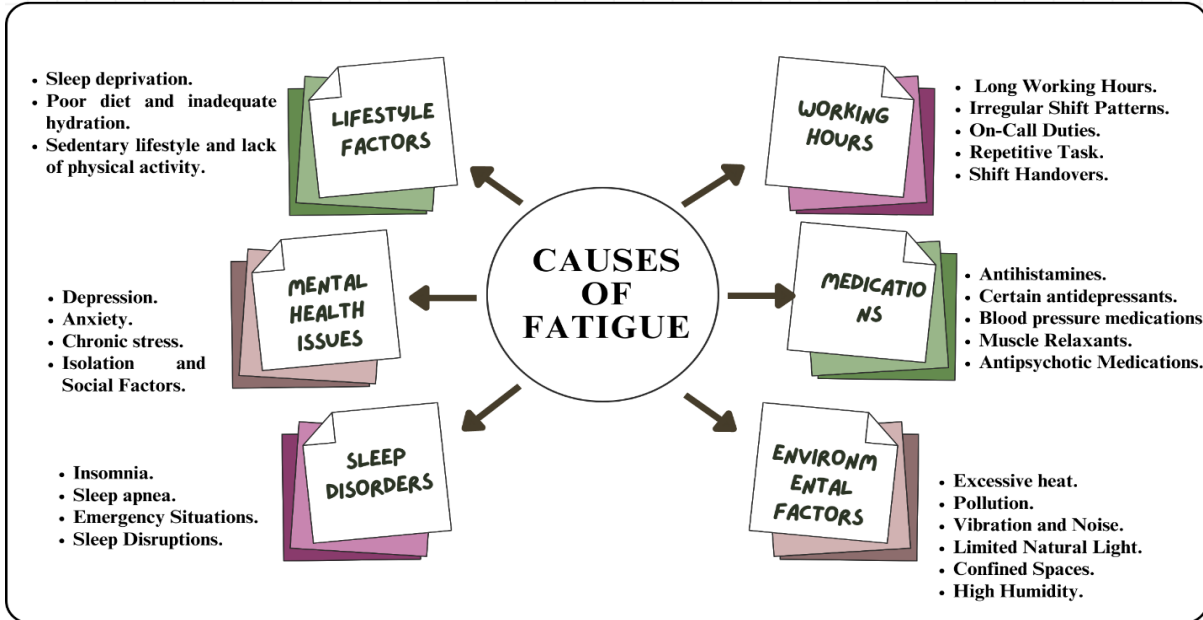


FIGURE 4. Causes of fatigue

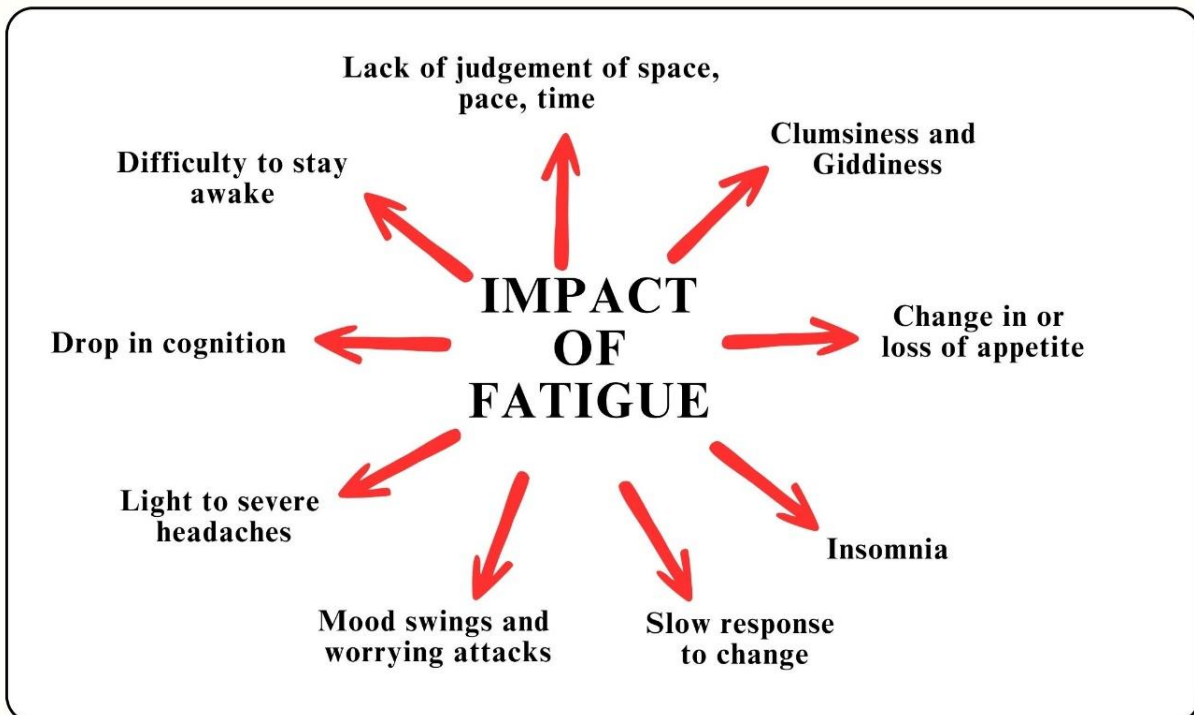


FIGURE 5. Impact of fatigue

Previous studies

A dynamic model that spans 180 days, or from the time an officer joins the company to the conclusion of their contract. This model depicts the contract time, or the time that officers typically spend on board. In the first test, which was conducted under the commonly acknowledged condition of eight hours of standard labor (both in port and on the open sea), fatigue levels were essentially nonexistent. The second test on the same journal was based on the supposition of eight hours of regular work and four hours of extra work, for a total of twelve hours of labor per day (Wendel-Vos et al., 2003). Due to this need, there was daily overtime of four hours. The officer worked for over twelve hours a day without taking a break because of fatigue, although production was determined to be low throughout the simulation. Another study was conducted on passenger and freight ships that pass through Norwegian waters by Hystad & Eid (2016). The findings of this study provide only weak evidence for the idea that as a seafarer's time aboard rises, fatigue levels rise. The number of days spent at sea did not directly correlate with the level of exhaustion or the quality of their sleep for the crew of the whole cargo and passenger ro-ro ship. These seafarers work on a 22-day rotation level (22 days on board, followed by 22 days off), and such a brief period at sea is insufficient for the ship's environment to have a negative impact on the seafarers.

A possible explanation for the limited effect of duration at sea on fatigue and sleep quality in their sample was predicted to be the healthy worker effect (HWE). The phrase "Healthy Worker Effect" was first developed by McMichael et al. to showcase the long-known tendency of actively working individuals to have a lower death rate than the population at large. Although their study cannot be clearly called an epidemiological study, one particular aspect of the HWE still holds significant relevance: the phenomenon often referred to as the "healthy worker survivor effect." Healthier workers are more likely to live on (i.e., survive) in the workforce in contrast to workers who are more responsive or sensitive to hazards, who in turn are likely to move to jobs with less exposure or leave the workplace all at once. The results from the study also showcase that seafarers working on

board ro-ro ships have shown higher levels of fatigue compared with seafarers working on offshore supply ships. To understand these results, it is important that we evaluate some of the differences between these two maritime constructs. The ro-ro ships under study sail a continuous and fixed-pattern route up and down the Norwegian coast. The journey from the southernmost to the northernmost port takes a week, with frequent port calls and long periods of inactivity. Offshore vessels have longer voyaged and longer periods of inactivity, which may contribute to fatigue among seafarers. Environmental stress, such as noise, ship movement, and vibration, is a significant factor affecting seafarers' wellbeing. The study found that environmental stress was positively correlated with poorer sleep quality and fatigue in the ro-ro data set. There was no study found that addressed the level of fatigue measured by tanker vessel seafarers. Particularly, there was no research carried out on bunker tanker seafarers' fatigue levels. Being one of the largest shares of the shipping industry and to prevent any accident that may cause disaster economically and environmentally, no research has been carried out on tanker seafarers' fatigue individually. Therefore, it is extremely important to conduct a study on tanker seafarers' fatigue. As we have seen in the Exxon Valdez catastrophe, one of the root causes was that the Officer on Watch (3rd Officer) was carried away by fatigue and could not maneuver the vessel as required. This research will bridge this gap. However, to fill the gap, a study has been taken for Singapore-registered bunker tankers and foreign-going tanker vessels with seafarers. This research would be able to fulfil the objectives of the study.

### **Methodology**

This chapter will outline all of the methodologies that were employed to carry out this study. According to the study's goals, quantitative research methods were employed. In order to accomplish the goals of this research, general research has been done in order to comprehend the contributing component of crew weariness on board the vessel. A survey of the Singapore bunker tanker crew has been carried out as the second step in fulfilling the goals of this research. Data was

evaluated to determine the relative importance of crew weariness as a contributing factor. On the basis of the data analysis from the second stage, recommendations for the third and final stage were taken into consideration in order to lessen fatigue on board bunker tankers operating in Singapore. By minimizing the frequency of accidents and casualties, the suggested solution will aid in reducing tiredness across the tanker fleet, which will benefit the entire industry both economically and environmentally. Additionally, all of the information is based on responses to a survey questionnaire from seamen on a bunker tanker ship. The survey was on a Google form, and the respondent received the link by email, social media, and their management company's seafarers. As a result, this chapter goes into further detail about the quantitative approaches that were used in the research study.



**FIGURE 6. Research Questions**

**Research framework**

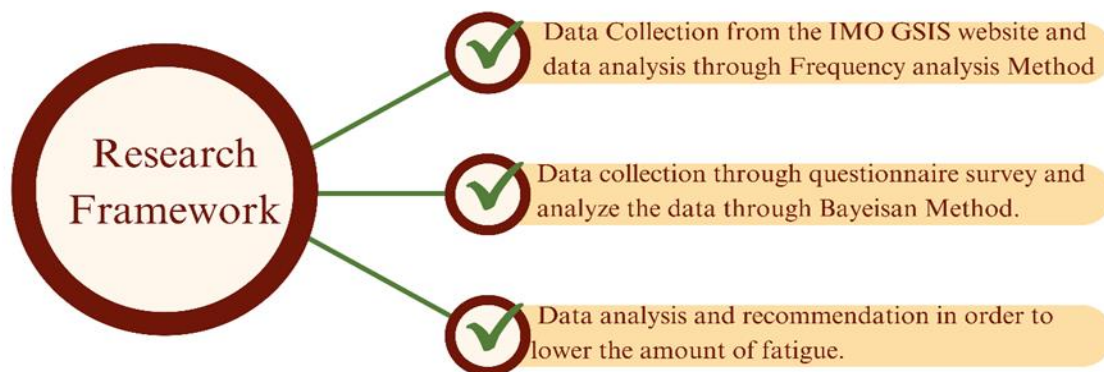
This study was focused on tanker vessels in general and Singapore-registered bunker tanker vessels in particular. There are typically 1,000 vessels in the Singapore port at any given moment. Nearly 4,500 sailors are employed at any given time on approximately 200 bunker tankers that are now

navigating Singapore's waterways. Nearly 3,000 of them are still working as seafarers on bunker tankers. The Maritime and Port Authority of Singapore has the bunker tankers' registration information. Foreign sailors employed on these ships are regarded as working in Singapore and are given employment passes. In accordance with MPA requirements, they must additionally obtain their Certificate of Recognition to go along with their national Certificate of Competency and Ship handling Training certificate.

**FIGURE 7. Research framework**

**Data Collections**

It is quite common practice to use questionnaires to collect data, especially when conducting in-depth, complex research. Questionnaires have been used by researchers, small and large businesses, commercial and public organizations, and individuals. The project's major component is thought to be the survey questionnaire. As a result, it needs to be meticulously and thoroughly prepared. Data were gathered for this study using a survey method based on questionnaires. The sailors who are currently working on the crews of Singapore bunker tankers were included in this survey using the Stratified Complex Random Sampling Process. During the survey, a Google Form link was distributed to the appropriate seafarer communities on social media. Data Analysis As inferred from the above literature, Bayesian analysis was invoked to understand the fatigue level among seafarers and the factors that were responsible for the increase in fatigue. In order to arrive at the analysis, a survey was conducted among seafarers, where their fatigue level was assessed. The various factors that could impact the



level of fatigue shown in Table 1 are: The data was collected over a period of four weeks, and after the data collection, it was imported into Python software to arrive at the results. Following are the inferences from the Bayesian network analysis.

**Bayesian networks**

Bayesian networks are a combination of probabilistic and graph models that are widely applied in various disciplines, including machine learning, data extraction, and analysis. They have a strong evidence-based deduction and are often confused by the complex structures, equations, and technical software involved. Bayesian networks use probabilities to determine the probability of outcomes, depicted in an acrylic graph. They are

also known as belief networks, decision graphs, and Bayesian models. It is a graph with nodes representing variables and Bayesian probabilities

defined. Structured learning is based on index learning, and the likelihood is obtained for each variable probabilistically for those variables present in the scenario.

A probabilistic paradigm incorporates mathematics and graphical representations of graph theory, but two problems must be addressed: ambiguity and unpredictability. Graphical models depict random dependency relationships, and algorithms provide a significant impact in analyzing and designing machine learning approaches. Observational learning has been researched, using experience, or observed evidence to generate new principles. Various approaches have been tried to reconstruct features, optimize ranking, and create local versions of the network to better approximate the global structure. Most analysis with Bayesian networks is limited to scenarios where the configuration does not change.

**TABLE 1. Impact of various factors**

Factors	Dependence
Physical Stress	Overtime, rough sea, maintenance level of vessel, age of vessel, Singapore port humidity.
Psychological Stress	Workload, personal problems, family issues, traffic density, shore leaves, performance demands.
Health Conditions	(a) Illness, age, and diet. (b) Diet variable was further dependent on drug, caffeine, alcohol intake
Ship Design	Redundancy, level of automation, equipment reliability, physical comfortless at workplace.
Ashore management factor	Crew selection, crew training, crew complement size, assistance from shore management factor, crew contact period, paperwork requirements.
Level of sleep and rest	(a) Rest break levels, quantity, quality, and duration of sleep and sleep related disorders. (b) Rest break levels are dependent on length of break levels. (c) Quantity, quality, and duration of sleep is further dependent on motion of ship, shift work and work schedule, accommodation temperature, vibration of the ship, noise levels on the ship. (d) Sleep disorders are further dependent on circadian rhythms, jetlag, unpredicted bunkering schedule.

Fatigue is the parent node in Figure 8, and the factors are referred to as "nodes-child nodes." The majority of the crew members are in good health and sleep soundly. The quality of the ship's design was likewise discovered to be typical. Some

seafarers were found to be extremely fatigued and to have had high levels of physical and psychological stress. Some members appear to have strong management while others do not, suggesting that the ashore management





FIGURE 9. Abbreviation of Parameters & variables

FIGURE 10. Heat Map

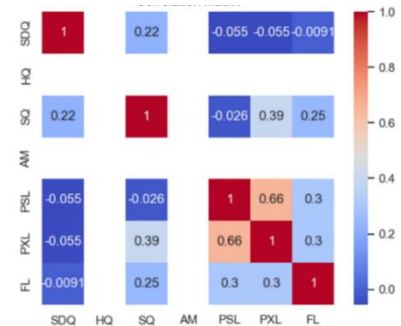
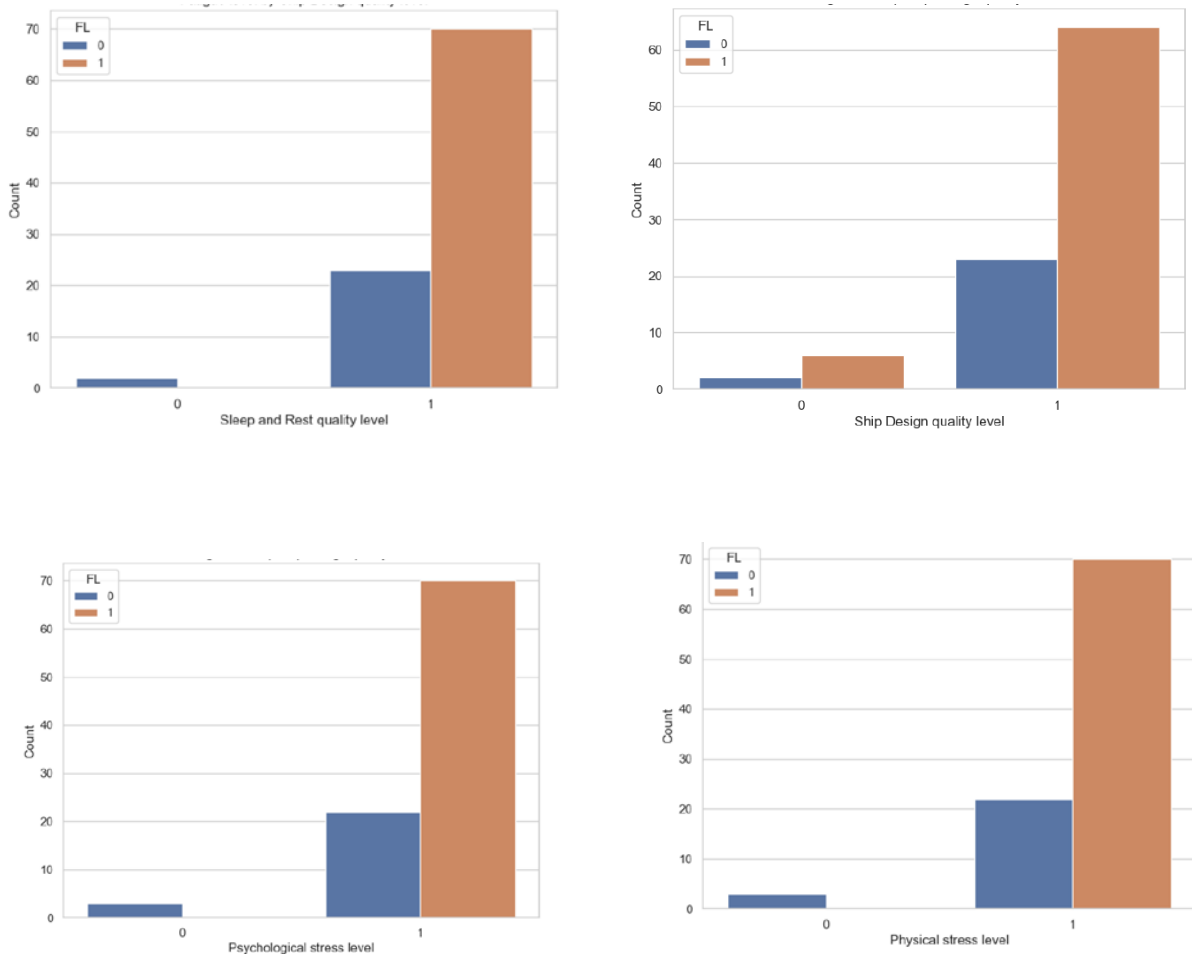


FIGURE 10. Correlation matrix

TABLE 2. Correlation and results

Correlation between	Results
Ship Design Quality and Fatigue Level	The mean FL scores of the two groups do not differ significantly, according to a p-value of 0.9305.
Sleep Quality and Fatigue Level	There is a significant difference between those who have good sleep and rest quality and those who do not, according to a p-value of 0.016 and a t-value of 2.44.
Physical Stress and Fatigue Level	There is a significant difference between the levels of fatigue in people with high psychological stress and those who do not, according to a p-value of 0.0029 and a t-value of 3.05.
Psychological Stress and Fatigue Level	There is a significant difference between the levels of fatigue in people with high psychological stress and those who do not, according to a p-value of 0.0029 and a t value of 3.05. .



**FIGURE 12. Frequency plots (Sleep and Rest Quality level; Ship Design Quality Level; Psychological Level; Physical stress level).**

**Results from the Bayesian Estimator**

The values in figure 13 are the probabilities of all possible combinations of values for the six variables. In figure 13, the first row of the table corresponds to the case where all six variables have the value 0. The probability of this case is 0.0007, which means that this case is expected to occur with a frequency of 0.07% in the data. Similarly, the third row corresponds to the case where only the SL variable has the value 1, and all other variables have the value 0. The probability of this case is also 0.038, which means that this case is also expected to occur with a frequency of 3.80% in the data. The other rows in the table correspond

to all possible combinations of values for the six variables. For each row, the probability of that combination is listed in the last column of the table. The joint probability distribution is useful for analyzing the relationships between different variables. For example, it can be used to calculate the conditional probabilities of certain events given the occurrence of other events. The last row, for example, shows that fatigue level 1 occurs along with sleep quality of 1 and physical stress quality of 1, leading to a probability of 62.5% of the case occurring. This shows a strong correlation between bad sleep and high physical stress, leading to high fatigue levels.

AM	PSL	SDQ	SQ	HQ	FL	phi (AM, PSL, SDQ, SQ, HQ, FL)
AM(0)	PSL(0)	SDQ(0)	SQ(0)	HQ(0)	FL(0)	0.0007
AM(0)	PSL(0)	SDQ(0)	SQ(0)	HQ(0)	FL(1)	0.0007
AM(0)	PSL(0)	SDQ(0)	SQ(1)	HQ(0)	FL(0)	0.0038
AM(0)	PSL(0)	SDQ(0)	SQ(1)	HQ(0)	FL(1)	0.0038
AM(0)	PSL(0)	SDQ(1)	SQ(0)	HQ(0)	FL(0)	0.0056
AM(0)	PSL(0)	SDQ(1)	SQ(0)	HQ(0)	FL(1)	0.0056
AM(0)	PSL(0)	SDQ(1)	SQ(1)	HQ(0)	FL(0)	0.0324
AM(0)	PSL(0)	SDQ(1)	SQ(1)	HQ(0)	FL(1)	0.0031
AM(0)	PSL(1)	SDQ(0)	SQ(0)	HQ(0)	FL(0)	0.0030
AM(0)	PSL(1)	SDQ(0)	SQ(0)	HQ(0)	FL(1)	0.0004
AM(0)	PSL(1)	SDQ(0)	SQ(1)	HQ(0)	FL(0)	0.0154
AM(0)	PSL(1)	SDQ(0)	SQ(1)	HQ(0)	FL(1)	0.0773
AM(0)	PSL(1)	SDQ(1)	SQ(0)	HQ(0)	FL(0)	0.0148
AM(0)	PSL(1)	SDQ(1)	SQ(0)	HQ(0)	FL(1)	0.0143
AM(0)	PSL(1)	SDQ(1)	SQ(1)	HQ(0)	FL(0)	0.1936
AM(0)	PSL(1)	SDQ(1)	SQ(1)	HQ(0)	FL(1)	0.6256

FIGURE 13. Values of the joint probability distribution

Maximum Likelihood Estimator

The dependencies between various independent variables in a dataset are displayed by Bayesian networks. We can predict the conditional probability distributions (CPDs) for each node using Bayesian estimation and fit the model with a maximum likelihood estimator. Based on the data gathered, we can forecast the network's variables. The Python output that displays the variables' probabilities is shown in the image below. The

number in parentheses following the variable name indicates the number of states that each variable has. According to the model, there is a 10.5 percent chance that ship design quality will be in state 0 and an 89.5 percent chance that it will be in state 1 (Figure 14). According to the model, there is a 4.5 percent chance that sleep quality will be in state 0 and a 95.5 percent chance that it will be in state 1, as shown in figure 15. According to the model, there is a 5.5 percent chance that physical and psychological stress will be in state 0, and a 94.5 percent chance that it will be in state 1.

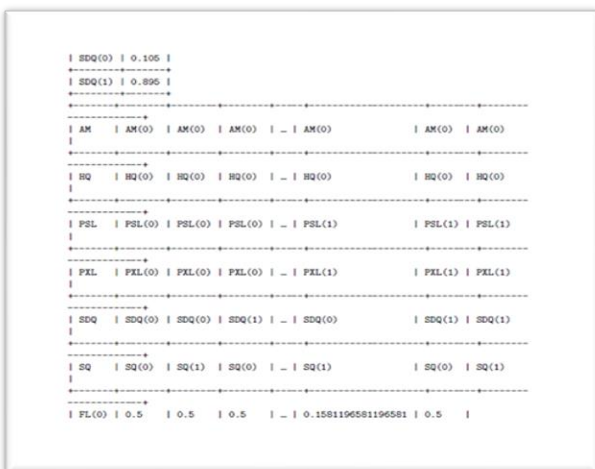


FIGURE 14. The probability of the variables

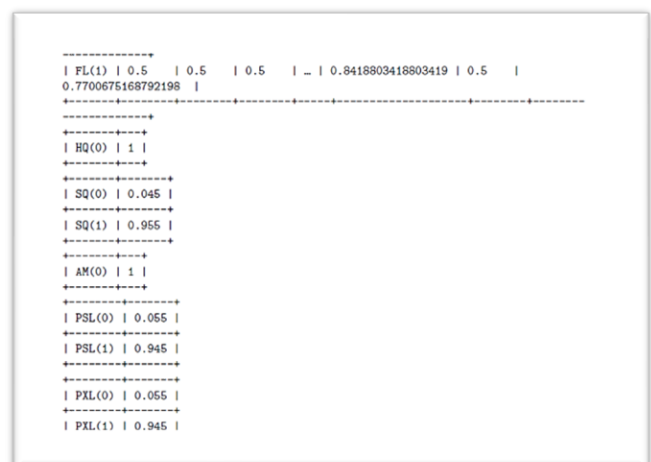
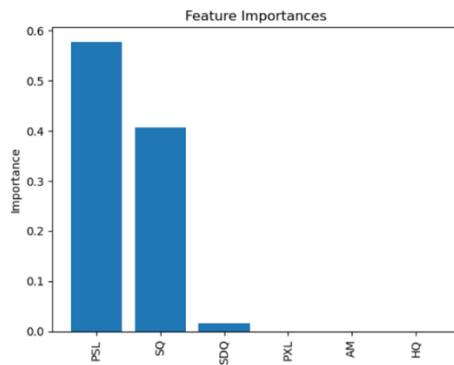


FIGURE 15. The probability of the variables



**FIGURE 16. Bayesian Estimator Results**

The above graph shows the most impactful features for fatigue levels, namely physical stress, and sleep quality. It can be said with a fair amount of certainty that in order to improve the fatigue level of seafarers, there is a need to address physical stress and sleep quality.

#### **Discussion And Recommendation**

The most important factors that impact fatigue levels are physical and psychological stress. The following measures can be taken to manage fatigue levels in light of the aforementioned: Department managers and the human resources department ought to be aware of the Workload of the crew: The line managers must evaluate the workload of the crew members. It's crucial that the workload be distributed more evenly. The task's estimated manhour and effort requirements should be known to the line manager. The crew should undergo frequent reviews and interventions to increase task efficiency, training levels, delegation, and teamwork as opposed to solo effort to prevent mental stress and cognitive exhaustion. Employee morale will increase as a result, as will productivity on the job and fatigue levels. The team and the line manager should have a six-month view of the effort anticipated over the following six months, as well as the number of months during which they will not have to use all of their bandwidth. The ability to manage job load and general fatigue level through flexibility in the workplace, extracurricular activities, and the pace of work with leaves A career map, effort estimate map, and leave map should be given to each crew member so they may pace their job appropriately. Weekly check-ins on fatigue levels, incentive and recognition programs, and

productivity management all play a part in controlling both. People who contribute to teamwork, manage team values, and check in with each other can receive rewards. Personal issues: This is a tricky situation to navigate because people's desire to talk about their lives might vary greatly most of the time. How managers monitor the personal lives of their teams depends critically on their emotional intelligence. It is necessary to assess daily body language, health statuses, job attitudes, and team interactions. To gauge the degree of organisational and personal intervention necessary to delve into the personal affairs of the team and assist them in managing their general levels of exhaustion, a manager must improve their intuition and team-reading abilities. The team should have a team mentor, physiotherapist, or counsellor with them who can check in on the team's mood while ensuring their privacy. The employee will receive adequate interventions to maintain their mental health. In order to determine whether there are any outlier variables for the team members that need to be catered to, it is crucial that HR take action and determine the primary motivators and demotivators at work for each individual team member. Family problems: An intervention needs to be prepared to address the employee's mental health and general stress levels while also taking into account the team's personal values, line managers' personal values, and overall organizational values. This is a difficult situation to handle since the manager must walk a tight line between upholding employee dignity, remaining professional, and also assisting the employee in finding a solution. Few people proactively recognize that their immediate junior may be dealing with a really serious personal issue that cannot be resolved quickly and is affecting work performance. In these situations, supervisors frequently engage in harsh, dictatorial behavior that punishes subordinates. Performance demand: An organization must make sure that, while being aware of the employee's level of fatigue, it is also constantly monitoring the performance that is expected of the employee. This is because, at the end of the day, it is a value-creating enterprise. To ensure that the employee is aware of the expectations, the performance demands must be regularly explained to them, as must a weekly

check-in of the organizational key result areas. Making sure that the employee has the necessary training before starting work is one of the human resources department's top priorities because failing to do so increases the likelihood that the resource will perform poorly on the job. It is crucial that the company never underestimate the cost of making a bad hire. While skills are being cut and diced, the majority of organizations are seeking specialists today. It's possible that the supervisor is a specialist in his or her own right and is seeking out complementary skill sets in the intern or potential employee. Although this is still a relevant issue today, it is crucial that the human resources department address it properly rather than merely addressing an immediate organizational need. The long-term success of the organization depends on a balanced team of specialists and generalists. Although the current trend has been largely toward developing specialists, this will ultimately prove to be very detrimental to the organization if they lack the resources to manage workplace complexity.

Leave levels for the crew: Leaves are a critical component of the employee's salary structure and the employee's motivation towards work. Leaves in companies are earned leaves, medical leaves, paternity and maternity leaves, and casual leaves. Employees should treat leaves within the overall pacing of their work. Also, it is important for the line manager to treat leaves judiciously and also keep an eye on how leaves can be given to the crew from the point of view of managing overall fatigue levels. It is also critical that leaves are used as tools to recharge from a fatiguing situation and that employees come back to work refreshed and do not need more leaves immediately after the leave has been expended. This is another significant issue that needs to be addressed at the workplace with immediate effect, as leaves are one of the key things a prospective resource looks for when he joins an organization. It is important that all leaves are not treated as sick leaves or casual leaves. Some leaves can be taken by employees just to recharge themselves from the rigors of work. Recharge leaves should be recognized and encouraged as a separate line item in the compensation structure of the organization, as that is the line item that will make both the employer and the employee more focused and trusting towards each other, showing

that each is interested and invested in long-term loyalty and commitment. Overall Mental Health of Seafarers: A sense of belonging and ownership is one of the key reasons people survive and thrive at work and in their families. While one is taking a worker to the workplace, it is important that the worker is given an adequate sense of belonging at the workplace. This can happen when there is a recurrently long and strong relationship with supervisors, peers, and subordinates. Multiple changes above and below a worker Multiple changes in roles and job structures can leave a worker displaced, disoriented, and with a feeling of worthlessness at work. The best workers can start to second guess their talent, and the organizations themselves will start to second guess the talent at the workplace. This will become a vicious cycle in which it will become impossible for workers to trust the employers and for employers to distrust the workers. All these activities can accumulate and lead to a drop in productivity and an increase in fatigue levels at the workplace. It is important at the workplace that workers know their supervisors, peers, and subordinates, and vice versa. A sense of familiarity at the workplace goes a long way toward building long-term relationships and ensuring that employee health and productivity are always at their optimum. A good relationship with the supervisor will go a long way toward ensuring that the worker's mental and emotional health is at its optimum. At times, it has been noticed that workers' diets are impacted in the presence of a demanding boss. Some workers are unable to eat, and some are unable to sleep. All these have a concrete impact on the mental health and fatigue level of the worker at the workplace. The solution to this issue is to give the worker a sense of security at the workplace so that he feels that he is in a nurturing environment.

### **Conclusion**

The maritime sector is vital to the global economy, and those who work on deck—deck officers, cadets, chefs, and cooks—contribute in one way or another to the efficient running of their everyday lives. Organizational structures must be created in such a way that the employees' physical, mental, and emotional health is continuously assessed and corrected. It's critical that employees receive

humane, sympathetic treatment at work and are treated like real people. It's crucial that businesses do not treat their employees like simple fifth-grader kids because, as people age, the complexity of their lives becomes multifaceted. In order to maintain employees' motivation levels, the workplace needs to value people's experience, age, and personal lives. Before drawing any conclusions concerning occupational weariness, it is crucial that the aforementioned factor be addressed. Some people are worn out because of their roles' lack of structure; others are worn out because of their bosses' high expectations; some people are worn out because they have high expectations for themselves that they are unable to meet; and most of the time, people are worn out because they are naturally unable to say no to someone. Exhaustion is a multi-dimensional notion, so it's crucial to understand it from all angles rather than just focusing on physical fatigue. One of the largest influences on a worker's level of exhaustion at work is their emotional well-being. Seafarers are absent from their comfortable homes for far too long. They may perceive their lives as an endless struggle with no hope of relief. Additionally, the problem only gets worse if they don't even have suitable surroundings to care for their physical health. Since COVID, rest and recuperation have become even more crucial because of the effects they have had on society's overall health. The livelihoods of people have been disrupted; some have been cut off from their homes, while others have lost important family members. After COVID, it has been typical to experience displacement, income loss, and job loss. In conclusion, there are many factors that led to the seafarers' exhaustion. It has been discovered that studies have been done on passengers, container ship crews, and crews of all sorts of boats to determine the cause of exhaustion. The measurement of tanker vessel sailors' levels of weariness was not the subject of any studies. In particular, no studies on the level of weariness among bunker tanker sailors were conducted. Due to their significant market position in the shipping sector and the need to avoid any mishaps that could devastate the economy and environment, research on the individual fatigue of tanker sailors has been conducted. Therefore, it is crucial to carry out a study on weariness among tanker seafarers. As we

have seen, the Exxon Valdez disaster had a number of contributing factors, one of which was that the third officer on watch was too exhausted to operate the ship as needed. This study aims to close this gap. To close the gap, a survey of seafarers on bunker tankers and foreign-bound tanker vessels registered in Singapore was conducted. The goals of the study would be accomplished by this investigation. The study demonstrates that a number of variables, including physical stress, psychological strain, and shore management considerations, affect how tired sailors are. Physical stress and irregular sleep patterns, however, have the most effect on mariners' degree of weariness. In order to ensure that employees feel as though they are working in a nurturing environment where they can be productive at their highest levels and perform to the best of their abilities, the human resources department of the company needs to pay close attention to the employee's rest levels, the supervisor-junior relationship, as well as general hygiene and ambient conditions at the workplace. The promotion of supervisors to higher positions at work should only occur if they possess the necessary emotional as well as intellectual quotients. To safeguard a worker's mental and emotional health at work, an empathic supervisor can make a world of difference. These are essential success elements for ensuring that worker weariness stays within acceptable bounds.

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