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Unraveling Seafarer Fatigue: A Comprehensive Study on Fatigue Among Singaporean Bunker Tanker Crews and Effective Mitigation Strategies

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ABSTRACT

This study investigates the effects of crew fatigue on bunker barge employees, emphasizing the sources and causes of crew fatigue in bunker tankers operating in Singapore. This study investigates shipboard management, operations, planning, the worldwide oil market, supply and demand for seafarers, and Singapore's maritime industry. Anthropological approaches and statistical methods were used to investigate the factors that lead to fatigue and its effects on the workplace. This study investigates the organizational structure, international oil and shipping sectors, and Singapore's shipping business. Seafarer fatigue can be affected by numerous factors including the physiology of the crew and the construction of the vessel. Data collection and processing methods, including Bayesian networks and Python scripts, were analyzed. According to the findings of the study, fatigue among seafarers is caused by several factors, 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.

1. Introduction.

The maritime industry, acting as the route of global trade and economic exchange, relies on the intricate interplay of vessels navigating vast oceans. 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 [1]. Within this intricate network, bunker tankers assume a vital role as carriers of lifeblood that propels shipping vessels forward—fuel. This fuel sustains the movement of goods and resources and facilitates the seamless continuation of international commerce. However, beneath the surface of these operations is a critical concern: the well-being of seafarers who bear the responsibility of steering these bunker tankers through often treacherous waters [1].

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Singapore has emerged as a pivotal player in this maritime saga, boasting one of the world's most bustling ports and serving as a strategic nexus for international shipping activities [2]. The maritime landscape of Singapore encompasses not only its economic vitality but also its cultural diversity and historical significance [2]. Amidst this 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 unpredictable environmental conditions that they face.

Bunker fuel is a type of fuel oil that is utilized onboard ships. It is used as a fuel source for ship engines in bunkers [3]. Fuel oil with a high sulfur content, fuel oil with a low sulfur content, and diesel oil are the three primary forms of marine fuel utilized by ships. To date, there is a growing awareness toward reducing environmental pollution, and rigorous government policies are anticipated to offer prospects for fuels such as LNG, gasoil, and LPG as replacements for bunker fuels [4]. For example, on March 24, 1989, the oil spill caused by Exxon Valdez occurred in Prince William Sound in the state of Alaska [5]. Exxon Valdez is a massive oil supertanker operated by the

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 this collision, nearly 11 million US gallons of crude oil were released into the environment in the following few days [3]. Exxon found itself in an extraordinarily difficult financial position as a result of this accident, shelling out nearly $2 billion to clean up the leak and an additional $1 billion to pay related civil and criminal incriminations [6]. The incompetent management of the ship by a third officer on deck, which may have been caused by exhaustion or an excessive amount of work, was one of the factors contributing to the accident [3].

When sailors are overworked and exhausted, they are more likely to make significant errors in their decision-making processes, which can result in incidents with repercussions worldwide [7]. To reduce the likelihood of accidents of this type, save the environment, and ensure that the global economy continues to function normally, an investigation into the effects of weariness on seafarers working on Singaporean bunker tanker vessels is required.

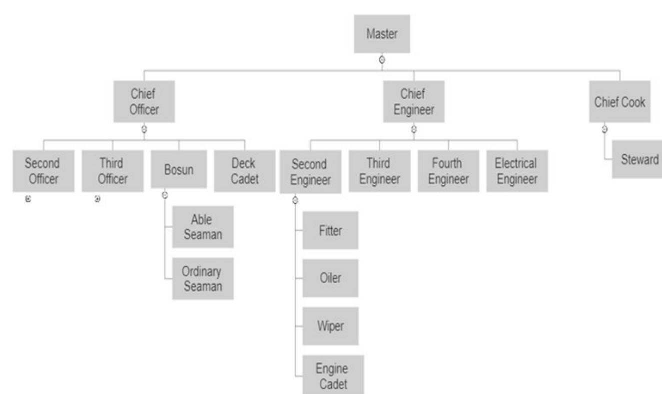
With all these complex interrelationships in mind, this study aims to investigate one of Singapore's most pressing problems: the problem of fatigued seafarers working on bunker tanker crews. This study aims to improve seafarers' well-being, streng then maritime safety, and contribute to the sustainable evolution of the global maritime industry by investigating the factors that contribute to fatigue, evaluating its far-reaching impacts, and proposing strategies to mitigate its effects. The main purpose of this study was divided into three distinct stages. 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 was to determine the relative significance and weight of each of the factors that contribute to the levels of weariness experienced by the bunker barge crew. This quantification is essential for constructing a hierarchy of treatments and for comprehending the proportionate influence of each component. Finally, this study aimed to provide actionable recommendations aimed at reducing the incidence of fatigue and its negative effects on 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 was accomplished in three interconnected stages.

2. Literature Review.

2.1. 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 [1]. For maritime businesses to be safe, effective, and profitable, ships must operate without a hitch both at sea and on land [8]. The coordination of these operations, which involves complex interactions between personnel, technology, rules, and logistics, is largely dependent on the structure of shipboard and shore management [6]. This section describes terms related to the organization of shipboards and shore management. The term "seafarer" refers to any person working on a ship for a specific period, including temporary workers such as pilots, stevedores, loading masters, cargo surveyors, and repair technicians. Shipboard organizations depend on the requirements of shipping companies with the main objective of maximizing efficiency [2]. The organizational structure includes the "master" as the sovereign authority, with other officers responsible for their functions. The chief engineer is responsible for the ship's machinery, whereas the chief officer handles deck maintenance and catering [9]. The deck cadet is a trainee under the supervision of a chief officer [10]. The chief engineer is responsible for maintaining the engine facility, while the electrical engineer handles the electrical equipment and refrigeration devices [11]. Seafarers are required to have competency certification according to the STCW 1978 standards and to participate in training, drills, and security tasks [12]. The chief cook oversees the catering department, with steward assistance in cooking, inventory, and gallery maintenance. The organizational structure of a shipboard organization is shown in Figure 1:

Figure 1: The organizational structure of a shipboard organization.



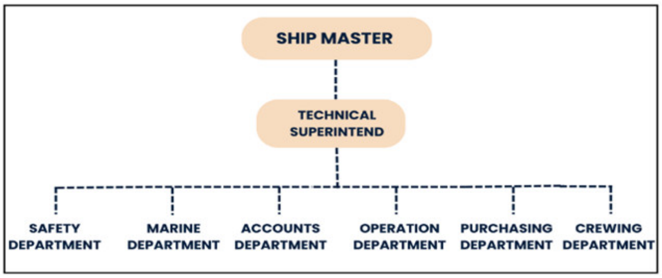
Source: Authors.

2.2. Shore Management Organization.

Each ship has an individual management board that oversees the management of the ship within the prescribed scope and limits. Several types of organizational structures meet the goals of the organization [13]. The structure of an organization depends on several factors: type of industry, type of skill set needed in the organization, product life cycle of products in the industry, level of experience required in the organization, age group of employees required in the organization, location, need for mobility, and blue-collar or white-collar first organization. The following section focuses on the shipping industry's organizational structure.

The shipping industry has an organizational structure, both on and offshore [14]. The shipboard management structure reports to the shore-based superintendent, who can have several ships under him, ranging from 2 to 5. Qualification-wise, most likely to be a former marine engineer with rich onboard and ashore experience or a highly qualified and decorated marine superintendent [15]. The ideal candidate for this role is likely to have rich expertise in cross-functional domains such as technical, commercial, operational, and administrative functions.

Figure 2: Organization Structure of Shore Management.



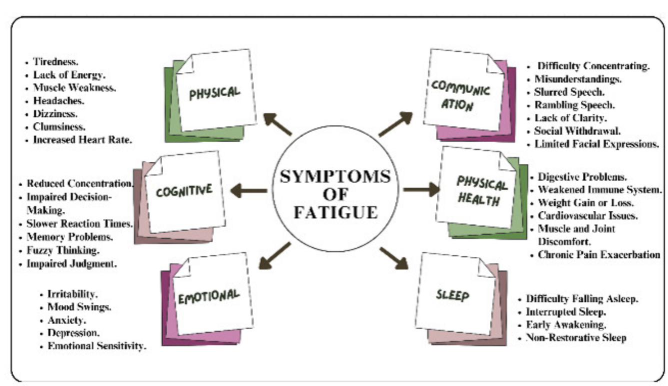
Source: Authors.

Figure 2 illustrates a ship's organizational structure, consisting of several departments such as safety, marine operations, purchasing, crewing, and accounts. Each department has its head responsible for its smooth functioning. The Technical Superintendent serves as a bridge between ships on the sea and onshore organizational functions. The organizational structure includes departments such as safety, marine, technical, operation, crewing, and accounts [8]. The safety department ensures safe operation by shipboard personnel and maintains the company's safety management manual. The marine department ensures compliance with national and international rules and regulations, ensures that the vessel is safe, and complies with local navigation regulations [16]. The operations department ensures that the vessel is fixed for commercial voyages and operates optimally, ensuring efficient operation and 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. It is crucial to maintain profitability by monitoring the changing global landscape and maintaining good relationships with vendors [17]. 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 [18]. The finance department handles the settlement of accounts, creates accounting procedures, manages credit, and maintains a company's overall financial results. It also prepares reports with investment bankers and other organizations to envision the long-term financial vision of the ship [19]. The Chief Financial Officer works closely with the Chief Executive Officer to ensure the organization's health and optimal decision-making. A description of the fatigue is presented in the following section.

2.3. *Fatigue.*

There is no universally accepted technical definition for fatigue. However, some terms appear in all definitions, such as decline in human performance and reduction in awareness or human reliability [20]. 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 [13]. In other words, fatigue generally includes an inability or disinclination to continue an activity that has been ongoing for a long time. Fatigue is also defined by the IMO as "a reduction in physical and/or mental capability as a result of physical, mental, or emotional exertion that may impair nearly all physical abilities, including strength, speed, reaction time, coordination, decision-making, and balance" [10]. Furthermore, it is a nonspecific symptom, as it is usually 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 status, bacterial or viral infections, or autoimmune illnesses; and psychiatric conditions such as depression, anxiety attacks, and somatoform disorders [13]. Fatigue may be caused by prescription medicines, including antihistamines, drugs prescribed for sleeplessness, or chemotherapy [21]. 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 delayed effects of traumatic episodes. There are a variety of signs of fatigue (figure 3), such as overall lethargy in an individual's activity, inability to perform a specific task within the scope of one's natural talent, or experiencing muscle fatigue as a result of a specific task. These symptoms can include chronic fatigue and sluggishness, which can impair judgment and attention span even after adequate rest [22]. Memory lapses and trouble remembering things begin to appear, which affects engineers' ability to handle technical jobs. Physical signs include impaired reflexes, impaired motor coordination, and a high risk of accidents. Additionally, persistent weariness frequently results in irritability, mood changes, increased tension, and anxiety. These symptoms can develop over time, possibly causing a reduction in overall job performance, safety issues, and detrimental effects on mental health.

Figure 3: Symptoms of fatigue.



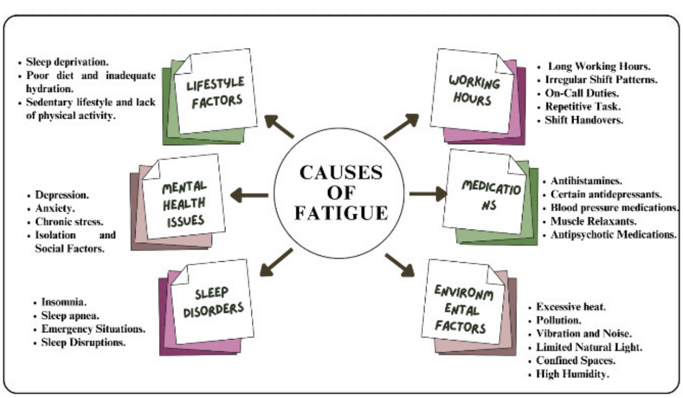
Source: Authors.

Fatigue is caused (Figure 4) by various factors in the maritime industry including long working hours, inadequate rest, high workload, repetitive tasks, environmental conditions, time zone changes, responsibility, pressure, isolation, lack of physical activity, inadequate nutrition, and cumulative fatigue. These factors disrupt natural sleep patterns, cause mental and physical exhaustion, and contribute to engineers' overall stress. Additionally, time-zone changes disrupt circadian rhythms, and the critical role of marine engineers in vessel safety and operational integrity can exacerbate fatigue [23].

Fatigue among seafarers has a significant impact on both individual professionals and maritime operations (Figure 5). At a personal level, weariness impairs cognitive capacity, resulting in reduced focus, compromised judgment, and sluggish reaction times. Marine engineers are crucial to guarantee the smooth operation of vessels and quick emergency response; therefore, their diminished mental acuity poses a serious safety risk. Some physical effects include reduced motor coordination, increased risk of accidents, and increased discomfort due to insufficient sleep [24]. Ongoing fatigue and physical stress can occur over time.

Chronic Health Problems. The emotional effects of exhaustion include increased stress, irritability, mood changes, and the 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. All of 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 [25]. Reduced awareness makes it difficult to quickly recognize and react to navigational dangers, bad weather, and technical problems. The safety of the ship, crew, and environment may be compromised as weariness spreads across the crew, impairing team coordination, communication, and decision-making. 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.

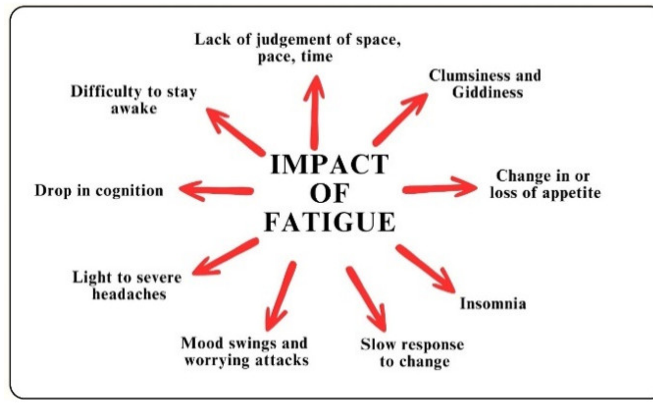


Source: Authors.

2.4. 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 the 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 in the same journal was based on the supposition of eight hours of regular work and four hours of extra work for a total of 12 hours of labor per day [26].

Figure 5: Impact of fatigue.



Source: Authors.

Due to this need, there was a daily overtime of four hours. The officer worked for over 12 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 passing through Norwegian waters [15]. The findings of this study provide only weak evidence that as a seafarer's time aboard rises, their fatigue levels rise. The number of days spent at sea did not directly correlate with the level of exhaustion or the quality of sleep for the crew of the entire cargo and passenger ro-ro ship. These seafarers work on a 22-day rotation level (22 days onboard, followed by 22 days off), and it is clear that such a brief period at sea is insufficient for the ship's environment to hurt 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 highlight the long-known tendency of actively working individuals to have a lower death rate than the general population. Although their study cannot be 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) 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 of this study also show that seafarers working on board ro-ro ships have higher levels of fatigue than those working on offshore supply ships. To understand these results, it is important to evaluate the differences between the two maritime constructs. The RORO ships under study sailed a continuous and fixed-pattern route up and down the Norwegian coast. The journey from the southernmost port to the northernmost port took a week, with frequent port calls and long periods of inactivity. Offshore vessels have longer voyages and periods of inactivity, which may contribute to seafarers' fatigue. Environmental stress, such as noise, ship movement, and vibration, is a significant factor affecting the well-being of seafarers.

The study found that environmental stress was positively correlated with poorer sleep quality and fatigue in the ro-ro data set. No study has addressed the level of fatigue measured by tanker vessel seafarers. In particular, no research has been conducted on the fatigue levels of bunker–tanker seafarers. As one of the largest shares of the shipping industry and for preventing accidents that may cause disasters economically and environmentally, no research has been carried out on tanker seafarers' fatigue. Therefore, it is extremely important to conduct studies on tanker–seafarer 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 study bridges the gap in the literature. To fill this gap, a study was conducted on Singapore-registered bunker tankers and foreign-going tanker vessels with seafarers. This study fulfills its objectives.

3. Methodology.

This chapter outlines all the methodologies employed in this study. Quantitative research methods were employed to achieve this study's goals. To accomplish the goals of this research, general research has been conducted to comprehend the contributing components of crew weariness on board a vessel. A survey of the Singapore bunker tanker crew was carried out as the second step in fulfilling the goals of this research. The data were evaluated to determine the relative importance of crew weariness as a contributing factor. Based on the data analysis from the second stage, recommendations for the third and final stages were considered to reduce 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 the information is based on responses to a survey questionnaire from the seamen on a bunker tanker ship. The survey was conducted using a Google form, and the respondents received the link via email, social media, and their management company's seafarers. As a result, this chapter provides further detail on the quantitative approaches used in this study.

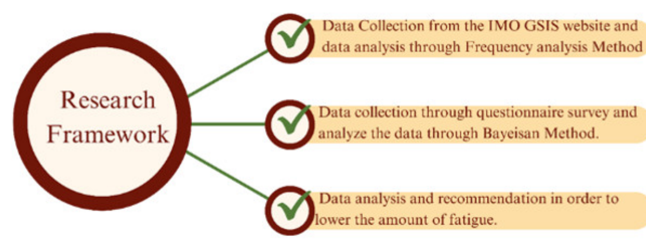
This study focused on tanker vessels in general and Singapore-registered bunker tanker vessels in particular. There are typically 1,000 vessels in Singapore ports at any given time. Nearly 4,500 sailors are employed at any given time on approximately 200 bunker tankers currently navigating Singapore's waterways. Nearly 3,000 still work as seafarers on bunker tankers. The Maritime and Port Authority of Singapore has registration information for bunker tankers. Foreign sailors employed on these ships are regarded as working in Singapore, and given employment passes. Based on MPA requirements, they must additionally obtain their Certificate of Recognition. to comply with the

Figure 6: Research Questions.

Source: Authors.

national certificate of competency and ship-handling training certificates.

Figure 7: Research Framework.



Source: Authors.

3.1. Data Collection.

It is common practice to use questionnaires to collect data, especially when conducting in-depth and complex research. Researchers, small and large businesses, commercial and public organizations, and individuals used questionnaires. The major component of the project was a survey questionnaire. Therefore, they must be meticulously and thoroughly prepared. Data were gathered using a questionnaire-based survey method. The sailors currently working on the crews of Singapore bunker tankers were included in this survey, using a Stratified Complex Random Sampling Process. During the survey, a Google Forms 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 responsible for the increase in fatigue. A survey was conducted among seafarers to arrive at the analysis and their fatigue levels were assessed. The various factors that could impact the level of fatigue shown in Table 1 are as follows. The data were collected over four weeks, and after data collection, they were imported into Python software to arrive at the results. The following are inferences from the Bayesian network analysis.

3.2. 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 strong evidence-based deductions and are often confused by the complex structures, equations, and technical software involved. Bayesian networks use probabilities to determine the probability of the outcomes, as depicted in an acrylic graph. These are also known as belief networks, decision graphs, and Bayesian models, respectively. It is a graph with nodes representing defined variables and Bayesian probabilities. Structured learning is based on index learning and the likelihood is probabilistically obtained for each variable for the variables present in the scenario.

A probabilistic paradigm incorporates mathematical and graphical representations of graph theory; however, two problems must be addressed: ambiguity and unpredictability. Graphical models depict random dependency relationships and algorithms that significantly impact the analysis and design of machine-learning approaches. Observational learning has been studied using experience and observed evidence to generate new principles. Various approaches have been used to reconstruct features, optimize rankings, and create local versions of networks to better approximate global structures. Most analyses using Bayesian networks are limited to scenarios in which 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, and alcohol intake
Ship Design	Redundancy, level of automation, equipment reliability, and physical comfortless at the workplace.
Ashore management factor	Crew selection, crew training, crew complement size, assistance from shore management factor, crew contact period, and 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 the length of break levels. (c) Quantity, quality, and duration of sleep are further dependent on the motion of the ship, shift work and work schedule, accommodation temperature, vibration of the ship, and noise levels on the ship. (d) Sleep disorders are further dependent on circadian rhythms, jetlag, and unpredicted bunkering schedules.

Source: Authors.

Fatigue is the parent node in Figure 8, and the factors are referred to as "node-child nodes." Most crew members were in good health and slept well. The quality of the ship's design was likewise discovered to be typical. Some seafarers were extremely fatigued and experienced high levels of physical and psychological stress. Some members appeared to have strong management, whereas others did not, suggesting that the ashore management component was evenly distributed. The distribution of factors among the sailors is shown in Figure 8.

Figure 8: Bayesian networks.

Source: Authors.

3.3. *Heat Maps.*

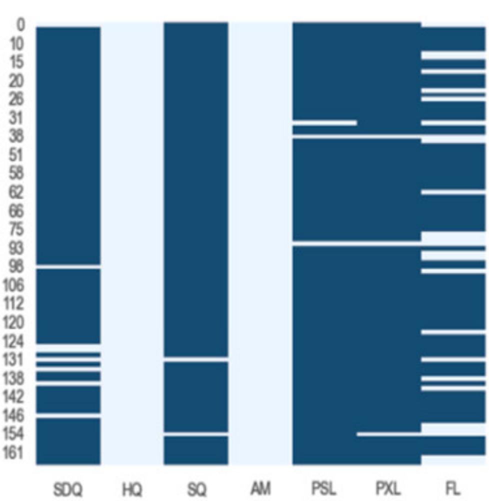
One of the inferences from the data analysis is that the data are presented to cross-functional teams, where different teams have different skill sets. Earlier in the board room and CXO levels, there was a high chance that only specialists were present, who could quickly demystify the data in its raw form. However, as organizations hire people from different fields, data must be presented in a manner that is easily understood, read, and interpreted by different people in a room. Spatial representations of data have become increasingly common to cater to an improved understanding of the different functional heads of organizations. Heat maps are spatial representations of the current situation. Heat maps are used to handle noisy and biased data. They help in visualizing the volume of data or incidents within a data source and assist viewers towards the focus regions of the most significant data visualizations. The parameters and variables considered in the seafarer fatigue analysis are shown in Figures 9 and 10, respectively. Figure 11 shows the correlation matrix between the ship design quality and fatigue level. From the above data, we can infer that the SDQ variable did not significantly impact fatigue level, as shown in Table 2.

The charts in Figure 12 show the frequency plots of the various factors leading to fatigue levels among seafarers. In Figure 12, an SDQ-87 score of 1 out of 95 indicates that the majority of crew members think the ship's design quality is good. All the numbers in HQ, except for eight, show that the majority of the crew members report being in good health. SQ-93 out of 95 members has a quoted value of 1, which indicates that the majority of crew members consider their sleep to be of normal quality. No crew member stated that ashore management issues were causing them to become tired; hence, the AM-shore management values were zero. Most crew members reported average levels of physical stress (92 out of 95). PSXL: Most crews reported average levels of psychological stress (92 out of 95). Seventy of the 95 crew members reported having some amount of fatigue, while 25 claimed not to have any (FL: the majority of crew members indicated a fatigue level of different people in a room. Spatial representations of data have become increasingly common to cater to an improved understanding of the 1). It may be argued that the bulk of the crew members felt some sort of fatigue.

Figure 9: Abbreviation of Parameters & Variables.

Source: Authors.

Figure 10: Parameters & Variables.



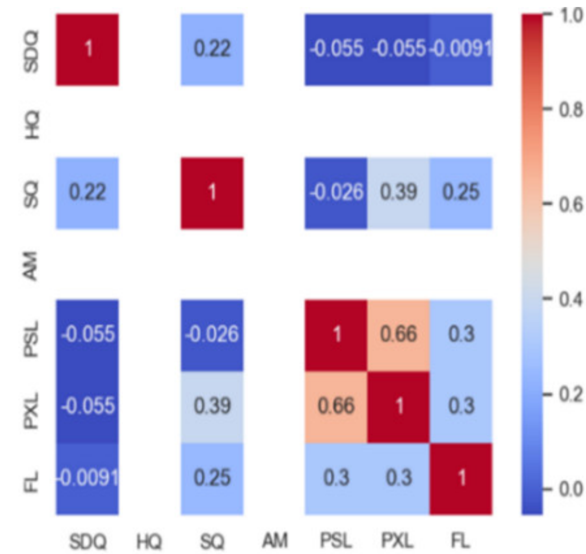
Source: Authors.

4. Results.

4.1. 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 a value of 0. The probability of this case is 0.0007, which means that it is expected to occur at a frequency of 0.07%. Similarly, the third row corresponds to the case in which only the SL variable has a value of 1 and all other variables have a value of 0. The probability of this case is also 0.038, which means that it is also expected to occur at a frequency of 3.80% in the data. The other rows in the table correspond to all possible combinations of the values for the six variables. The probabilities of this combination in each row are 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. For example, the last row 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 cases occurring. This indicates a strong correlation between poor sleep and high physical stress, leading to high fatigue levels.

Figure 11: Correlation matrix.



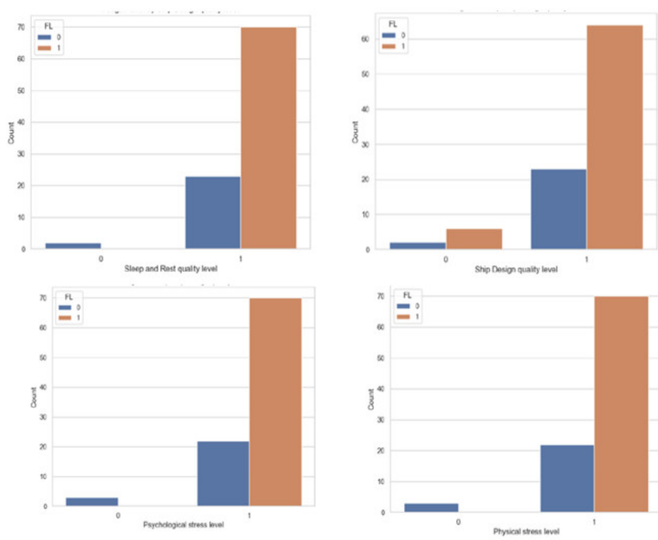
Source: Authors.

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.

Source: Authors.

Figure 12: Frequency plots (Sleep and Rest Quality level, Ship Design Quality Level; Physiological Level; Physical stress level).



Source: Authors.

Figure 13: Values of the joint probability distribution.

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

Source: Authors.

4.2. Maximum Likelihood Estimator.

The dependencies between various independent variables in the dataset were displayed using 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 gathered data, we can forecast the network variables. The Python output that displays the probabilities of the variables is shown in the following image, where the number in parentheses following the variable name indicates the number of states for each variable. According to the model, there is a 10.5 percent chance that the 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.

SDQ(0)	0.105
SDQ(1)	0.895

AM	AM(0)	AM(0)	AM(0)	…	AM(0)	AM(0)	AM(0)
HQ	HQ(0)	HQ(0)	HQ(0)	…	HQ(0)	HQ(0)	HQ(0)
PSL	PSL(0)	PSL(0)	PSL(0)	…	PSL(1)	PSL(1)	PSL(1)
PXL	PXL(0)	PXL(0)	PXL(0)	…	PXL(1)	PXL(1)	PXL(1)
SDQ	SDQ(0)	SDQ(0)	SDQ(1)	…	SDQ(0)	SDQ(1)	SDQ(1)
SQ	SQ(0)	SQ(1)	SQ(0)	…	SQ(1)	SQ(0)	SQ(1)
FL(0)	0.5	0.5	0.5	…	0.1581196581196581	0.5	

Source: Authors.

Figure 15: The probability of the variable.

FL(1)	0.5	0.5	0.5	…	0.8418803418803419	0.5	0.7700675168792198

HQ(0)	1

SQ(0)	0.045
SQ(1)	0.955

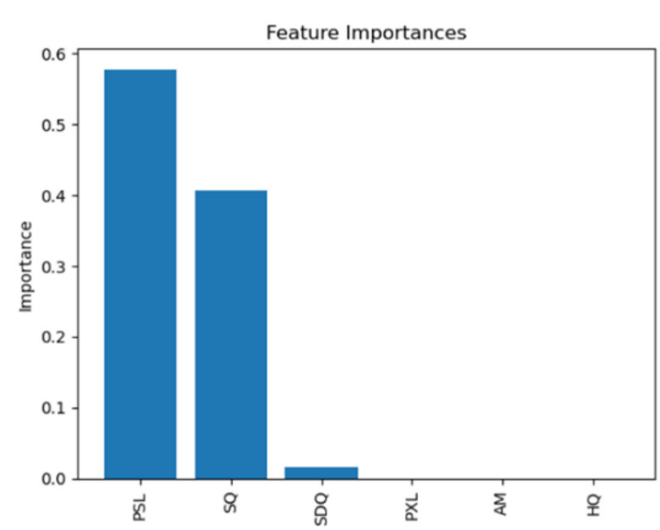
AM(0)	1

PSL(0)	0.055
PSL(1)	0.945

PXL(0)	0.055

Source: Authors.

Figure 16: Bayesian Estimator Results.



Source: Authors.

5. 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: department managers and the human resources department should be aware of the workload of the crew and line managers must evaluate the workload of the crew members. The workload must be evenly distributed. The line manager should know the estimated manhours and effort requirements of the task. Crews should undergo frequent reviews and interventions to increase task efficiency, training levels, delegation, and teamwork as opposed to solo efforts to prevent mental stress and cognitive exhaustion. Employee morale increases as a result of productivity and fatigue levels. The team and 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 leave career maps, effort estimate maps, and leave maps 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 play a part in controlling for both variables.

People who contribute to teamwork, manage team values and check each other receive rewards. Personal issues: This is a tricky situation to navigate, because people's desire to talk about their lives may vary greatly. How managers critically monitor the personal lives of their teams depends on their emotional intelligence. Therefore, it is necessary to assess daily body language, health status, job attitudes, and team interactions. To gauge the degree of organizational and personal intervention necessary to delve into the personal affairs of the team and assist them in managing their general levels of exhaustion, managers must improve their intuition and team reading abilities. The team should have a mentor, physiotherapist, or counselor with them to check the team's mood while ensuring privacy. Employees receive adequate interventions to maintain their mental health. To determine whether there are any outlier variables for team members that need to be catered to, it is crucial that HR takes action and determines the primary motivators and demotivators at work for each team member. Family problems: An intervention needs to be prepared to address employees' mental health and general stress levels while also considering the team's, line managers, and overall organizational values. This is a difficult situation because the manager must walk a tight line between upholding employee dignity, remaining professional, and assisting employees in finding solutions. Few people proactively recognize that their immediate junior may be dealing with serious personal issues that cannot be resolved quickly, which affects their work performance. In such situations, supervisors frequently engage in harsh dictatorial behaviors that punish subordinates.

Performance demand: An organization must ensure that, while being aware of the employee's level of fatigue, it constantly monitors the employee's expected performance. 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 well as a weekly check-in of the key organizational result areas. Ensuring that the employee has the necessary training before starting work is one of the top priorities of the human resources department because failing to do so increases the likelihood that the resource will perform poorly on the job. A company must never underestimate the costs of making a bad hire. While skills are being cut and diced, the majority of organizations are seeking specialists today. It is possible that the supervisor is a specialist in his or her own right and seeks complementary skill sets for internal or potential employees.

Although this is still a relevant issue today, the human resources department must address it properly rather than merely addressing immediate organizational needs. The long-term success of an 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 detrimental to the organization if they lack the resources to manage workplace complexity. Leave levels for the crew: Leaves are a critical component of employees' salary structure and motivation to work. Leaves in companies are medical, paternity, maternity, and casual leave. Employees should treat their leave at the pace of their work. In addition, the line manager needs to treat leaves judiciously and monitor how leaves can be given to the crew from the perspective of managing overall fatigue levels. It is also critical that leaves are used as tools to recharge from a fatigue situation and that employees return 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 an immediate effect, as leaves are one of the key things a prospective resource looks for when he joins an organization. All leaves must not be treated as sick or casual. Employees can take some leaves to recharge themselves from the rigor of their 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 taking a worker in the workplace, the worker must be given an adequate sense of belonging. This can occur when there are recurrently long and strong relationships 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 worthless at work. The best workers can guess their talent second, and the organizations themselves will start to guess their talent in the workplace. This will create a vicious cycle in which it will become impossible for workers to trust and distrust their employers.

All these activities can accumulate and lead to a drop in productivity and an increase in fatigue levels in the workplace. In the workplace, workers must know their supervisors, peers, and subordinates, and vice versa. A sense of familiarity in the workplace goes a long way toward building long-term relationships and ensuring that employees' 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 affected by the presence of a demanding boss. Some workers are unable to eat and some are unable to sleep. All these factors have a concrete impact on the mental health and fatigue levels of workers in the workplace. The solution to this issue is to give the worker a sense of security in the workplace so that he feels that he is in a nurturing environment.

Conclusions.

The maritime sector is vital to the global economy, and those who work on 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 such that employees' physical, mental, and emotional health are continuously assessed and corrected. Employees must receive humane, sympathetic treatment at work and be treated like real people. Businesses must not treat their employees like super fifth-grader children because, as people age, the complexity of their lives becomes multifaceted. To maintain employees' motivation levels, the workplace needs to value their experiences, age, and personal lives. Before concluding on occupational weariness, the aforementioned factors must be considered. Some people are worn out because of their role's lack of structure; others are worn out because of their bosses' high expectations; some people are worn out because they have high expectations 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 multidimensional notion; therefore, it is crucial to understand it from all perspectives rather than just focusing on physical fatigue. One of the largest influences on workers' level of exhaustion at work is their emotional well-being. Seafarers were absent from their comfortable homes for too long. They may perceive their lives as endless struggles without hope of relief. Additionally, the problem worsens only if they do not 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. People's livelihoods have been disrupted: some have been cut off from their homes, while others have lost important family members. After COVID, it is typical to experience displacement, income loss, and job loss. In conclusion, many factors can lead to seafarer exhaustion. Studies have been conducted on passengers, container ship crews, and crews of all types of boats to determine the causes of exhaustion. Measurement of the tanker vessel sailors' levels of weariness was not the subject of any study. In particular, no studies have been conducted on the level of weariness of bunker tanker sailors. Owing to their significant market position in the shipping sector and the need to avoid mishaps that could devastate the economy and environment, research on the individual fatigue of tanker sailors has been conducted. Therefore, it is crucial to study tanker seafarers' weariness. As we have seen, the Exxon Valdez disaster had several contributing factors, one of which was that the third officer on watch was too exhausted to operate the ship as needed. This study addresses this gap in the literature. To close this gap, a survey of seafarers of bunker tankers and foreign-bound tanker vessels registered in Singapore was conducted. The goal of this study was to accomplish this objective. This study demonstrated that several variables, including physical stress, psychological strain, and shore management, affect how tired sailors are.

However, physical stress and irregular sleep patterns had the greatest effect on the degree of weariness of mariners. 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, supervisor-junior relationship, and general hygiene and ambient conditions at the workplace. Supervisors should be promoted to higher positions at work only if they possess the necessary emotional and intellectual qualities. To safeguard workers' mental and emotional health at work, an empathic supervisor can create a world of differences. These are essential success elements for ensuring that worker weariness remains within acceptable bounds.

In this section, we present the conclusions of at least one objective stated in the Introduction.

No new information or data has been added to this section. The conclusions are drawn based on what has been explained previously. There should be no conclusions based on the assumptions, ideas, or data not presented in the previous sections.

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