CAPTAIN MD RANAKUL ISLAM MASTER OF SCIENCEOF 2024

ANALYSIS OF FATIGUE AMONG SINGAPORE BUNKER TANKER SEAFARERS AND MITIGATION STRATEGIES

CAPTAIN MD RANAKUL ISLAM

MASTER OF SCIENCE
UNIVERSITI MALAYSIA TERENGGANU

2024

TITLE PAGE

ANALYSIS OF FATIGUE AMONG SINGAPORE BUNKER TANKER SEAFARERS AND MITIGATION STRATEGIES

CAPTAIN MD RANAKUL ISLAM

**Thesis Submitted in Fulfilment of the Requirement for the degree of Master of Science in the Faculty of Maritime Studies
Universiti Malaysia Terengganu**

JULY 2024

Pusat Pengurusan Siswazah (PPS)

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Dedicated this thesis to:

The people who have been my constant source of inspiration, support, and encouragement throughout this challenging journey. To my family, whose unwavering love and belief in me have been my pillars of strength. I am forever grateful for your sacrifices and patience, which have made this achievement possible.

To my friends, who stood by me with their encouragement, late-night study sessions, and moments of laughter that provided a much-needed respite from the academic rigors. To my supervisors and advisors, whose guidance and expertise have shaped my research and expanded my horizons. Your dedication to fostering my intellectual growth has been invaluable. To all the participants and individuals who generously contributed their time and insights to this study, your contributions have been essential in advancing knowledge in this field.

Finally, my perseverance and determination pushed me through the challenges and doubts. This thesis is a testament to the belief that hard work and dedication make anything possible.

Thanks a lot

Abstract of thesis presented to the Senate of Universiti Malaysia Terengganu in fulfilment of the requirements for the degree of Master of Science

ANALYSIS OF FATIGUE AMONG SINGAPORE BUNKER TANKER SEAFARERS AND MITIGATION STRATEGIES

CAPTAIN MD RANAKUL ISLAM

JULY 2024

Main Supervisor : Capt. Mohammed Ismail Russtam Suhrab, Ph.D

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Fatigue significantly impacts the maritime industry on both global and domestic scales, often leading to severe consequences that can disrupt global trade. As a major global shipping hub, Singapore's strategic position in the bunker market means that any disruption to the Singapore Straits or its ports can result in substantial losses and supply chain interruptions. This study investigates the factors contributing to fatigue among Singaporean bunker tanker seafarers, focusing on physical health, psychological well-being, the quality of rest, ship design, and shore management practices. The primary objectives of this research are to identify and analyse the factors contributing to fatigue among bunker crew members and to propose recommendations for mitigating these issues. To achieve these objectives, the study utilizes IMO GISIS investigative reports on maritime accidents and incidents, reviews relevant literature, and consults with industry experts. Additionally, feedback was collected from 161 bunker crew members via questionnaires. The data were analysed using Bayesian networks and Python scripts. Findings reveal that fatigue among seafarers is influenced by multiple factors, with psychological stress (0.32) and Physical (0.31) being the most significant contributors, followed by poor sleep- rest quality (0.19), suboptimal ship design (0.15) and various stressors related to workload, personal life, and family concerns. Minor contributing factors include adverse weather conditions at Singapore ports, the age and maintenance of tankers, sea conditions, bunkering schedule and high traffic density. The study provides actionable recommendations to address these challenges, including enhancing crew monitoring of rest periods, increasing crew size, improving access to mental health support, and incorporating modern navigational equipment such as ECDIS and AIS. It also advocates for fostering positive supervisor-subordinate relationships, maintaining conducive workplace conditions, and emphasizing emotional intelligence in leadership roles. Additionally, it suggests improvements in ship design and automation to reduce seafarers' workloads and calls for timely shore assistance and proper vessel maintenance. Implementing these holistic strategies will help manage physical and psychological stress, optimize vessel design, and ensure adequate rest, thereby enhancing the seafarers’ well-being and improving the safety and operational efficiency of Singapore's bunker industry.

Abstrak tesis yang dikemukakan kepada Senat Universiti Malaysia Terengganu
sebagai memenuhi keperluan untuk Master of Science

ANALISIS KELETIHAN DI KALANGAN PELAUT KAPAL BUNKER SINGAPURA DAN STRATEGI MITIGASI

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Keletihan memberi kesan ketara kepada industri maritim pada skala global dan domestik, dan kesan negatifnya boleh mengganggu perdagangan global. Sebagai hab perkapalan global yang utama dan kedudukan strategik Singapura dalam pasaran bunker juga bermakna, sebarang gangguan kepada Selat Singapura atau pelabuhannya boleh mengakibatkan kerugian yang besar dan menganggu rantaian bekalan. Kajian ini menyiasat faktor-faktor yang menyumbang kepada keletihan di kalangan pelaut kapal tangki bunker Singapura, memfokus kesihatan fizikal, kesejahteraan psikologi, kualiti rehat, reka bentuk kapal dan amalan pengurusan dari pejabat. Objektif utama penyelidikan ini adalah untuk mengenal pasti dan menganalisis faktor-faktor yang menyumbang kepada keletihan di kalangan anak kapal bunker dan cadangan untuk menangani isu tersebut. Untuk mencapai objektif, kajian ini berdasarkan laporan berhubung penyiasatan IMO GISIS mengenai kemalangan dan insiden maritim, kajian literatur yang relevan, dan juga berunding dengan pakar industri. Selain itu, maklum balas juga dikumpul daripada 161 anak kapal bunker melalui soal selidik. Data tersebut dianalisis menggunakan rangkaian Bayesian dan skrip Python. Penemuan

mendedahkan bahawa keletihan di kalangan pelaut dipengaruhi oleh pelbagai factor. Tekanan psikologi (0.32) dan tekanan fizikal (0.31) adalah penyumbang paling ketara. Isu lain termasuk corak tidur dan rehat berkualiti rendah (0.19), reka bentuk kapal yang tidak optimum (0.15) dan pelbagai tekanan yang berkaitan dengan beban kerja, kehidupan peribadi dan kebimbangan keluarga. Faktor penyumbang kecil termasuk keadaan cuaca buruk di pelabuhan Singapura, umur dan penyelenggaraan kapal tangki, keadaan laut, jadual bunker, dan kepadatan aliran perkapalan yang tinggi. Kajian juga menyediakan cadangan tindakan yang boleh diambil untuk menangani cabaran, termasuk meningkatkan pemantauan kru bagi tempoh rehat, peningkatan saiz kru, meningkatkan akses kepada sokongan kesihatan mental, dan menggabungkan peralatan navigasi moden seperti ECDIS dan AIS. Kajian juga menyokong pengeratan hubungan yang positif antara penyelia dan subordinat, mengekalkan tempat kerja yang kondusif, dan penekanan kecerdasan emosi dalam kepimpinan. Selain itu, kajian mencadangkan penambahbaikan dalam reka bentuk kapal dan automasi untuk mengurangkan beban kerja pelaut dan keperluan bantuan awal dari pejabat dan penyelenggaraan kapal yang betul. Perlaksanaan strategi holistik dapat membantu untuk menguruskan tekanan fizikal dan psikologi, mengoptimumkan reka bentuk kapal, dan memastikan rehat yang mencukupi, sekali gus meningkatkan kesejahteraan pelaut dan meningkatkan keselamatan dan kecekapan operasi maritim Singapura.

ACKNOWLEDGEMENTS

Alhamdulillah, thanks to Allah S.W.T for blessing me and providing me with good health and strength to complete my studies. Millions of thanks to my beloved parents for their understanding, endless love, courage, financial support, and everything. My gratitude and special appreciation go to my supervisor and co-supervisor for their guidelines, advice, support, patience, unlimited creative ideas, and constructive criticism. Special thanks to FPM staff for corresponding sincerely, tolerating my requests and providing facilities during laboratory work periods to smoothen my journey in completing this study. I would also like to thank my laboratory mates as well as the rest of FPM postgraduate students who helped me in many ways and encouraged me throughout this project. May Allah's blessings always be with them.

Thank you

APPROVALS

I certify that an Examination Committee has met on 04th July 2024 to conduct the final examination of Captain Md Ranakul Islam, on her Master of Science thesis entitled **"ANALYSIS OF FATIGUE AMONG SINGAPORE BUNKER TANKER SEAFARERS AND MITIGATION STRATEGIES"** in accordance with the regulations approved by the Senate of Universiti Malaysia Terengganu. The Committee recommends that the candidate be awarded the relevant degree. The members of the Examination Committee are as follows:

ANUAR BIN ABU BAKAR, Ph.D
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Date

This thesis has been accepted by the Senate of Universiti Malaysia Terengganu in fulfilment of the requirement for the degree of Master of Science.

____

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Date:

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UMT or other institutions.

CAPTAIN MD RANAKUL ISLAM

Date: 14-Oct-2024

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The maritime industry is the lifeblood of global trade, allowing products, raw materials, and energy resources to travel across the globe's oceans. Singapore is a bustling marine hub located at the crossroads of key shipping routes and recognised to one of the world's key ports (Walker *et al.,* 2018). However, amid this thriving and vital industry, there remains a mostly unresolved issue that requires our immediate attention: the fatigues suffered by sailors operating on Singapore's bunker tankers. Bunker tankers are the true champions of marine logistics, tasked with fuelling other ships in order to keep global commerce flowing smoothly. Even in the face of a difficult adversary - fatigue - these seamen fulfill their responsibilities with steadfast determination (Chua *et al.,* 2022). This study interested to delve deeply into the complicated topic of seafarer fatigue in the context of Singapore's bunker tanker business, with the dual goals of fully understanding the contributing variables and discovering effective solutions to minimize weariness and improve the well-being of these seafarers.

The maritime industry is fundamentally challenging. Mariners are tasked with navigating open waters, often in extreme weather conditions, while remaining vigilant for the safety of their ship and cargo. Bunker tanker seamen, for instance, face a unique set of problems that make them particularly vulnerable to fatigue. Their working hours are erratic, shifts are longer and irregular, and they are subjected to the harsh marine environment, but they must always maintain safety standards. These elements combine to create an extremely harsh working atmosphere. It is impossible to overestimate the importance of bunker tanker seamen in Singapore's maritime industry. They play an important role in ensuring that ships are properly fuelled, thus contributing to the world's economy running and dependability of global trade. However, the significance of their employment comes at a cost, as seafarer fatigue poses a significant risk to the individuals involved as well as the maritime sector as a whole (Döring e*t al.,* 2022; Smith *et al.,* 2006; Xiao & Lam, 2023).

Seafarer fatigue is a serious problem with far-reaching repercussions. When sailors are tired, their neuropsychological capacities suffer. This might result in operational inefficiencies and potential dangers. Simple errors, such as misjudging distances or failing to perform normal maintenance duties, might result in major mishaps or ecological catastrophes in the delicate marine ecology. Therefore, the consequences of fatigue extend beyond the well-being of seafarers to ecological sustainability and the economic wellbeing of the marine business (Rajapakse & Emad, 2023; Smith *et al.,* 2006). Moreover, fatigue's impact extends beyond its operational implications. It affects the crews' emotional and physical health as well. Chronic or long-term fatigue can result in physical health issues like heart disease, musculoskeletal disorders, and sleep abnormalities. Furthermore, the stress, anxiety, and sadness that frequently accompany continual vigilance and unpredictable work patterns can lead to serious mental health issues. As a result, the repercussions of seafarer weariness extend into personal and psychological well-being (Allen *et al.,* 2008).

Table 1.1 – Fatigue contributing to maritime incident (Source: IMO GISIS Marine Casualties and Incidents)

Sr. No	Incident	The ship's name involved the Incident	Incid-ent date	Severity	Fatigue as a contributing factor
1	Fatality of the crew after falling overboard from Ince Northwind	INCE NORTHWIND (IMO 9969118)	03/12/2023	Very serious marine casualty	The OS appeared nervous before climbing the pilot ladder and was seen as tired and exhausted during climbing due to his body weight.
2	Serious injury to a crew member while operating the vessel's lathe, in position 47° 21.1' N 006° 25.8' W	Dogan (IMO 9625475)	07/06/2023	Marine casualty	The safety investigation was unable to verify the quality of his rest.
3	Grounding and stranding of the Maltese-registered general cargo, ATLANTA On the island of Agios Theodoros, Greece.	Atlanta (IMO 9513373)	29/04/2023	Marine casualty	The safety investigation could not verify the quality of the 2nd Officer's rest.

4	Four Crew members were injured while working on the forward mooring station during adverse weather.	Beluga Reefer (IMO 9015204)	30/06/ 2023	Very serious marine casualty	Sleep patterns of the deck crew were impacted by their inconsistent work and rest schedules. When he left, the bosun had been working since 20:00 the previous evening and his shift was supposed to conclude at 04:00 so that he could start his rest. The bosun's regular rostered work hours were from 8:00 to 18:00, with lunch breaks arranged in between.
5	Occupational Fatality of Bosun	Combination carrier Barramundi (IMO 9813113)	07/03/ 2021	Very serious marine casualty	The Company's SMS's safe work procedures were updated to address the risks associated with heat stress, as well as recommendations for evaluating the current weather to ascertain whether heat stress posed a risk when conducting pre-task risk assessments and what steps should be taken to mitigate any potential negative effects.
6	Fall overboard and consequent crew member death while fastening a combination ladder of the oil/chemical tanker registered in Malta	Mariner A (IMO 9288954)	05/02/ 2023	Very serious marine casualty	Whilst the bosun’s hours of work / rest met the relevant requirements, the safety Investigation was unable to verify the quality of his rest.
7	Missing Able Seafarer Deck 2	Cape Satsuki (IMO 9960136)	30/07/ 2023	Very serious marine casualty	The ASD2 was not following company policy when he brought alcohol on board.

8	The harbor pilot's death in Singapore following his fall into the water during a transfer.	GP 30, Kencana Raya (IMO 8888575), Luna	11/02/2023	Very serious marine casualty	It should be emphasized that the PSAM follows the MLC's rules, which are intended for seafarers who are regularly on day work or shift duty, in order to manage the work and rest hours of its pilots and launch crew through the use of a shift system. However, given the varied nature of their jobs, pilots and launch crew may not find these rules appropriate or applicable. The launch crew and pilots' tiredness risk management may be something the PSAM should investigate.
9	One person lost their life when a man went overboard from the stern trawler Copious (LK 985).	Copious (IMO 9395757)	18/02/2021	Very serious marine casualty	The accident happened at approximately 0300, falling into what is referred to as the Window of Circadian Low.
10	Occupational death (Deceased crew)	ALM Aries (IMO 9873034)	05/03/2022	Very serious marine casualty	It is apparent from the rotation cycle of the vessel that ABs did not get 6 hours rest in length, though The rest hour log shows MLC 2006 compliance but does not appear to be a realistic record.
11	At Flensburg Firth, on board the sailing vessel Speedy Go, an individual went overboard and died.	Speedy Go	08/04/2022	Very serious marine casualty	Skipper suffering from fatigue- the skipper did not appear to be rested, which may have contributed to inattentiveness.

12	Collision with Fishing Vessel	Happy Hiro(IMO 9303390), JULITA S-2	22/05/ 2022	Very serious marine casualty	2/O claimed that it was impossible to maintain proper relaxation and recuperation under this working arrangement. Additionally, he had informed the Master and C/O that he was experiencing problems sleeping ever since leaving Taicang on May 22, 2022, partly as a result of uneven watchkeeping that distorted any significant regularity.
13	Mooring fatality onboard Aruba Pearl on 26 October 2022	Aruba Pearl (IMO 8313702)	26/10/ 2022	Very serious marine casualty	Addressed the concerns around fatigue and mental health by reducing the contract periods of crew From nine months to six months.
14	Engine room fire on board MPV Everest	MPV Everest (IMO 9769130)	05/04/ 2021	Marine casualty	According to the study, the chief engineer doing the manual gasoline transfer was very fatigued, which is known to negatively impact performance. This led to a likely attentional loss, which is why the manual fuel transfer occurred. The tank is overflowing and going unnoticed as the transfer is not being watched.

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, this study aims 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 goal of this study is to ascertain the relative importance and weight of each component that affects the bunker barge crew's degrees of fatigue. This quantification is essential for constructing a hierarchy of treatments and comprehending each component's proportionate influence. In the end, the research aims to provide actionable recommendations 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.

1.2 Problem Statement

Seafarer fatigue among bunker tanker operators has emerged as a critical concern within Singapore's dynamic and essential maritime industry. This issue not only jeopardizes the safety and well-being of the crew but also introduces significant environmental and operational risks. Irregular work hours, prolonged and unpredictable shifts, exposure to harsh environmental conditions, and the continuous demand for heightened vigilance exacerbate fatigue in this sector. The resulting decline in cognitive and physical performance adversely impacts the efficiency, safety, and sustainability of marine operations.

Addressing this challenge is imperative, given the central role of Singapore's maritime sector in global trade and the potential consequences of operational disruptions. This study aims to thoroughly investigate the extent of fatigue among Singapore's bunker tanker seafarers, identify the underlying factors contributing to their fatigue, and propose actionable recommendations to mitigate and prevent its adverse effects.

1.3 Research Questions

During the process of creating the research design, a number of specific research questions and issues have been outlined in order to meet the goal of this study, which is to eliminate weariness among the crew members of the tanker vessel. The key queries are enumerated here.

1. What factors contribute to fatigue among bunker crews in Singapore's maritime industry?
2. What is the current level of fatigue experienced by bunker crews operating in Singapore?
3. What measures and strategies can minimize and mitigate fatigue among bunker crews in the Singaporean maritime context?

1.4 Objectives

This study aims to-

1. **Analyze and Identify Contributing Factors:** Examine and identify the diverse factors contributing to fatigue among bunker crews in the Singaporean maritime industry, including physical, psychological, and environmental influences.
2. **Assess Current Fatigue Levels:** Evaluate the prevailing levels of fatigue experienced by bunker crews operating in Singapore, considering their working conditions, shift patterns, and exposure to environmental stressors.
3. **Develop Evidence-Based Recommendations:** Formulate a set of evidence-based recommendations and mitigation strategies designed to effectively

reduce and manage fatigue among bunker crews, thereby improving their well-being and enhancing maritime operations' overall safety and efficiency.

1.5 Scope of the Research

The research is a comprehensive study set within Singapore's dynamic maritime setting. It aims to solve the complex problem of seafarer fatigue, with a focus on the bunker tanker business. As a vital maritime hub, Singapore hosts the activities of these vessels that power the global economy. This study will identify the elements that contribute to exhaustion among bunker operators, assess the current levels of weariness in this industry, and provide personalized ways to address this widespread problem. While the research will be limited to Singapore, it hopes to contribute significant knowledge aimed at improving seafarer well-being, safety, and operational efficiency in this critical maritime niche.

1.6 Significance of the Research

This research aims to decode the underlying intricacies of seafarer weariness and uncover effective pathways for its reduction and eventual removal to ensure seafarers' well-being and safer shipping in Singapore port waters for the bunkering industry.

1.6.1 Enhancing Seafarers' Well-Being

One of the most significant implications of this research is its ability to improve the well-being of seafarers operating aboard bunker tankers. By recognizing and treating the underlying causes of weariness, the research's recommendations may enhance these individuals' quality of life. Seafarers are the backbone of the maritime sector, and their well-being is not only a moral responsibility but also vital for job performance and longevity.

1.6.2 Ensuring Maritime Safety

Fatigue among seafarers is a major safety hazard. Combating fatigue in the bunker tanker business can improve safety for both seafarers and the vessels they operate. The study's results and mitigation strategies can help lower the risk of accidents, errors, and environmental dangers, resulting in safer marine operations in Singapore's waters.

1.6.3 Boosting Operational Efficiency

Fatigue can cause inefficiencies and poor performance in the maritime industry. The research can potentially improve the operating efficiency of bunker tanker crews by identifying and reducing the elements that contribute to tiredness. Improved working conditions and fewer fatigue-related errors can help to streamline operations and eventually assist the economic viability of the maritime industry.

1.6.4 Nurturing Sustainability

Singapore's maritime sector is critical to the country's economic growth. This research adds to the long-term viability of this critical industry by reducing seafarer fatigue. Reduced fatigue can contribute to increased job satisfaction and retention among seafarers, providing a stable workforce and continuous expansion in the marine sector.

1.6.5 Valuable Industry Insights

The study provides insights and actionable recommendations for industry stakeholders, shipowners, policymakers, and marine organizations. By implementing the findings, these stakeholders may build a safer, more efficient, and more sustainable maritime environment. As a result, our research serves as a knowledge resource to inform industry practices and policies.

CHAPTER 2

LITERATURE REVIEW

A literature review is of significant importance for researchers as it serves as a comprehensive overview of the aspects to be studied and addresses the questions raised by the research. It enables the researcher to delve deeply into the ideas, information, and findings of prior studies, articles, and related literature, allowing for a thorough exploration and description of the relevant content.

2.1 Introduction

The maritime industry, acting as the routes of global trade and economic exchange, relies on the intricate interplay of vessels navigating vast oceans. The global bunker fuel market was valued at approximately $120.1 billion in 2019 and is expected to rise at a compound annual growth rate of 3.1 percent over the next seven years, to reach $130.1 billion by 2027 (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. 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. Singapore's maritime landscape encompasses its economic vitality, 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 arduous nature of their work to the extended hours they put in and the erratic environmental circumstances they deal with (Oldenburg *et al.,* 2009).

Bunker fuel is a kind of fuel oil that ships utilize in their auxiliary and main engines to produce power and propel themselves. It is used as a fuel source for the ship's engines in the bunker tanks (Ait Allal *et al.,* 2019). The three main types of marine fuel that ships use are diesel oil, fuel oil with a low sulfur level, and fuel oil with a high sulfur concentration. As of right now, Growing public awareness of the need to reduce pollution in the environment and strict government regulations are expected to present opportunities for fuels like LNG, gasoil, LPG, methanol, hydrogen, and others to replace 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 super tanker operated by Exxon Shipping Company and heading in the direction of Long Beach. About 2.5 kilometers west of Tatitlek, Alaska, on Bligh Reef in Prince William Sound, the Exxon Valdez ran aground in 1989. As a result of the collision, approximately 11 million US gallons of crude oil were released into the environment over the course of the following few days. Exxon found itself in an extraordinarily difficult financial position as a result 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 poor decision-making during the navigation of the ship by the third officer on the bridge, which may have been caused by exhaustion or an excessive amount of work, contributed to the accident.

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). To lessen the possibility of incidents of this nature, protect the environment, and guarantee the smooth operation of the world economy, an investigation of the effects of fatigue 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 (Bateman, 2009).

In the maritime transportation sector, awareness of weariness and its possible effects on health and safety has been progressively increasing. Seafarer fatigue has repeatedly emerged as a primary cause or a major contributing factor in up to 80% of maritime incidents (Rajapakse & Emad, 2023). This fatigue is intrinsically linked to the crews' well-being, the vessels' integrity, and the marine environment's preservation. Fatigue's perilous nature is further underscored in ferry shipping, which directly threatens passenger safety. A sobering reminder is provided by the terrifying event involving MS Herald of Free Enterprise in 1987, which resulted in the drowning of 183 passengers and crew members. According to a research conducted by Cardiff University in the UK, almost one-third of ferry crew members acknowledged being involved in an incident or accident related to exhaustion. Alarmingly, nearly 89% of these crew members disclosed that fatigue had compromised their concentration (Jiao *et al.,* 2020). A parallel trend was observed in a US study, where 74% of crew members in a US state ferry system confessed to experiencing tiredness at work 2-3 times per week, with 23% admitting to falling asleep at work multiple times in a month. Furthermore, 19% made errors in judgment due to fatigue, and another 19% experienced near misses, which are unplanned events with the potential to cause harm but mercifully didn't result in injuries or damage – fatigue was a significant factor in these incidents (Haycox, 2020).

2.2 Research Framework

This research primarily focuses on tanker vessels, specifically Singapore-registered bunker tanker vessels, and addresses the issue of seafarer fatigue. Singapore, being one of the international largest shipping hubs, plays a significant role in the global bunker market. At any given time, there are approximately 1,000 vessels in the Singapore port, with around two hundred bunker tankers operating in Singaporean waters. These vessels employ nearly 4,500 seafarers, and approximately 3,000 of them serve on bunker tankers registered with the Maritime and Port Authority of Singapore (MPA). Foreign seafarers working on these ships are treated similarly to those working in Singapore and are issued Employment Passes. Additionally, they are required to obtain a Certificate of Recognition in accordance with their national Certificate of Competency and Ship Handling Training Certificate, as mandated by the MPA. The senior officers are working two months on board one months on leave and Junior officers and crews are five months on board two months on leave. This is just as an example. Company to company varies it.

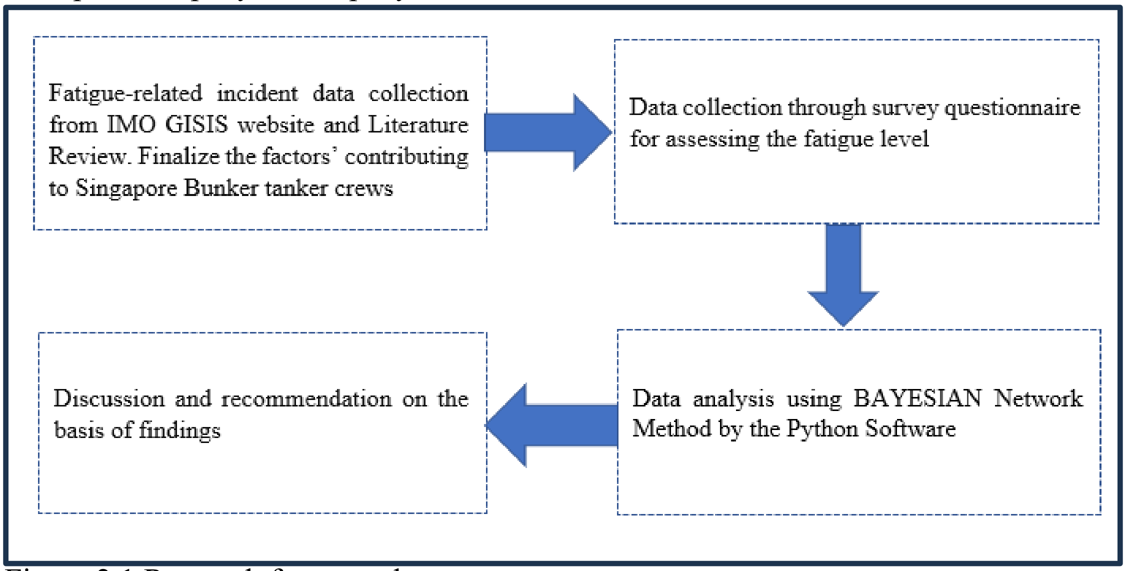


Figure 2.1 Research framework.

As shown in Figure 2.1, the research framework comprises three crucial steps to understand and address fatigue levels among seafarers on Singapore bunker vessels. In the initial phase, data is collected from the International Maritime Organization (IMO) Global Integrated Shipping Information System (GSIS) website. This step provides a foundational understanding of existing trends, regulations, and industry-wide perspectives on seafarer fatigue. In the second step, a questionnaire survey is conducted, gathering firsthand insights from seafarers onboard Singapore-registered bunker vessels. The collected data is then analyzed using Bayesian methods, allowing for a nuanced and probabilistic approach to understanding the multifaceted factors contributing to fatigue. This statistical analysis helps identify key physical and psychological stressors influencing seafarer well-being. In the final step, a set of targeted recommendations is proposed based on the findings derived from the data analysis. These recommendations are designed to specifically address and mitigate the identified factors contributing to fatigue, aiming to enhance seafarers' overall health, safety, and performance within the unique context of Singapore-registered bunker vessels.

Furthermore, it’s important to note that while fatigue is an issue on various types of vessels, this study specifically focuses on seafarers on Singapore-registered tanker vessels. Given Singapore's role as a major bunker replenishment port and the continuous nature of this operation, with bunker barges operating around the clock to meet the demands of customer vessels, the potential risks associated with fatigue cannot be underestimated. The study also recognizes that Singapore is the 5th largest holder of gross tonnage among countries, with nearly 464 foreign-going tanker vessels known for their high-risk operations. The consequences of incidents involving tanker vessels are often more severe than those involving general cargo vessels, bulk carriers, and container vessels. Therefore, a thorough examination of fatigue among seafarers on Singapore-registered bunker tanker vessels is crucial to ensure safety in this high-stakes industry. Overall research design shown in figure 3.1 shows the research methodology flowchart.

2.3 Bayesian network

A potent synthesis of graph and probabilistic models is a Bayesian network, extensively applicable across various disciplines such as machine learning, data extraction, and data analysis. It offers a robust and evidence-based approach that closely aligns with human reasoning. However, the complexity of Bayesian networks, with their intricate constructs, equations, and technical software, can be perplexing to many. To make these concepts accessible, it is essential to present them in a clear and straightforward manner, ensuring they are comprehensible to a general audience.

The foundation of Bayesian methods lies in the realm of probability and odds. Probability theory includes frequentist and subjective interpretations. For example, When we say that there is a 0.5 chance of a coin landing heads, it signifies that heads will appear about half of the time in many coin tosses. This also translates to a betting scenario where if someone bets on heads and it lands heads, they win a dollar. In the context of scientific constructs, some advocate for a third approach, an objective method that represents a shared belief rather than an expression of individual subjective uncertainty. The Bayesian method leverages probability clauses to deduce the likelihood of outcomes. These probabilities are represented in an acyclic graph, which is instrumental in determining the most influential factors in the final outcome. Both joint and conditional probabilities play a pivotal role in this process. Various names, such as Belief Networks, Decision Graphs, and Bayesian Models know Bayesian networks.

Variables are represented as nodes in a Bayesian network, and they are given Bayesian probability. The foundation of structured learning is the idea that education is fundamentally index-based. After taking into account all of the factors in the scenario, probabilistic likelihoods are given for each variable. It locates a Directed Acyclic Graph (DAG), where each variable in the structure is represented by a single node. Notably, if the given requirements hold true for none of the nodes lower in the network, variables within the system are conditionally independent of their non-descendants with respect to their values. The goal of recent study has been to have an empirical understanding of the workings of Bayesian networks. The definition and solution of problems can benefit greatly from the analysis of learned dependency graphs. The field of Bayesian network modeling has advanced due to a number of methods, such as the Cooper-Herskovitzler k2 algorithm (originally proposed in 1992) and virtual annealing Bayesian Networks (enhanced in 1995).

Bayesian networks are grounded in a probabilistic paradigm that incorporates mathematical concepts and graphical representations, influenced by graph theory.

They address two fundamental issues: ambiguity and unpredictability. Joint probabilistic systems can have random dependent relationships represented using graphic models. When it comes to assessing and creating machine learning strategies, algorithms are essential. Probabilities are used in diagrammatic models to represent random variables as nodes, and compressed mutual probability distributions can be used to show the relationships between pairs of variables. Writer-prompts and reader-prompts are two crucial types of software applications for Bayesian networks. Undirected models can also include Bayesian networks and Markov random fields (MRFs). Recent years have seen a great deal of research on observational learning, which uses experience and observed evidence to produce fresh insights. Although a number of strategies have been investigated, the focus is on modifying the data as needed to rebuild characteristics without changing the graph as a whole. To generate a localized version of the network that more closely approximates the global structure, optimization techniques are used.

The majority of Bayesian network analysis takes place in conditions when the network configuration doesn't change. For small numbers of random variables, traditional algorithms frequently use scores to calculate the likelihood of all Directed Acyclic Graph (DAG) models. These methods cover every potential configuration of the model.

2.4 General perspective on fatigue

Fatigue is commonly perceived as a natural response to prolonged and intense activities, typically described as an overwhelming sense of tiredness or sleepiness (Smith *et al.,* 2006). Nevertheless, this simplified portrayal hardly does justice to the complexity of the concept. Fatigue can be categorized into two main types: active and passive fatigue. Active fatigue emerges from overstimulation, often stemming from relentless and unavoidable work-related demands that necessitate constant attention and responsive actions. Conversely, passive fatigue results from under-stimulation, as seen in tasks like prolonged monitoring of an unchanging display. A further differentiation has been proposed, distinguishing central fatigue, associated with the malfunction of the central nervous system, from peripheral fatigue, linked to the malfunction of the peripheral nervous system (Rajapakse & Emad, 2023).

However, a more practical classification emphasizes acute and chronic fatigue. Acute fatigue, often referred to as "normal" or short-term fatigue, is typically linked to an identifiable cause, frequently arising from intense physical or mental exertion or even a flu-like illness. Episodes of acute fatigue typically last for less than three consecutive months. Acute fatigue is usually self-limiting and can be mitigated by appropriate measures such as rest or addressing the underlying condition. It generally has a minimal impact on daily life and overall quality of life. Nevertheless, if not effectively managed, acute fatigue can serve as a precursor to a more chronic condition (Allen *at al.,* 2010)

In contrast, chronic fatigue, often referred to as pathological fatigue, is characterized by greater intensity and has a more profound impact on daily activities and the individual's overall quality of life. It lasts for a long time usually three months or more and cannot be completely relieved by rest or restorative measures. Additionally, psychiatric conditions such as depression can be associated with chronic fatigue, although the causal relationship between the occurrence of depression and the experience of fatigue remains complex and multifaceted. Myalgic encephalomyelitis, another name for chronic fatigue syndrome, is a unique example because it is not caused by an underlying medical illness. This syndrome is typified by enduring and extreme fatigue, accompanied by other nonspecific symptoms, including muscle pain, joint pain, impaired memory or concentration, and swollen lymph nodes. Unlike other forms of fatigue, chronic fatigue syndrome is not substantially relieved by rest, significantly hampers an individual's daily functioning, and affects their ability to fulfill responsibilities (Åkerstedt *et al.,* 2002a; Grech, 2016; Hystad & Eid, 2016; Lützhöft *et al.,* 2007).

2.5 Definition of fatigue

Defining fatigue poses a complex challenge, lacking a universally agreed-upon technical definition, but common elements persist in various interpretations. Diminished human performance and a decrease in awareness or reliability characterize fatigue broadly (Dincer, 2000). It is marked by feelings of tiredness, weariness, or sleepiness resulting from prolonged engagement in physical or mental tasks, stress, challenging environments, or insufficient sleep. International Maritime Organisation defines fatigue as a reduction in physical and/or mental capability due to exertion, impairing physical abilities. It is a nonspecific symptom indicating various causes, including physiological conditions, medical situations, psychiatric conditions, and the effects of prescription medicines or erratic lifestyles (Golding & Gresty 2015).

In the realm of occupational fatigue, a recommended definition addresses previous shortcomings: "When an organism's muscles, organs, or central nervous system have been subjected to previous physical activity and/or mental processing without enough rest, fatigue occurs when there is not enough systemic energy or cellular capacity to sustain the initial level of activity and/or processing using regular resources (Maleki e*t al.,* 2022; Maurier e*t al.,* 2011; Sivaprasad e*t al.,* 2023).

Given the focus on occupational fatigue in this thesis, the definition proposed by Soames-Job and Dalziel serves as a guiding framework (Soames Job & Dalziel, 2020). It distinguishes between physical and mental fatigue, where physical fatigue results from extended periods of physical activity, reducing the capacity for desired activities. In contrast, mental fatigue stems from mental strain or intense emotional experiences, leading to reduced energy and motivation, decreased vigilance, and subjective sleepiness (Arzaghi *et al.,* 2017, 2018; Wan *et al.,* 2019). This comprehensive understanding of fatigue encompasses various dimensions, addressing the challenges in defining this complex phenomenon.

2.6 Symptoms of Fatigue

There are various signs of fatigue (Figure 2.2), 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 due to a specific task. These symptoms can include chronic fatigue and sluggishness, which can impair judgment 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 (Abrahamsen *et al.,* 2022; Åkerstedt & Wright, 2009; Firdaus Nor e*t al.,* 2019; US Government Accountability Office, 2021).

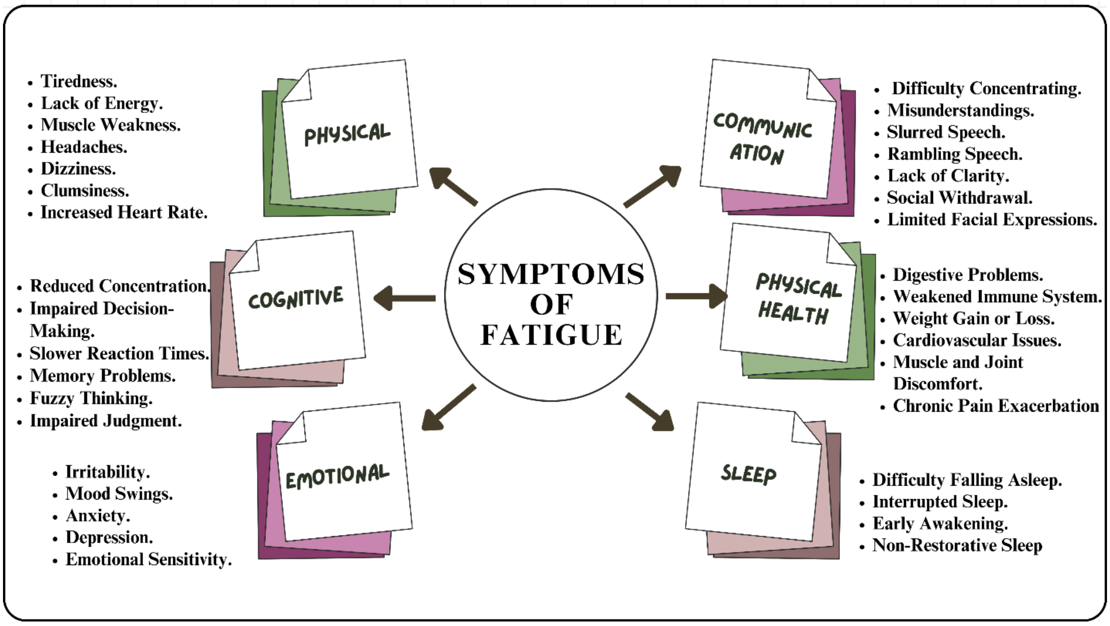


Figure 2.2 Symptoms of fatigue.

2.7 Casual factors of fatigue

Exploring the causes of fatigue in seafarers involves a comprehensive analysis of recognized maritime risk factors and their interactions and insights from occupational risk factors identified in professions beyond seafaring (Allen *et al.,* 2008).

A study that used questionnaires with sailors found a correlation between fatigue symptoms and a number of environmental and occupational risk factors that are present at sea. These variables included the quality of one's sleep, work hours, shift patterns, duration of a tour, job demands, stress related to one's employment, disruptions in sleep, and difficulties navigating time zones. (Wadsworth *et al.,* 2008). There was a relationship between the number of risk variables and the degree of weariness, indicating a relationship with poor cognitive function and health effects. A thorough understanding of weariness at sea necessitates taking these elements into account collectively, according to recent studies. It also emphasizes how important it is to avoid working longer than two sets of six hours in a 24-hour period because longer workdays considerably increase feelings of drowsiness (Smith *et al.,* 2006).

Over a 20-year period, a comprehensive study focused on work and health difficulties, encompassing a representative sample of 58,115 adults in Sweden, revealed important factors associated with exhaustion. Female gender, being under 49 years old, having a high socioeconomic class, having pre-existing illnesses, having difficult job conditions, working overtime, and physically taxing work were among these indicators. A few of the specific factors that contribute to seafarer weariness are shown in Figure 2.3. Shift work, physical workload, and stress at work are important risk factors. (Åkerstedt *et al.,* 2002b).

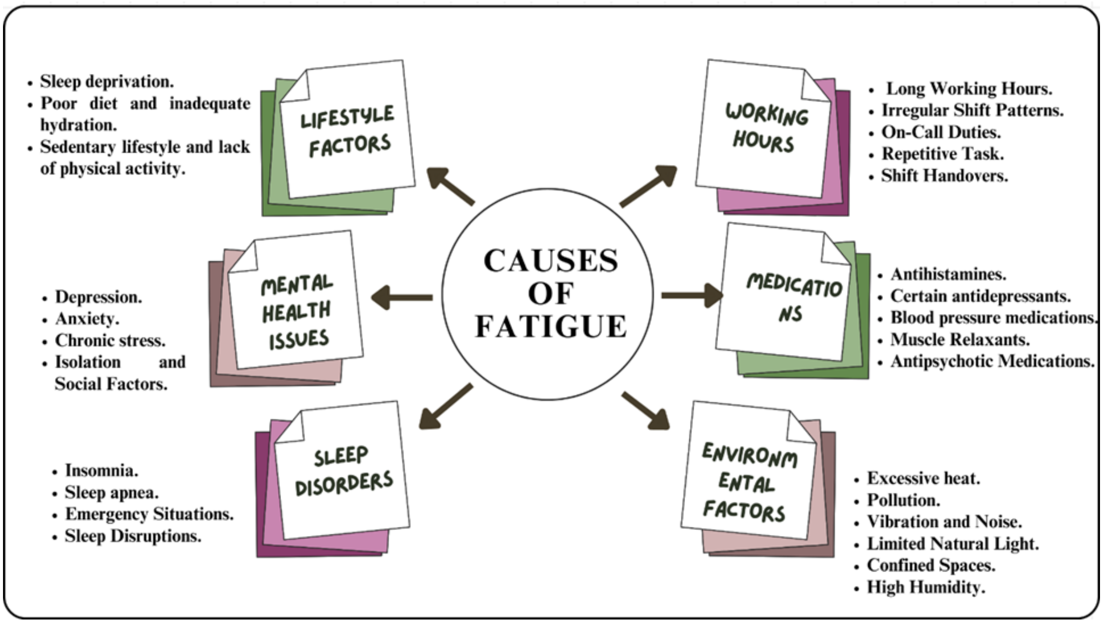


Figure 2.3 Causes of fatigue.

Furthermore, the main correlation with the biochemical and metabolic alterations linked to fatigue that have been discovered is sleep deprivation, not subjective sleep quality. While the focus of past studies was on the length of sleep, an increasing amount of epidemiological research explores the relationship between the quality of sleep and health effects (Ferrie *et al.,* 2011). Experimental demonstrations highlighting adverse health effects following substantial reductions in sleep duration underscore a causal relationship between sleep and health (Porkka-Heiskanen *et al.,* 2010; Tobaldini *et al.,* 2014). These results highlight how crucial it is to manage and mitigate these risk factors in order to successfully battle fatigue in the maritime sector and other industries. In new sections, a brief explanation of fatigue-related factors is elaborated.

2.8 Psychosocial Stress

A difficult situation arises when considering the impact of psychosocial work factors on weariness and sleep. Unfavorable psychosocial work characteristics have relatively minor consequences; high job strain is linked to trouble falling asleep and decreased psychomotor vigilance during night shifts, but it has no discernible effect on the amount or quality of average sleep (Härmä, 2013). A thorough analysis of psychological stress among seafarers demonstrates that the maritime industry is marked by a variety of mental, psychological, and physical stressors, such as sleep deprivation, fatigue, multicultural environments, loneliness on board, and family separation. There are different stresses in different departments and strata on board. In order to address the mental health concerns linked with these stressors, it is necessary to help seafarers reduce their stress levels and create coping mechanisms for handling these "inevitable" stressors. Workplace stress and social conditions interact to cause sleep disturbances and poor wakefulness, and age and gender may have an impact on these associations. One key connection between stress and sleep is the inability to put an end to work-related worries during leisure time. High levels of stress or work-related worries right before bed have been linked to sleep problems. Furthermore, workplace stress often correlates with an increased time required to fall asleep due to ruminating over work-related matters (Åkerstedt, 2006).

Job control and workload only have a minor to moderate impact on the quality of sleep. Transitioning from a non-high-strain job to a high-strain job was associated with significantly worsened sleep quality and increased fatigue, while the opposite transition improved sleep-related issues, according to a longitudinal study on the relationship between job demands and job control. This result is consistent with a study that looked at how recovery from exhaustion, sleep quality, work-life balance, and the frequency of self-reported "near misses" at work are affected by work-time control and the unpredictability of working hours. High levels of control and diversity in work hours had a favorable impact on work-life balance and health.

One study discovered no correlation between differences in psychosocial work characteristics and negative emotional reactions and objective sleep efficiency as assessed by actigraphy recordings. On the other hand, people who overcommitted to their jobs or had little social support at work were more likely to self-report having trouble sleeping (Jackowska *et al.,* 2011). Another study demonstrated that a workweek characterized by a heavy workload and significant stress heightened sleepiness, impaired sleep quality, and disrupted the diurnal cortisol secretion pattern, resulting in a flatter pattern likely due to increased evening cortisol levels during the stressful week (Dahlgren *et al.,* 2005). Daily variations in self-reported fatigue, based on sleep diaries, are associated with poor sleep quality, reduced sleep duration on the preceding night (as measured by actigraphy recordings), higher stress levels, and the occurrence of cold or fever on the same day (Åkerstedt e*t al.,* 2014).

2.9 Mental Health Factors

The wellbeing and mental health of seafarers is one of the primary problems. All levels, ethnicities, and ages of the crew might be impacted by poor mental health. The first step in helping crew members on their recovery journey is to identify mental health issues. Support, knowledge, and education are crucial in this process.

2.9.1 Stress

Numerous stressors, including as bad weather, sharp temperature swings, extended sea periods, noise, and vibrations, are experienced by seafarers. Conflicts amongst crew members, being away from home, working long hours, getting irregular or poor-quality sleep, eating mediocre cuisine, changing crews frequently, and employment and contract uncertainty are additional stressors. Furthermore, stress on board can be heightened by the fear of piracy attacks (Abila & Acejo, 2021). Stress and fatigue share a close relationship (Leszczyńska e*t al.,* 2008). Stress can arise from fatigue and may be associated with alcohol and drug abuse, as well as other mental health issues (Szymańska e*t al.,* 2006). Some authors have proposed methods for measuring and preventing stress (McVeigh e*t al.,* 2019; Xiao *et al.,* 2017).

Environmental factors are the main source of stress for seafarers, and these factors can have serious consequences such as substance abuse and, in the worst cases, suicide. Several articles have delved into the issue of suicides on board from various perspectives, such as examining the number of cases over the years, the progression of mental illness leading to suicide, and its association with alcohol and drug abuse (Lefkowitz *et al.,* 2019; Mellbye & Carter, 2017).

Suicidal inclinations at sea are described by Szymańska et al. (2006) as the result of intense stress that exceeds an individual's capacity for adaptation. This situation genuinely threatens personal well-being and can erode self-preservation instincts. Remedies and measures to alleviate psychological issues related to the maritime working environment are also explored. Some of these measures may involve promoting on-board exercise programs, addressing alcohol misuse, and enhancing sleep and dietary habits (Slišković & Juranko, 2019). Additionally, telemedicine can provide professional guidance to help seafarers cope with psychological challenges during their time at sea, offering remote advice and support (Bailo *et al.,* 2022; Bashshur *et al.,* 2016; Nittari *et al.,* 2019). Figure 2.4 provides an illustration of the psychosocial aspect of fatigue.

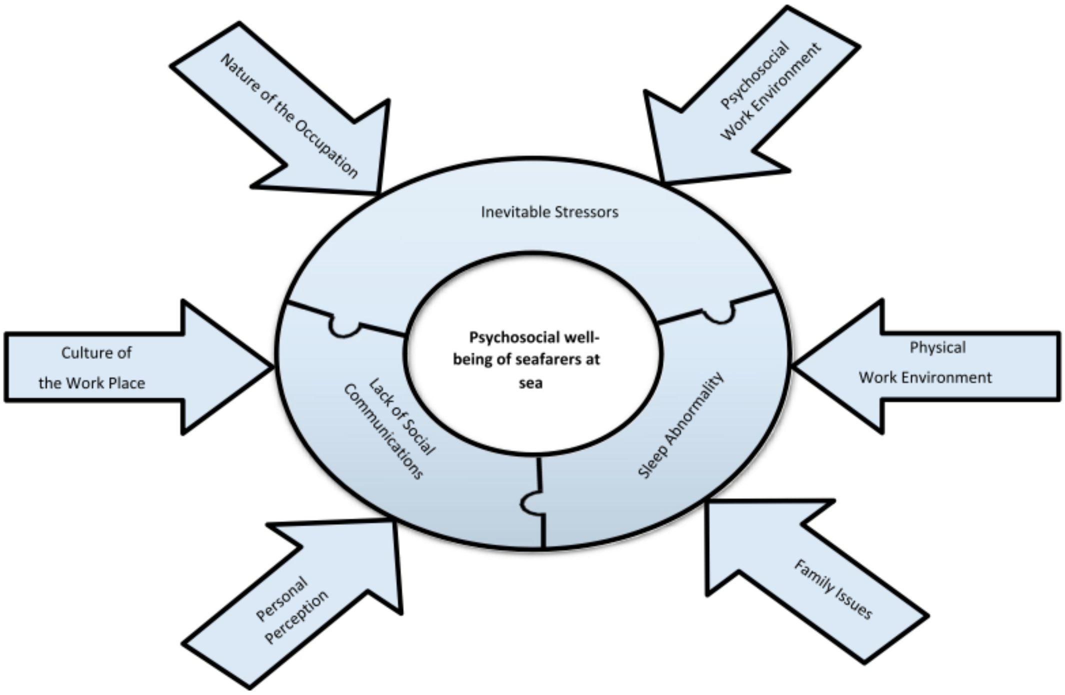


Figure 2.4 Psychosocial aspect of fatigue. (Source: https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-022-13154-4)

2.9.2 Loneliness

Loneliness can be particularly pronounced during long navigation periods and is closely tied to the extended separation from family. This separation impacts seafarers and has repercussions at the family level, affecting partners and possibly causing intimate and relational consequences. Even suicide has been linked to loneliness, particularly in the case of vulnerable people employed in remote locations like the open sea. Seafarers may try to cope with loneliness by resorting to excessive smoking and alcohol consumption (McVeigh *et al.,* 2019). Furthermore, the lack of social contacts on board, often exacerbated by language barriers among colleagues, contributes to feelings of loneliness (Mellbye & Carter, 2017)

Boredom can have detrimental effects on mental health, impacting the quality of work performed and contributing to seafarer fatigue. Furthermore, It's critical to understand the difference between social isolation, which is a condition of lack of social interaction, and loneliness, which is a person's subjective emotional state. Social isolation leads to psychological issues like boredom, marginalization, exclusion, anger, despair, sadness, frustration, and, most notably, loneliness. It has played a significant role in the psychological issues that seafarers face and has contributed to the decline in seafaring in western nations. Isolation can lead to despair and depression (Bailo *et al.,* 2022; Döring *et al.,* 2022; Smith *et al.,* 2006).

The provision of communication tools and stations like Skype or other video calling software, internet access, access to video recordings of major sporting events, and receiving global news are just a few of the communication-based solutions that have been proposed to combat loneliness and isolation on board. It's also critical to recognize the compounding effect of social media use-related perceived social isolation. Continuous exposure to idealized representations of people living highly social and successful lives can lead to feelings of envy, which may contribute to depression (Abila & Acejo, 2021).

The COVID-19 pandemic, which began in late 2019, exacerbated isolation conditions for many seafarers (Battineni *et al.,* 2021; Nittari *et al.,* 2022). Travel restrictions and border closures delayed crew rotations and increased seafarers' time at sea. Shore leave was heavily restricted (it was outright banned in several ports) due to health-related concerns. These difficulties have made sailors' stress levels even higher. Other factors that have contributed to this include fear of infection, unstable employment, worry for family members' well-being, and limited access to healthcare.

2.9.3 Abuse

Abuse is a worrying issue that can happen on ships between coworkers or between employers and employees, whether it's verbal or physical. Seafarers who have experienced severe and prolonged mistreatment are at a higher risk of developing depression, anxiety, and suicidal ideation. The main types of abuse that are observed on board are verbal or physical assaults, humiliation, personal insults, mockery, both in private and in public, fits of rage directed at a specific person or group, continuous criticism, and making irrational demands of coworkers or staff.

Authorities responsible for overseeing maritime operations need to recognize the problems stemming from abuse onboard, as they can profoundly impact the mental and professional well-being of seafarers. Wrongdoings should be reported promptly, with mechanisms in place to protect the whistleblower's identity and prevent any negative consequences. Investigations into these instances should be carried out impartially and independently, carefully examining the circumstances that lead to abusive behaviors. Particularly in instances involving recurrent physical abuse and other work-related settings, maritime authorities and shipping businesses must to keep a careful eye on these actions and impose severe punishments.

2.9.4 Regulations

The absence of comprehensive international regulations governing the activities of seafarers worldwide compounds the challenge of addressing stress onboard ships. In the articles under review, existing norms are examined in the context of specific situations. For instance, Allen *et al. (2008)* delve into the issue of fatigue and the regulations surrounding seafarers' working hours and shifts. The challenge that they take on is precisely confirming the real working hours while on a cruise. Their method asks for more effective work-hour management, possibly by using logbooks or registers.

Strict adherence to regulations that already exist and contain mandatory measures, together with a coordinated effort to address the issue of fabricated record-keeping, are also essential requirements. Because some ship managers or individual employees on commercial vessels fear that their enterprises may be subject to regulatory scrutiny, which could jeopardize their current or future employment, working hours are frequently underreported. Maximum Working Hours Permitted Onboard Are outlined in the International Labor Organization (ILO) Convention. Improved living conditions on board, such as air conditioning and noise reduction, are covered by ILO Conventions 92, 133, 140, 141, and 147. The 2006 Maritime Labor Convention's restrictions on working and off-duty hours are similar to those found in ILO 180.

According to the International Safety Management Code, the ship's master and the corporation must act quickly to address any indicators of exhaustion, excessive work hours, or insufficient rest that are apparent or should become apparent. This underscores the necessity for stronger legislative support on matters of immediate concern to seafarers. Achieving this goal requires collaboration between national and international shipping companies and agencies (Fan *et al.,* 2023; Stannard *et al.,* 2015).

2.10 Working environmental factor

Numerous factors inherent to the maritime environment significantly contribute to the prevalence of fatigue at sea. It is imperative to acknowledge that seafarers operate within confined spaces, often in isolation from their homes. Initially, a seafarer's tour of duty typically spans 3 to 6 months, subject to unpredictable environmental conditions, such as rapidly changing weather patterns. Additionally, the demarcation between work areas and recreational spaces on board vessels is often unclear, blurring the lines between labor and leisure. Moreover, the modern maritime workforce comprises crew members from diverse countries and backgrounds who must coexist for extended durations while at sea. These complexities collectively create a unique confluence of factors that significantly elevate the susceptibility of seafarers to fatigue. The maritime domain exposes seafarers to a myriad of discernible risk factors stemming from their working environment, thereby intensifying the likelihood of experiencing fatigue during their service (Gilliat-Ray *et al.,* 2023; Uğurlu *et al.,* 2021).

2.10.1 Operational Factor

The demanding operational nature of seafaring, further compounded by the inherent challenges of shift work, adds to the multifaceted issue of seafarer fatigue. Shift work, which frequently includes nighttime hours, has been connected to a number of mental and physical health issues. In addition to dealing with the disturbance of their daily routines and work-rest cycles, shift workers frequently feel cut off from their social lives. Seafarers' quality of life can be severely impacted by night shifts in a shift work system. These shifts can cause physical complaints, chronic exhaustion, persistent sleepiness, and difficulties engaging in regular social activities. Alarming data from investigations reveal that a significant proportion of human-induced accidents primarily occur between the critical hours of 01:00 and 03:00 (Uğurlu *et al.,* 2021).

It is impossible to overestimate the importance of uninterrupted, enough sleep because it provides much-needed relaxation and helps mariners function at their best.

Regrettably, the nature of seafaring often makes it challenging to achieve such sleep patterns. Fatigue resulting from incomplete sleep cycles remains a pervasive issue and a major contributor to maritime accidents. Seafarers' working schedules are often at odds with the natural rhythms of their individual biological clocks, disrupting their circadian rhythms. This disruption is becoming more pronounced with the increasing speed of vessels. A careful analysis of maritime accidents underscores the pivotal role that circadian rhythms play in influencing seafarers' alertness levels and overall performance. In addition to these factors, the demanding nature of the maritime industry introduces an array of stressors. Intensive paperwork, adherence to shift-based timetables, and the prevalence of overtime work compound the fatigue issue among seafarers, significantly increasing the risk of human error (Abila & Acejo, 2021; Carotenuto *et al.,* 2012).

2.10.2 Technical Factor

The advent of advanced technology, including the integration of computer-controlled systems on-board, has undeniably enhanced the technical capabilities of ships. However, this technological progression has had unintended consequences, primarily the seafarers number reducing on-board vessels. Consequently, seafarers remaining on these technologically advanced vessels often find themselves compelled to work harder and for more extended periods, leading to heightened levels of fatigue. This fatigue, in turn, directly threatens the safety of lives and the integrity of the vessels themselves (Baygi *et al.,* 2022).

In addition to the demands imposed by technology, other technical factors come into play. Seafarers' ability to sleep and perform well can both be significantly impacted by the noise level on board. The entire ship is filled with noise, coming from the main engine, generators, pumps, and air conditioning systems, among other sources. Noise exposure can have a variety of impacts, from physical and physiological diseases to disruptions in human function and increased weariness in general. Severe weather at sea might make weariness more of a problem since there is more movement about the ship. Seafarers must use more energy to stay balanced due to the increased motion, which puts additional physical strain on them. Simultaneously, this motion frequently results in seasickness, further diminishing direct work satisfaction and exacerbating both physical and mental fatigue. These technical factors are pivotal contributors to seafarer fatigue, necessitating careful consideration and mitigation measures to safeguard seafarer well-being and maritime safety (Abaya *et al.,* 2015; Hjarnoe & Leppin, 2014).

2.11 Irregular work and sleep quantity

It might be difficult to get the recommended 7 to 9 hours of sleep per day especially when working shifts while at sea. Most individuals need this amount of sleep, ideally in one uninterrupted night. Significant differences between shift workers and daytime employees as well as different watch systems have been found in the large body of research on fatigue related to shift work in seafarers. A case-control study comparing rotating shift workers and daytime workers found a similar sleep profile in both groups, but insomnia was closely linked to sleep duration, anxiety, depression, fatigue, and diminished quality of life (Vallières *et al.,* 2014). In comparison to steady watch systems, alertness was lower in rotating watch systems.

Shift work causes drowsiness during working days that prolong into days off, makes it harder to fall asleep, and shortens sleep. Only by changing shift patterns can these difficulties be partially addressed. There is no conclusive evidence that chronic sleep problems result from long-term shift work, although retrospective studies suggest this possibility (Åkerstedt, 2003). Shift work and extended working hours contribute to sleep debt (Bayon *et al.,* 2014). Sleep, performance, accident risk, and secondary health outcomes including cardiovascular illnesses are all significantly impacted by shift employment that include night hours. The main cause of this is the incompatibility of the circadian rhythm, which is geared toward the day, with the requirement to work and sleep at the "wrong" biological time of day. Excessively lengthy shifts (more than 12 hours) and individual phase intolerance are additional factors that enhance work shift tiredness and the accompanying accident risk. This can lead to shift work-related disorders in individuals who experience the most pronounced sleepiness and performance impairment during the biological night and insomnia during the biological day (Åkerstedt & Wright, 2009).

Shift work-related insomnia varies among different work schedules, with evening shift insomnia being more prevalent in a 2-shift rotation than in a 3-shift rotation schedule (29.8% and 19.8%, respectively). Night shift insomnia is higher among 3-shift rotation workers compared to permanent night workers (67.7% and 41.7%, respectively). Rest-day insomnia is more common among permanent night workers compared to 2- and 3-shift rotations (11.4% compared to 4.2% and 3.6%, respectively) (Flo *et al.,* 2013).

Transitioning from a forward-rotating to a backward-rotating shift system is likely to increase sleep difficulties between successive afternoon shifts but decrease social disruption (Barton *et al.,* 1994). Fatigue is more pronounced in 2-watch systems (e.g., 6 on/6 off) than in 3-watch systems (e.g., 4 on/8 off) (Lützhöft *et al.,* 2007), particularly between 4:00 and 6:00 a.m. when the biological drive for sleep is at its peak. Eriksen et al. (2006) demonstrated that, within a 6 on/6 off system, sleepiness levels are highest during the night shift from midnight to 6 a.m. and increase toward the end of the shift. The 6/6-watch system (12 daily work hours) is associated with a higher risk of severe sleepiness for marine officers during the early morning hours compared to the 4/8-watch system with 8 daily work hours. Officers reported shorter sleep duration, more frequent nodding-off on duty, and increased sleepiness. About 17.6% had fallen asleep at least once while on duty during their career (Härmä *et al.,* 2008).

These findings were corroborated in the HORIZON project, which employed three linked marine simulators to create a realistic voyage experience. Bridge and engine crew members were studied on 4 on/8 off and 6 on/6 off-watch systems. Sleep and sleepiness were objectively assessed through polysomnographic recordings (Maurier *et al.,* 2011). A high frequency of severe sleepiness was observed, with several officers actually falling asleep while on watch. The 6 on/6 off watch system appeared to induce more sleepiness than the 4 on/8 off system, resulting in more incidents of seafarers falling asleep. Sleepiness onset during 6 on/6 off was apparent over a shorter timeframe than anticipated based on previous research. Marine watchkeepers were shown to be sleepiest during night watches and exhibited signs of sleepiness in the afternoon. Sleepiness gradually increased during the work periods as the week progressed. The study also revealed a significant impact of sleep disturbances during rest periods, with watchkeepers obtaining less sleep than needed for full rest. Watchkeepers' sleep averaged 6.5 hours in total, divided into two sessions: a primary one during the nighttime and a "nap" during the other rest period (Jørgen Riis Jepsen et al, 2015). Both subjective and objective peaks of sleepiness during the night and early morning watches coincided with a relatively high number of maritime accidents. Overtime work was demonstrated to substantially impact sleepiness, with a notable number of participants falling asleep during work after a short period of mild overtime.

Similar findings were reported in a study by Lützhöft et al. (2007), which also revealed shorter sleep periods within a 6/6 system, with sleep more frequently divided into two episodes. Sleepiness levels were higher during the 00:00–06:00 and 06:00–12:00 watches, increasing toward the end of the watch. Sleep duration varied among different watches, with longer sleep during the 06:00–12:00 and 18:00–24:00 off-duty periods. Whether sleep was fragmented into 2/3 episodes on an oceanographic vessel or 5/6 episodes on a fishing vessel, the 24-hour circadian alertness rhythm, as assessed by Visual Analogue Scales and actigraphs, remained intact in both cases. Seafarers experienced a circadian alertness dip during the nighttime and a pronounced afternoon dip. Sleep fragmentation should be attributed to occupational factors and social factors such as meal times. Lützhöft et al. (2007)

2.12 Irregular work and sleep quality

Objective indicators of sleep continuity are closely associated with perceived sleep quality, meaning that sleep quality is essentially synonymous with sleep continuity (Åkerstedt *et al.,* 1994). Disrupted sleep appears to be a more significant predictor of fatigue than other well-established risk factors for fatigue (Åkerstedt *et al.,* 2002a). This aligns with the observation that the subjective sense of peaceful sleep and ease of falling asleep contribute to improved sleep quality. Additionally, the duration of wakefulness before sleep and timing play crucial roles in determining the subjective perception of sleep quality (Åkerstedt *et al.,* 1997). Difficulties in waking up after sleep have been linked to factors like high work demands, low social support, male gender, younger age, and smoking (Åkerstedt *et al.,* 2002b). Disrupted sleep is associated with female gender, age above 49 years, existing illness, stressful work, physically demanding work, and shift work (Åkerstedt *et al.,* 2002a).

2.12.1 Physical Factor

Exposure to ship engine noise at a level of 65 dB(A) can harm sleep (Tamura *et al.,* 1997). However, this effect seems to be more subjective in nature, primarily affecting sleep quality, and it may not be as evident when assessed using actigraphy (Tamura *et al.,* 2002). Several studies have shown that sleep is often disrupted due to noise and the motion of ships. Motion sickness, which is a common experience for most seafarers, is a significant contributor to fatigue (Wertheim, 1998). Nevertheless, there is limited evidence regarding the extent to which ships' movements can impair physical and mental performance (Pisula *et al.,* 2012). Research has indicated that on days when vessel motions increased, crews experienced more challenges related to motion sickness and fatigue. Specific activities and responses were notably affected by vessel motions during such times (Haward *et al.,* 2009). Ishikawa Diagram influences fatigue shown in Figure 2.5.

2.12.2 Personal Factor

A study involving naval day workers and night workers revealed significant individual differences in the effects of shift duty scheduling. This finding underscores the need for strategies addressing fatigue to consider that different individuals may be better suited to different shifts (Goh *et al.,* 2000).

Age is one of the many individual elements that affect circadian rhythms; this is especially important in light of the trend toward an aging workforce in the maritime industry. The aging process reduces the speed of adapting to night work and substantially impacts sleep quality and the risk factors for chronic diseases (Ramin *et al.,* 2015). Additionally, sleep disorders tend to be more prevalent among older workers. Practical measures to enhance working conditions for older employees should focus on adapting work demands flexibly to accommodate varying levels of work ability, health, and social needs (Härmä & Ilmarinen, 1999). A study of naval seafarers found that older personnel did not experience more work-related fatigue than their younger counterparts. However, work-related fatigue tended to accumulate over time with continuous exposure to work demands on board (Bridger *et al.,* 2010).

While older shift workers often report increased subjective sleepiness, particularly affecting their work performance during morning and night shifts, a systematic review examining tolerance to shift work among older individuals yielded conflicting results. It concluded that there is limited evidence to suggest that older people are less tolerant of shift work. Nevertheless, it was argued that age-specific considerations should be incorporated into shift work planning (Blok & de Looze, 2011). Subjective sleep quality tends to deteriorate with age, leading to difficulties in awakening and feelings of not being well-rested after sleep. In contrast, fatigue appears to be more prevalent among younger individuals below the age of 49 years (Åkerstedt *et al.,* 2002a).

Furthermore, seafarers' fatigue significantly impacts 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 guarantee the vessel's smooth operation and quick emergency response; their diminished mental acuity poses a serious safety risk. Some physical effects include reduced motor coordination, increased risk of accidents, and increased discomfort from insufficient sleep (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 (Baygi *et al.,* 2022). 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 (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.

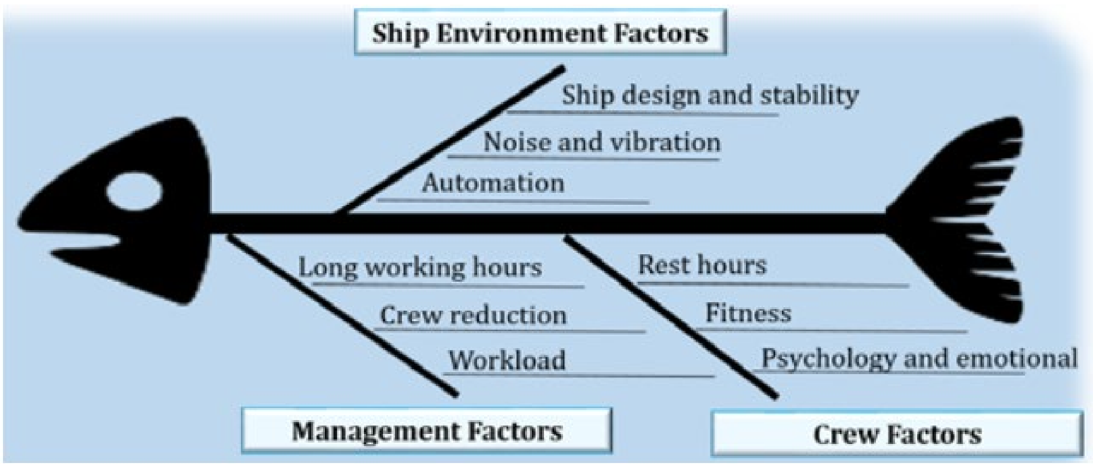


Figure 2.5 Ishikawa Diagram influences fatigue (Firdaus Nor *et al.,* 2019).

2.13 Fatigue and health

There is a long-standing correlation between general working population fatigue and increasing rates of sick leave, accidents, injuries, and disability. Research with a prospective design has demonstrated that psychosocial work aspects are important indicators of when weariness may start. Preceding fatigue has also been found to be significantly related to subsequent illness, as demonstrated by the study conducted by (Oldenburg *et al.,* 2013). It is clear that job qualities that are risk factors for fatigue act as a transitional stage between the onset of disease and exhaustion, even though the precise direction of the association between these variables and health problems has not always been conclusively determined.

Almost 20% of workers in Asian countries put in more hours than the minimum wage, and almost one in five work shifts, including nights. Even though there are a lot of publications about the negative effects shift employment has on society and health, the caliber of these works rarely keeps up with the volume. This problem is made worse by serious methodological issues in this sector. One of the most obvious methodological problems is that a large fraction of shift workers are a self-selected group, and those who stay in the shift for an extended period of time are known as the "survivor population." Maritime workers can likewise benefit from this observation. Every study that looks at the morbidity and mortality of sailors in comparison to the working population as a whole shows a similar issue. A highly selected group of "survivors" often appears to be even healthier than their onshore colleagues. A more accurate understanding of the situation emerges when events occurring after retirement are taken into account, as highlighted by (Xiao *et al.,* 2017).

One of the most common and fundamental aspects of employment aboard ships is working continuous shifts, which is also a major cause of fatigue. A prevalent health consequence of working shifts is sleep disruption, since shift workers report experiencing greater sleep disturbances than their daytime counterparts. This interruption has an effect on both the quantity and quality of sleep, possibly cutting sleep short by up to two hours each day. There is evidence that shift workers experience reduced stages 2 and rapid eye movement (REM) sleep. Data suggests that inadvertent naps during work hours may result from such deficiencies, which might cause drowsiness while working. Not only does time spent at work affect sleep quality, but people who are "on standby" may also have trouble sleeping. Depending on when shifts are completed, shift work might have different impacts onshore, but they usually go away two to three days later.

Additionally, shift work has a substantial impact on the work-home balance. This effect is amplified when employees are away from home for extended periods of time, which is typical for many seafarers. Some questions about shift work's long-term consequences on health are less resolved. According to certain research, shift workers are more likely to suffer from gastrointestinal diseases, which are marked by pain complaints and alterations in bowel patterns. Flatulence, dyspepsia, heartburn, and abdominal pains are among the most common problems from night workers. It was previously widely accepted that there was insufficient evidence to support a higher prevalence of cardiovascular disease in shift workers when compared to other groups. However, there is compelling evidence linking shift work to peptic ulcer disease and a relatively strong link between shift work and coronary heart disease. However, contemporary perspectives suggest a different story, with more recent data indicating a 40% increase in the risk for shift workers, as reported by (Slišković & Juranko, 2019).

Uncertainty surrounds the precise mechanisms underlying these health problems, but commonplace in the maritime environment are stress, smoking, poor eating habits, lack of exercise, altered socio-temporal patterns, disruptions in circadian rhythms, and low social support. An early mortality research from California found that male occupational groups working more than 48 hours a week had higher rates of atherosclerotic heart disease, indicating that prolonged working hours are also a risk factor for cardiovascular disease. Long-term prospective studies can examine mortality risk variables, and although it is conceivable that jobs that cause weariness could shorten life expectancy, conclusive findings from these research will take time to come to fruition. It can be difficult to look at the long-term health effects of professions like seafaring, where many people retire young. A person may no longer be considered an active seafarer and may not be included in estimations of health issues if they acquire chronic illnesses and fail medical exams.

2.14 Management Factors

Seafarers may experience stress-related issues as a result of managing vessels, and organizational features of management are crucial in this context. A thorough assessment of these organizational aspects reveals that ship management's ineffective employment policies and inadequate training harm onboard operations, leading to stress and fatigue among the crew. Moreover, tasks like paperwork requirements, schedule shifts, and overtime can significantly contribute to seafarers' fatigue, resulting in errors. Undeniably, the management style employed by shipping companies aboard ships holds great significance regarding its impact on seafarers' fatigue. Within this framework, certain shipping corporations neglect the needs and demands of seafarers, enforcing stringent regulations that lead to disputes and strain among the staff. Seafarers have to multitask due to the demanding conditions on board ships, which makes it difficult for them to follow all current laws. This adds to their already high stress levels. As a result, adhering to national and international laws and regulations pertaining to seafarers can also be a source of exhaustion and lower attentiveness. Additionally, the routine maintenance of the ship, which involves strenuous work, can impose an additional heavy burden on mariners (McVeigh *et al.,* 2019; Roberts & Marlow, 2005).

Travel planning and scheduling are another essential component of management elements, in addition to the organizational features. Because seafarers sometimes have to work overtime and under pressure to achieve tight schedules, the predefined durations between ports that are set by shipping management can be very taxing on them in this way. In order to meet these deadlines, sailors typically have to deal with inclement weather and dangerous maritime surroundings, which can lead to stress, anxiety, and increased levels of exhaustion. Similarly, the high traffic density encountered by vessels during sea navigation adds to the challenges, leading to various issues such as reduced alertness and impaired work performance (Abila & Acejo, 2021; Bal BeşİkÇİ *et al.,* 2016).

2.15 Ship Design Factors

Ship design is another crucial factor that can induce or mitigate seafarers' fatigue. Numerous aspects of ship design can affect the crew's capacity to rest and the workload they have on board, which in turn affects their stress levels. For professional seafarers familiar with the ship's operations, it becomes evident that automation is paramount in reducing workload, minimizing stress, and lowering fatigue levels. High levels of automation prove essential as they streamline tasks, require less time to accomplish, and make onboard equipment operation more effortless. Furthermore, considering the extended durations of up to six months spent at sea under harsh weather conditions, the reliability of the ship's equipment is a critical factor that significantly influences seafarers' fatigue (Tang, 2009).

The general consensus among seafarers is that, in comparison to newer ships, older ships are generally more difficult to run, less safe, and have less comfortable living areas. As such, a major factor that may raise stress levels among seafarers is the age of the ship. Given that adequate sleep and rest are fundamental components for optimal performance, the physical comfort of workspaces and quarters is a pivotal aspect of ship design that plays a vital role in mitigating fatigue. Finally, the ship's motion, often caused by poor vessel design, can also impact seafarers, increasing tiredness and fatigue (Russo *et al.,* 2020).

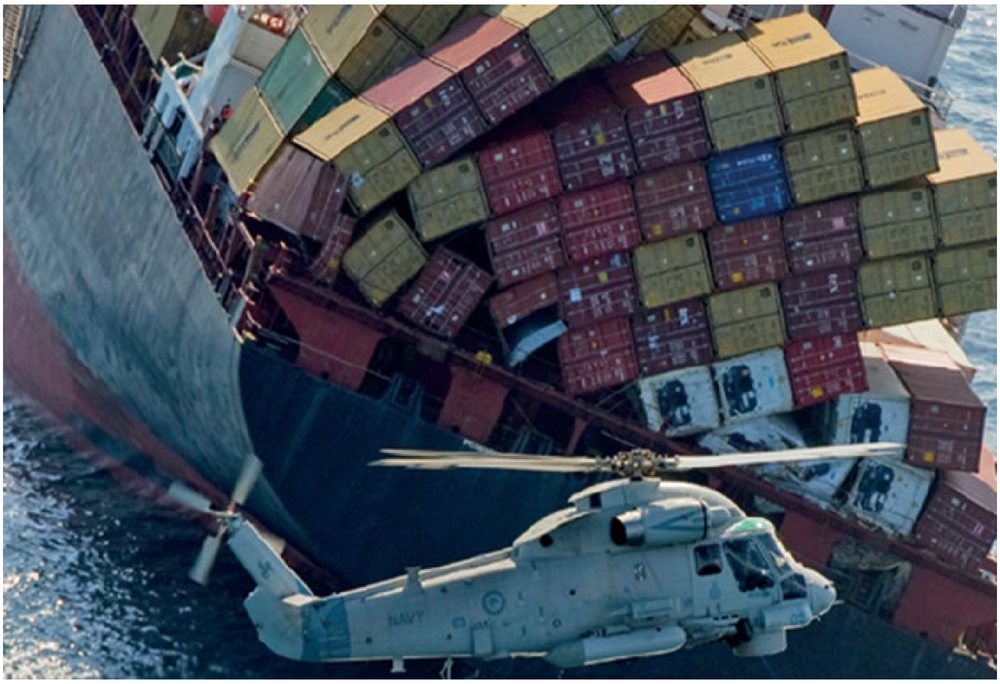


Figure 2.6 Ship accidents. Source: https://splash247.com/splash-extra-why-are-so-many-boxes-being-lost-at-sea/)

Figure 2.7 Ship accidents. (Source: https://www.vesselfinder.com/news/16269-2-Workers-Killed-13-Injured-Demolishing-cargo-ship-CSL-Virginia)

2.16 Consequences of Fatigue

Fatigue among seafarers can have serious implications, putting both individuals and the maritime sector at risk. Fatigue increases the chance of accidents and errors at sea by impairing cognitive functioning, slowing reaction times, and impairing decision-making abilities. This jeopardises the crew's safety and endangers the vessels and the sea environment. Continued fatigue impairs immunity, the heart, and general well-being, and it exacerbates a number of medical and psychological health issues. Furthermore, fatigue can cause decreased attentiveness, impaired interpersonal interactions among crew members, and increased absenteeism. The negative consequences extend beyond the personal realm, with potential legal bills, compensation, and damage to equipment or boats affecting organisational revenues. Furthermore, fatigue-related accidents can harm individuals' and marine enterprises' reputations, resulting in regulatory compliance concerns and a loss of trust from clients and consumers. Treating fatigue in the seafaring business is critical for individual health and well-being and the marine sector's safety, sustainability, and reputation. The following sections discuss the consequences of fatigue in maritime disasters, including fatigue and maritime disaster, depression and suicide, and other impacts (Mellbye & Carter, 2017).

2.17 Fatigue and Maritime Disaster

Fatigue The perception of fatigue as a contributing factor in maritime accidents gained significant attention, particularly following the occurrence of the Exxon Valdez accident. On March 24th, 1989, the US tanker Exxon Valdez ran aground on Bligh Reef near the coast of Alaska, triggering a comprehensive investigation by the US National Transportation Safety Board. This investigation identified fatigue as the primary factor contributing to the accident. It further revealed that no adequately rested officers were available to manage the navigation watch during the voyage (Golzio & Puerta-Díaz, 2021; Prabowo & Bae, 2019).

Another incident underscored the negative impact of fatigue in maritime accidents, the grounding of the Cittas in the English Channel. In 1997, this Germanowned container ship ran aground, causing damage to the vessel and environmental pollution. The investigation attributed the grounding to fatigue, echoing the findings in the Exxon Valdez accident. The watch-keeper responsible for the ship was severely sleep-deprived, which directly led to the accident. Subsequent maritime accidents also pointed to fatigue as a significant contributing factor (Diab & Shalaby, 2020; Laurent *et al.,* 2021). Two notable cases include the vessel Jambo off the coast of Scotland in 2003 and the grounding of Antari on the coast of Northern Ireland in 2008. In both incidents, fatigued officers were on watch duty. In the first case, the watch-keeping officer missed a course alteration due to impaired performance caused by fatigue. In the second case, the officer of the watch fell asleep shortly after taking over the midnight watch. These accidents resulted in severe consequences, including environmental damage, property loss, and the loss of innocent lives (Laurent *et al.,* 2021).

Despite the implementation of more stringent measures and regulations, a recurring pattern of accidents involving fatigue continues. Examples include grounding the Bahamas-flagged Crete Cement on the south-eastern tip of Aspond Island in 2008 and the Chinese registered bulk carrier Shen Neng 1 on Douglas Shoal in 2010. Investigations into these incidents once again identified fatigue as a significant factor contributing to the casualties. This consistent pattern underscores the pressing need for addressing seafarer fatigue to enhance maritime safety and mitigate the associated risks (Parlov, 2023).

Another study conducted by the US Coast Guard Research and Development Centre defines fatigue as a leading contributor to 16% of vessel accidents and 33% of onboard. Additionally, a study by Great Britain's Department of Transportation, which examined 1,647 collisions, groundings, and near-collisions occurring between 1994 and 2003, asserts that "A third of all groundings involved a fatigued officer alone on the bridge," emphasizing the troublesome connection between fatigue and accidents (Çakir, 2019).

Moreover, other sources reveal that fatigue is the primary cause in 11% to 23% of all reported collisions. According to the same source, this percentage might be even higher due to underreporting of fatigue-related cases (Houtman *et al.,* 2005). Similarly, the detrimental impact of fatigue on human alertness has been identified as the primary cause of numerous accidents involving Coast Guard ships in the USA, with "70% of CG personnel studied exhibiting signs of compromised alertness". Underlining the significance of fatigue in maritime accidents, the Japanese Maritime Research Institute suggests that the lack of alertness due to fatigue contributes to approximately 53% of marine casualties in the categories of collisions and stranding.

To understand maritime accidents caused by fatigue, it is crucial to investigate the time periods when accidents are most likely to occur. Several studies on this issue have indicated that the time between 00:00 and 00:06 hours is the riskiest period for accidents. As our understanding of fatigue and its effects on human performance has increased, there has been an increasing recognition of the hazards that operator fatigue poses to marine safety. For example, in 2003 the United Kingdom's Marine Accident Investigation Branch (MAIB) investigated the grounding of a general cargo ship [1], concluding that the chief officer had fallen asleep, sometime between 0405 and 0415 (local time) while on watch and alone on the bridge. It then conducted a study of vessel bridge watchkeeping to determine the extent to which fatigue, among other issues, affected marine safety [2]. The study examined all collisions, groundings, contacts, and near collisions that had occurred in the United Kingdom between 1995 and 2003. Investigators found that "a third of all the groundings involved a fatigued officer alone on the bridge at night (p. 3)." In the United States, the National Transportation Safety Board investigated three major fatigue-related accidents within a six-year period from 1980 through 1995 (Barry Strauch, 2015)

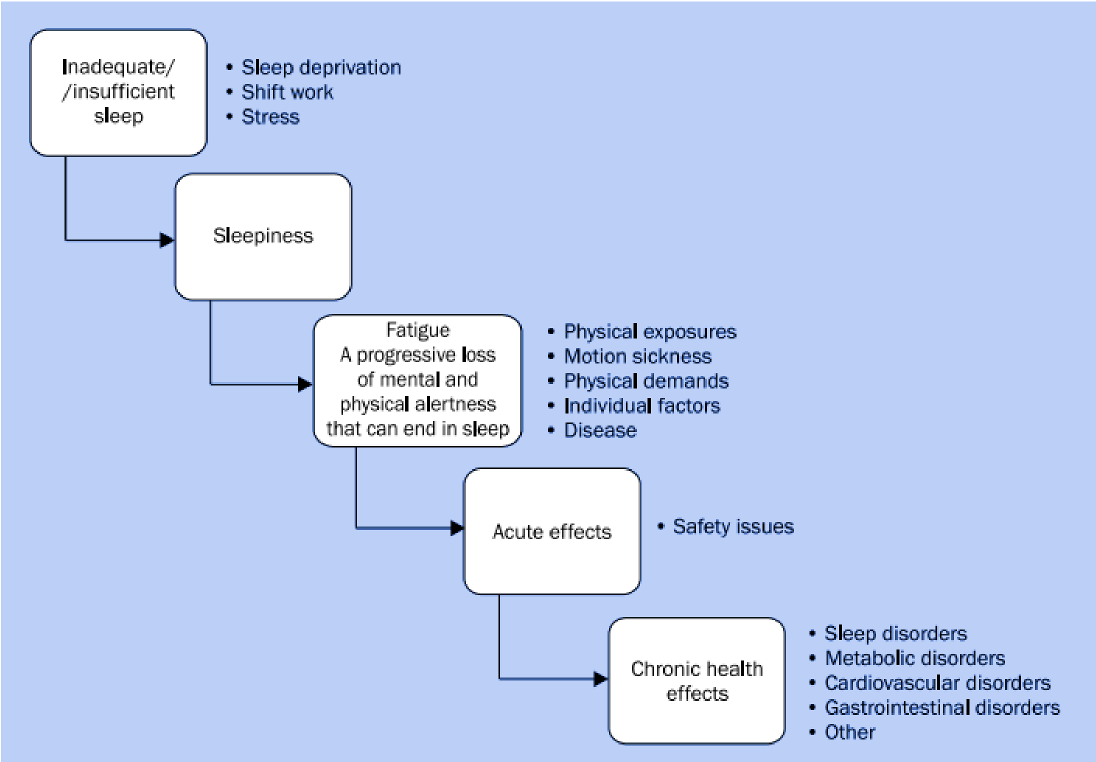


Figure 2. 8 Key determinants and outcome of fatigue (J. Jepsen e*t al.,* 2015).

More recently, a series of exceptional accidents have occurred due to fatigue. Among these are the incidents involving the ship Jambo in 2003 off the coast of Scotland and the sinking of the tug Thomas Herbert in 2004 off the shore of New York. One thing connected both incidents: the officer in charge of watch operations was tired. Due to fatigue-related performance impairment, the watchkeeping officer in the Jambo case failed to notice a course modification. Five sailors tragically lost their lives in the Thomas Herbert case when the watchkeeping seafarer fell asleep from a hard job and tiredness. In the instance of the Jambo event, these mishaps resulted in property loss and environmental harm, while in the second occurrence, innocent lives were lost. Consequently, all these cases emphasize fatigue's crucial role in maritime casualties worldwide.

2.18 Depression and Suicide

Fatigue General findings from studies on seafarers' mental health and well-being reveal contrasting trends. On one hand, there is a prevailing perception that the overall mental health of seafarers is relatively stable and positive. Reports such as The Manpower Report indicate that a clear majority of surveyed seafarers expressed satisfaction, happiness, and high levels of contentment. A 2012 study by Oldenburg et al. (2013) on stress and burnout syndromes found that the burnout risk among seafarers appeared to be moderate compared to most onshore occupations, despite seafaring being recognized as a demanding profession. Similarly, Besikci et al. (2016) found that self-reported fatigue and distress levels were not notably pronounced among seafarers. Additionally, the low rate of medical repatriation is considered a sign of good mental health among seafarers. For instance, in a study of 388,963 seafarers from the Philippines over a 5-year period, Abaya e*t al.* (2015) reported that only a small percentage had been repatriated, and a mere 1.8% of these repatriations were due to psychological or psychiatric issues, indicating that a very small proportion of seafarers experience mental health concerns that necessitate returning home while at sea. These results imply that there isn't any conclusive evidence linking seafarers to a higher risk of depression, even in spite of the risks and hazards of their line of work.

However, there are reports that present a contrasting view. The International Transport Workers' Federation Seafarers' Trust survey, for example, found that a significant percentage of seafarers knew colleagues who had considered suicide, with the percentage varying by home country. Furthermore, half of the respondents in this survey reported frequently or sometimes feeling anxious, depressed, and hopeless while at sea. The Women Seafarers' Health and Wellbeing Survey (Stannard *et al.,* 2015) identified stress, anxiety, and depression as the second most significant health issue for female seafarers. These findings are supported by multiple studies on fatigue, which consistently reported that seafarers experienced fatigue and sleep deprivation (Allen *et al.,* 2008). In addition, a study by Hjarnoe and Leppin (2014) indicated that seafaring was associated with a lack of positive health behaviors (such as physical exercise) and the presence of negative ones (such as smoking).

The overall picture is complicated because different research has shown conflicting results on sailors' mental health and wellbeing in recent years. A deeper examination of the issue reveals that various factors influence seafarers' mental health, and the specific circumstances, ranks, and types of voyages play a significant role. Looking at suicide rates from the late 1970s to the early 2000s, Roberts and Marlow (2005) concluded that suicide risks were strongly associated with the rank of the seafarer, with nearly 90% of suicides occurring among ratings and catering crew. Furthermore, Large deep-sea ships accounted for almost 87% of all suicides, indicating that journey type and rank have been important factors in determining the suicide rates of seafarers.

2.18.1 Rank

Two studies conducted by Oldenburg et al. (2009, 2013) yielded some unexpected findings regarding the stress levels among seafarers of different ranks. Their primary conclusion was that, with the exception of galley staff, officers appeared to be the most stressed rank of seafarers. This elevated stress level was attributed to their "high responsibility for the crew and the ship and the constantly changing job demands, such as port clearance, district routes, and watch-keeping at sea (Abaya *et al.,* 2015). Their subsequent study further supported this conclusion, which revealed that officers spent considerably shorter periods on board (4.8 months compared to 8.3 months for ratings) but had significantly higher numbers of working hours. Correspondingly, officers more frequently reported experiencing higher stress levels due to time pressure (Roberts & Marlow, 2005).

In terms of rank, it would seem that, based on self-reported stress levels, officers are the group at the highest risk. This finding contrasts with a study by Carotenuto et al. (2012), which found that ratings and non-officers were more susceptible to high-stress levels than officers. However, it is worth noting that the latter study used data from earlier periods. The relationship between rank and stress or "burnout" appears to have evolved over the past decade, with officers now being more vulnerable to stress than ratings. This observation is supported by Allen et al. (2008), who reported that 61% of officers frequently felt affected by fatigue. On the other hand, a study by Thomas et al. (2003) focused on the impact of seafaring on seafarers' spouses and families. It found that officers' families had better relationships with the officers due to their longer leave periods, allowing them to spend more time at home. Consequently, when comparing seafarers across ranks, the patterns are mixed: officers experience more work-related stress but also appear to have stronger family and spousal relationships because of their shorter time on board.

2.18.2 Social Isolation

The shorter periods that officers spend at sea and their effect on relationships, as previously discussed, can be expected to lead to reduced social isolation. This contrasts with the findings that a significant percentage of registered suicides between 1976 and 2002 occurred on deep-sea ships. Roberts and Marlow (Roberts & Marlow, 2005) argue that seafarers on deep-sea trading vessels are often continuously at sea for weeks or months, exposed to socially and professionally isolated conditions. Recent reductions in ship crewing numbers and extended separation from their families exacerbated the situation. More recent publications align with this pattern. In surveys listing the biggest stressors on board, separation from families was consistently reported as a major concern, ranking higher than other factors such as time pressure and long working days. "Time away from home," which was cited as the main drawback of sailing by more than 50% of respondents, was the most important factor inspiring seafarers to resign from their occupations. These studies provide some evidence, if limited, that sailors' mental health is indeed negatively impacted by being away from friends and family, with deep-sea vessels being more vulnerable to this effect.

Feelings of social isolation are exacerbated by spending months away from home and having few communication chances; this is a problem that several research specifically address. The importance of social isolation as a threat to mariners' mental health is further supported by data. One such sign is the demand for better connectedness among seafarers. 76% of participants in the 2014 Futurenautics Crew

Communications Survey said that improved internet connectivity was the most wanted on-board amenity. Ninety percent of participants in the 2016 ITF Seafarers' Trust study considered Internet connectivity to be the most important port-based humanitarian provision. Similar concerns about increased connectedness were expressed in The Manpower Report, albeit with a lesser priority than other grievances and preferences of seafarers.

The effect of seafaring on the families of those who sail. It was discovered that a seafarer's family life may suffer greatly depending on the duration of their contract and the amount of time they spend at sea. Longer contract lengths made it more difficult for spouses to maintain intimate and emotional interactions, and they reported feeling lonely during the seafarers' absence.

The available evidence suggests that spending extended periods at sea and away from home can have a negative impact on seafarers' mental health. Not only is there direct evidence through self-reported stress levels, but there are also other indications, such as Haka et al. (2011) study on motivational factors and the importance of connectivity. The advancement of communication technology in the last decade may have reduced the distance between seafarers and their spouses, family, and friends. For example, Tang (Tang, 2009) noted in 2007 that the Internet had become a convenient means for seafarers and their partners to stay in contact and for seafarers' partners to build a community. It is doubtful whether access to online forums and websites has diminished since then. While all types of seafarers can experience isolation, the evidence suggests that time at sea is a significant exacerbating factor, making it relevant to discuss social isolation and deep-sea voyages together.

2.18.3 Gender

Globally, women make up only 1-2 percent of seafarers. Anxiety, stress, and depression rank second among women sailors' most commonly reported health concerns, after back and joint discomfort, according to the women's health and wellbeing study. While melancholy and anxiety seem to be more evenly distributed, the incidence of reported back and joint pain differs depending on the type of employment and ship. This suggests that women seafarers' health may be less affected by the ship type they work on than their male counterparts. However, when comparing women seafarers' experiences of anxiety, stress, and depression with those of male seafarers, it is important to recognize that women tend to be more predisposed to reporting these symptoms in various settings (Stannard *et al.,* 2015; Thomas *et al.,* 2003).

Women who work at sea also report experiencing discrimination based on their gender, which can take many different forms. Examples include sexual harassment and false assumptions about their ability to perform. Due to prejudices held by certain employers, who think that having women on board could cause sexual tension and envy and lower crew morale, women seafarers also frequently struggle to secure and keep jobs. It makes sense that women who work at sea would have greater rates of depression and suicide than women in less male-dominated fields, given the prejudice and discrimination they frequently face.

2.18.4 Multinational and multicultural

Over the past 25 years, there has been an increase in the number of multilingual and multicultural ship crews. However, there is limited information regarding the potential contribution of these changes to seafarers' depression and suicide. There is one study that provides data on suicide among seafarers from some Asian countries, along with a related study on the Hong Kong fleet, both reflecting the situation in the late twentieth century. Nielsen D (1999)

One study found that cross-cultural communication on board tends to be more successful in terms of interaction and outcomes when seafarers share cultural similarities, whereas it is less successful when they are culturally distant from each other. Cultural distance between seafarers is a significant factor contributing to stress and can result in difficulties in communication and building relationships on board. An important indicator of cultural distance is variations in pronunciation and usage of

Maritime English. (Ioana VR, 2013). Similarly, Alfiani (2010) suggests that there is a "cultural adjustment period" during which seafarers may experience mental pressure and psychological constraints due to not understanding the cultural boundaries with their crewmates. Speaking one's mother tongue in such situations can lead to suspicion among non-speakers of that language, potentially contributing to loneliness and unsatisfying social relationships, which are potential risk factors for depression and suicide. Furthermore, the importance of "soft" social skills for seafarers enables them to navigate misunderstandings and potential conflicts between people from different cultures. Cross-cultural conflicts may arise from differences in values, understandings, and languages, which can obstruct the development of positive relationships. Although topics such as language and culture are considered relevant to understanding seafarers' depression and suicide, their actual impact has yet to be fully investigated (Mellbye & Carter, 2017; Stannard *et al.,* 2015; Tang, 2009).

2.19 Research Gap

Although there has been an increase in empirical study on fatigue among maritime sector personnel in the last two decades, there is still a dearth of thorough studies on the fatigue level of crews operating bunker tanks; in fact, no paper has been located on this topic.

2.19.1 Insufficient Focus on Bunker Crew Fatigue in Singapore

The marine industry is complicated, with numerous roles and responsibilities, each with its own challenges and stressors. Despite the fact that exhaustion in the maritime sector has been extensively studied, there is a deficiency in the literature on fatigue with reference to bunker workers operating in the Singaporean maritime environment. Bunker crews play an important part in the sector since they are in charge of fuelling vessels, a task that presents unique problems and working conditions. Existing research frequently takes a broader approach, focusing on seafarers or broader categories of marine personnel, and may not delve into the specific dynamics and complexities of bunker crew employment. As a result, the research fails to effectively address the various variables and pressures that bunker operators in Singapore face, perhaps leading to a lack of focused solutions to alleviate their weariness.

Fostering the well-being of bunker personnel in Singapore and ensuring the safe and effective operation of maritime vessels in the area depend on comprehending and addressing the unique challenges they confront. By focusing only on this particular group, the study aims to provide insight into their particular problems and help develop a more focused and successful fatigue management plan for the Singaporean marine industry.

2.19.2 Inadequate Understanding of Factors Contributing to Fatigue.

While fatigue is a well-documented issue, the particular factors contributing to fatigue among bunker crews in the Singaporean setting have not been thoroughly investigated in the available literature. Fatigue is a multidimensional problem influenced by various physical, psychological, and environmental elements, all of which can differ dramatically depending on the individual maritime role and operation setting. Bunker personnel in charge of the high-stakes task of refueling vessels are expected to face distinct stressors and obstacles that have not been properly investigated. These could include the physically demanding nature of their profession, long work hours, inconsistent shift patterns, exposure to environmental stressors, and the physical demands of handling fuel transfer equipment. The available research lacks a detailed examination of these contributing elements, which impedes the development of focused interventions and mitigation techniques. It is difficult to apply effective strategies to alleviate weariness and improve the well-being of bunker personnel without a good understanding of the specific stressors they confront.

The study attempts to fill a research vacuum by providing a complete assessment of the contributing factors to fatigue among bunker personnel in the Singaporean maritime industry. This will not only add to the source of information about fatigue in the marine sector, but it will also allow for the development of more specific and targeted tactics to combat fatigue and improve the overall working conditions and safety of Singaporean bunker workers.

2.19.3 Lack of Current Data on Fatigue Levels.

The existing literature on marine fatigue may not provide current and up-to-date statistics on the degrees of fatigue experienced by Singapore bunker workers. This study gap is especially important because the nature of labor and environmental factors impacting fatigue might change over time. Understanding current fatigue levels is critical for a number of reasons. For starters, it serves as a baseline for evaluating the efficacy of any fatigue-reduction therapies or tactics. It isn't easy to estimate precisely the impact of these measures without current data.

Second, like many other industries, the marine business is vulnerable to changes in rules, technologies, and operational procedures. These changes may have an immediate or indirect impact on bunker personnel's working conditions and fatigue levels. A lack of current information can stymie adapting industrial practices and laws to new difficulties. Furthermore, the COVID-19 epidemic has presented new pressures and hurdles to the marine industry, influencing crew rotations, shore leave access, and general working conditions. The rejoining of the rotational crew on the same vessel was hampered, and the crew couldn’t go to shore leave due to human movement control due to the pandemic situation. The influence of such unforeseeable events on bunker crew fatigue levels may not be adequately established in the available literature.

As a result, the research's goal of conducting a comprehensive study of present fatigue levels among Singapore bunker operators is critical. This evaluation not only serves as a useful reference point for understanding the scope of the problem, but it also acts as the foundation for developing treatments and strategies tailored to the current challenges these crews confront.

2.19.4 Absence of Customized Mitigation Strategies for Bunker Crews.

Numerous initiatives have been made to combat fatigue and improve the well-being of its staff, including seafarers and other maritime workers. On the other hand, existing research frequently gives generalized fatigue mitigation measures that are broadly relevant to many tasks within the sector. These techniques may not sufficiently address the unique problems and operational circumstances experienced by Singapore bunker workers.

Bunker workers perform an important part in the marine supply chain, dealing with the high-pressure duty of fuel transfer, sometimes in extreme weather circumstances and aboard a variety of vessels. Their tasks and pressures are unique and may necessitate customized techniques to manage and reduce fatigue properly. Due to a lack of sector-specific fatigue mitigation measures for bunker personnel, these vital workers may be left without necessary support and solutions. This disparity is significant because tackling weariness among bunker operators is critical for the well-being of bunker crews and the safety & efficiency of Singapore's maritime operations.

The research's goal of developing evidence-based suggestions and mitigating strategies geared specifically to bunker personnel operating in the Singaporean marine context is a significant contribution. The study intends to bridge this research gap and give practical solutions that can considerably enhance the working conditions, safety, and general quality of life for these crew members by understanding the unique issues faced by bunker workers and developing customised techniques.

2.19.5 Limited Integration of Working Conditions and Environmental Stressors

The marine fatigue literature frequently explores individual elements leading to fatigue in combination. While research investigates topics such as working conditions, shift patterns, and environmental stresses independently, few studies incorporate these components, particularly when it comes to Singapore bunker workers. Bunker operators have a unique set of pressures that go beyond the standard causes that contribute to fatigue in the marine industry. Their employment entails handling dangerous items, working in restricted areas, and potentially being exposed to environmental stressors such as extreme weather and vessel movement. When these elements are combined with the demands of irregular shift patterns and extended working hours, a complicated interplay of effects on fatigue levels results. A lack of studies thoroughly exploring how these elements combine and impact the fatigue levels of bunker operators can stymie the development of effective mitigating techniques. It is essential to comprehend the cumulative effects of different stressors on crew members in order to address fatigue efficiently.

The research goal of considering and analysing the relationship between working circumstances and environmental stressors specific to Singapore bunker workers is a significant contribution. The project intends to provide a more comprehensive view of the issues these crew members encounter by taking an integrated approach to studying these aspects and, as a result, develop more focused and effective techniques for minimizing fatigue and increasing overall safety and well-being. This technique can potentially fill a large vacuum in the existing literature, which frequently overlooks these critical relationships.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explores the entire research process, from data collection to analysis. To gather enough data and knowledge to answer every research question is the goal. To accomplish the objectives of this research, several methods have been employed. This chapter will provide a detailed account of the methodologies used to complete this research. Mixed methods (Qualitative and Quantitative) are utilized in this research in alignment with the research objectives. The initial stage involves a comprehensive study to grasp the factors contributing to crew fatigue on board vessels. The second stage, aimed at achieving the research objectives, includes a survey conducted among the crew of Singaporean bunker tankers. Data analysis is performed to determine the significance of factors contributing to fatigue among bunker tanker vessel crews. In the third and final stage, recommendations are considered to mitigate fatigue on board bunker tankers plying in Singapore, based on the analysis of data from the second stage and with the consultation of the subject matter experts. These proposed recommendations are expected to alleviate fatigue across the tanker fleet, leading to economic and environmental benefits by reducing accidents and casualties in the industry. Furthermore, the data for this research is derived from responses to a survey questionnaire from seafarers on bunker tanker vessels. The questionnaire was administered using Google Forms, and the link was distributed to respondents via email, social media, and through the management company to their seafarers. Thus, this chapter offers a more detailed description of the research methods employed, focusing on the quantitative approach.

3.2 Sample Design

A crucial component of research is sample design, which outlines the process for choosing a representative sample from a specific population. It includes the method by which things are selected from the population and could also include the sample size. The 4,500 Singapore bunker tanker crew members who are now serving on board or on vacation make up the population under examination in this research. The representation basis (sampling method) and element selection (sampling method) are used to classify different sample designs.

Both probability and non-probability sampling are possible for the sample in terms of representation. Random selection is a necessary component of probability sampling, while non-probability sampling does not rely on it. The sample can be either unrestricted or restricted based on element selection criteria. Probability sampling, often referred to as random or chance sampling, is characterized by equal and positive probabilities of selection for every section of the population, ensuring that the sample represents the entire population. Major probability sampling procedures include:

Simple Random Sampling: Each member of the population is assigned a number, and a sample of a specified size is drawn using a random number chart or a lottery system. It is relatively straightforward but may miss small subgroups. (Kothari,1990)

Systematic Random Sampling: The entire population is numbered, and every nth number (e.g., every 6th or 12th number) is selected to create the sample. This method is easy to implement and more likely to represent different subgroups. (Kothari,1990)

Stratified Random Sampling: The population is divided into homogeneous groups (strata) based on a particular characteristic, and random samples are drawn from each group. This approach allows for representative samples from each subgroup.

Cluster/Multistage Sampling: Samples are selected through various stages and are often used for large-scale surveys across extensive areas. For this study of seafarers on Singapore bunker tanker crews, a Probability sample design is employed, specifically, a Stratified Complex Random Sampling Design. (Kothari,1990)

Stratified Complex Random Sampling Design: When a population is not homogeneous, stratified sampling is applied to create a more representative sample. The data set is divided into sub-data sets (strata) that are more homogeneous, and items are selected from each stratum to constitute the sample. This method provides more precise norms for each stratum and, by estimating each component more accurately, results in a better estimate of the whole population. (Kothari,1990)

Non-probability sampling: Non-probability sampling is a sampling procedure that does not afford any basis for estimating the probability that each item in the population has of being included in the sample. Non-probability sampling is also known by different names such as deliberate sampling, purposive sampling and judgement sampling. In this type of sampling, items for the sample are selected deliberately by the researcher; his choice concerning the items remains supreme. In other words, under non-probability sampling, the organisers of the inquiry purposively choose the particular units of the universe for constituting a sample on the basis that the small mass that they so select out of a huge one will be typical or representative of the whole. For instance, if the economic conditions of people living in a state are to be studied, a few towns and villages may be purposively selected for intensive study on the principle that they can be representative of the entire state. Thus, the judgement of the organisers of the study plays an important part in this sampling design. In such a design, the personal element has a great chance of entering into the selection of the sample. The investigator may select a sample that will yield results that are favorable to his point of view, and if that happens, the entire inquiry may be vitiated. Thus, there is always the danger of bias entering into this type of sampling technique. But if the investigators are impartial, work without bias and have the necessary experience to make sound judgement, the results obtained from an analysis of a deliberately selected sample may be tolerably reliable. However, in such a sampling, there is no assurance that every element has some specifiable chance of being included. Sampling errors in this type of sampling cannot be estimated, and the element of bias, great or small, is always present. As such, this sampling design is rarely adopted for large inquiries of importance. However, in small inquiries and research by individuals, this design may be adopted because of the relative advantage of time and money inherent in this method of sampling. Quota sampling is also an example of non-probability sampling. Under quota sampling, the interviewers are simply given quotas to be filled from the different strata, with some restrictions on how they are to be filled. In other words, the actual selection of the items for the sample is left to the interviewer's discretion. This type of sampling is very convenient and is relatively inexpensive. However, the samples selected certainly do not possess the characteristics of random samples. Quota samples are essentially judgement samples, and inferences drawn on their basis are not amenable to statistical treatment in a formal way. (Kothari,1990)

In this study, seafarers are not homogeneous based on their roles, so they are subdivided into groups according to their rank on board to obtain data for similar positions in bunker tanker crews. A non-probability sampling technique is used for this study. When calculating sample size, factors such as a 95% confidence level, 0.5 standard deviation, ±10% margin of error, and 1.96 Z-score at the 95% confidence level are taken into account.. The sample size can be calculated as:

$$P = \frac{(Z-score)^2 \times SD \times (1-SD)}{(Margin\ of\ error)^2} \qquad (3.1)$$

$$P = \frac{(1.96)^2 \times 0.5 \times (1-0.5)}{(0.10)^2}$$

$$P = \frac{0.9604}{0.01}$$

$P \approx 96.04$

Hence, 97 respondents are required for this survey to ensure a representative sample.

3.3 Data Collection

The survey approach used in this study is questionnaire-based data collection. The questionnaire is an important tool for getting information from seafarers, particularly those serving on Singapore bunker tanker crews, and the survey employs a non-probability Sampling Design.

The initial step in data gathering was to design a well-structured questionnaire. To ensure the success of this survey, significant care was taken in creating it, from the overall format and question sequence to the formulation and wording of individual questions. The questionnaire was painstakingly crafted to be precise, useful, and free of bias. It used a systematic order of questions, with general queries coming before particular ones, to optimize the results. A brief, engaging introduction summarizing the survey's objectives and introducing the investigators and surveyors was included in the questionnaire. Demographic questions such as age and rank were placed at the start. Controversial or potentially off-putting subjects were carefully placed near the conclusion to urge participants to provide genuine responses.

The questionnaire's questions were clear and succinct, with no possibility for bias. Questions were carefully written, both favourably and negatively, to reduce response bias. To guarantee clarity and brevity for the replies, double-barrelled questions, which combine many topics into one, and double negatives were avoided. Leading questions that could affect responses were also avoided.

Following the development of the questionnaire, it was rigorously validated by a team of researchers and industry experts, including Captain Anam Chowdhury; Master Mariner, Captain Noor Apandi Bin Osnin; Sr. Lecturer, UMT, Captain Ghazi Abu Taher; Sr. Marine Superintendent, Stellar Ship Management Pte Ltd and Mar. Engr Latiful Islam, Sr. Technical Superintendent, Komaya Shipping, to verify its validity and reliability. Validity checks verified whether the questionnaire accurately measured the variables it was designed to measure, while reliability tests assessed the instrument's ability to produce consistent results. A number of criteria were used to assess the validity of the questionnaire, including construct, criterion, face, and content validity. Based on the expert opinions of researchers and face validity assessed the questionnaire's appearance and perceived usefulness in fulfilling the research objectives.

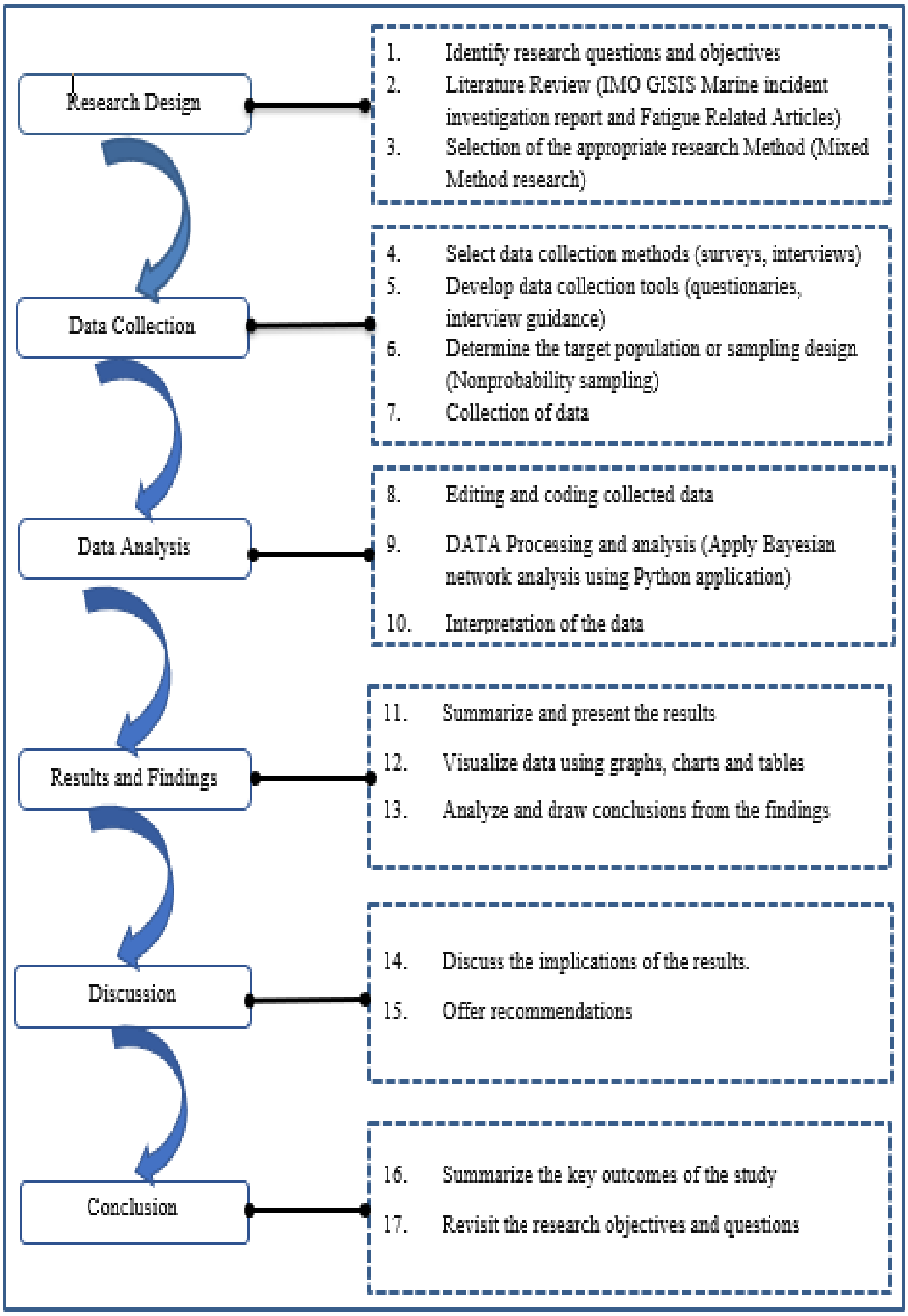


Figure 3.1 Research methodology flowchart.

Seafarers were given access to the questionnaire using an online platform, Google Forms, during the actual data gathering process. The poll link was sent via email to reach the Singapore-registered tanker vessel seafarer community. This strategy provided an expedient manner of gathering replies and allowed the study to include a diverse spectrum of seafarers.

3.3.1 Data Collection Through Interview Method

Data is gathered through interviews, in which oral stimuli are presented and oral responses are obtained. Personal interviews and, if practical, telephone interviews can be used to carry out this strategy.

(a) Personal Interviews: The personal interview method entails an interviewer, a person designated to conduct the interview, posing questions, generally in a face-to-face interaction, to the other person or persons involved. While the interviewee may occasionally pose questions, the interviewer typically initiates the interview and gathers the required information. Personal interviews are conducted in a structured manner, making them structured, utilizing predetermined questions and highly standardized recording techniques to maintain consistency and accuracy. It is conducted with the industry experts for fatigue contributing factors used for the survey questionnaire.

(b) Telephone Interviews: This data collection method involves contacting respondents via telephone. It is conducted with the industry experts for fatigue contributing factors used for the survey questionnaire.

As a data collection method, interviewing is the process of asking questions and obtaining responses from participants involved in a study. Interviews can take various forms, including individual face-to-face interviews and group interviews conducted in a face-to-face setting or remotely through online applications. The medium for conducting interviews can be face-to-face, over the telephone, or through remote online platforms. Interviews can be categorized into different types:

Structured Interviews: These interviews follow a predetermined set of questions and a standardized approach for recording responses. Semi-Structured Interviews: These interviews combine predetermined questions with the flexibility to explore topics in greater depth or in response to participant responses. Unstructured Interviews: In unstructured interviews, there are no predetermined questions, allowing for open-ended discussions and exploration of various topics. Face-to-Face Interviews: These interviews are conducted in person, providing a direct and personal interaction between the interviewer and the interviewee. Interviews offer valuable insights and data, making them a versatile method for gathering information on the survey questionnaire and understanding the perspectives and experiences of participants in a study.

3.4 Survey Layout

Furthermore, the design and layout of the questionnaire facilitate the collection of reliable responses. The questionnaire was printed on coloured paper from Universiti Malaysia Terengganu (UMT), with each section of questions assigned a distinct colour to enhance professionalism and presentation. Additionally, the questions were organized clearly and systematically.

3.5 Cover Letter

The shape and content of the cover letter are considered crucial parts of survey administration because they can considerably boost the response rate (Frohlich, 2002). A one-page letter from the University Malaysia Terengganu (UMT) was written on letterhead. The cover letter first presented the questionnaire and underlined the benefits and goals of the research for them as practitioners. The cover letter communicated the researcher's identity and connection to the donors. Third, the cover letter explained that their responses would be totally anonymous and destroyed after the data analysis procedure was completed, as well as addressing the ethical considerations of this research.

3.6 Ethical Consideration

In this study, it had been expected that a few ethical factors would be carefully considered before the survey procedure. Regarding the ethical concerns of Kumar (2011), the following measures were used to acquire information from the subjects.

3.6.1 Gathering information

Before any data or individuals were recruited in the survey study, informed consent was acquired from the subjects. All participants were advised that their participation was entirely voluntary and that individuals might withdraw from the research at any time. The consensus was gathered during the respondents' approach to the face-to-face survey and once before they participated in the study.

3.6.2 Seeking consent

Before obtaining consent, the researcher ensured that all participants were given full disclosure about the type of information collected, the motivation behind the gathered information, the purpose of the questionnaires, how they were to participate in the study, and the direct or indirect impact the study would have on them.

3.6.3 Sensitive information

All participants were treated secretly in order to protect the collected data. All respondents are aware of the fundamental core values of data privacy and confidentiality. Since this research evaluates fatigue level, it is essential that business entities will be challenged about their reputation. Each participant was asked for limited but appropriate sensitive information. Furthermore, all data acquired was totally secret. The researcher did not provide the person or name specifics of any organizations in any of the studies or publications resulting from this research.

3.7 Chapter Summary

To put it succinctly, the methodology chapter functions as the foundational plan for the study, delineating the methodical strategy implemented to examine the extent of fatigue experienced by crew members aboard bunker vessels registered in Singapore. The chapter begins with an extensive exposition of the research design, placing particular emphasis on a multi-stage procedure. The initial phase consists of gathering data from the Global Integrated Shipping Information System (GSIS) website of the International Maritime Organization (IMO), which provides a comprehensive view of fatigue related incident across the entire industry. The last phase involves gathering primary data using a questionnaire survey distributed to seafarers working on bunker vessels registered in Singapore. In conjunction with this stage, a comprehensive Bayesian analysis is conducted, enabling a more nuanced comprehension of the various elements that contribute to fatigue. The statistical findings obtained from this investigation provide guidance in identifying significant physical and psychological stressors that impact the well-being of seafarers. In conclusion, the chapter concludes with the formulation of specific suggestions derived from the data analysis results. The following suggestions have been customised to tackle particular elements recognised within the distinct context of bunker vessels registered in Singapore. Their overarching objective is to alleviate fatigue and improve seafarers' well-being, security, and productivity in this industry. The methodology chapter serves to build a comprehensive and coherent structure for the research, ensuring that data collection, analysis, and suggestions are all presented logically and coherently.

CHAPTER 4

RESULTS

In the previous chapter, there was a detailed discussion about the analyses that have been conducted related to model measurement and construct measurement. This chapter discusses the results based on the study's research question. Finally, provides a statistical evaluation of the study. The chapter will begin with a replication of the study, followed by an overall discussion and conclusion of the analysis and results based on the research question. The next part is followed by an in-depth description of the study's theoretical and practical execution and contribution. Finally, the final section discusses the study's limitations and future recommendations.

4.1 Data analysis

The study aimed to investigate the levels of fatigue among seafarers and identify the contributing factors. A survey was administered to seafarers to conduct this analysis, assessing their fatigue levels. Several factors that could influence fatigue levels were considered, including:

4.1.1 Physical Stress

- This variable is influenced by factors such as overtime, rough sea conditions, vessel maintenance level, age of the vessel, and humidity at the Singapore port.

4.1.2 Psychological stress

- Factors such as Performance demand, shore leave facility, seafarer's individual and family issues, workload, and traffic density in navigation areas influence psychological stress.

4.1.3 Health condition

- Health conditions are affected by variables like illness, age, and diet.
- The diet variable is further influenced by drug use, caffeine intake, and alcohol consumption.

4.1.4 Ship Design

- Ship design is dependent on redundancy, level of automation, equipment reliability, and the physical comfort of the workplace.

4.1.5 Ashore Management Factors

- The governance of the management company influences the seafarers' fatigue. For example, Quality crew selection, Crew complement, Crew training, assistance from the company to the vessel's personnel, Crew contract period, and paperwork requirements.

4.1.6 Sleep and Rest Factors

- The quality of sleep and rest is influenced by factors such as rest break levels, quantity, and duration of sleep, as well as sleep-related disorders.
- Rest break levels depend on the length of break intervals.
- Quantity, quality, and sleep duration are further affected by the ship's motion, shift work and schedules, accommodation temperature, ship vibration, and noise levels.
- Circadian rhythms, jetlag, and unpredictable bunkering schedules can influence sleep disorders.

Data collection spanned four weeks, and following this phase, the data was processed using Python software to derive insights. Python has emerged as the preferred language for a wide range of data science applications, owing to its ability to integrate general-purpose languages with domain-specific languages like MATLAB seamlessly.

In Figure 4.1, the factors are referred to as nodes, with "Fatigue" serving as the parent node and the various influencing factors as child nodes. Notably, a majority of the crew members were found to have good health and normal sleep quality, and they were associated with ships having a normal design quality. However, an observation highlighted that certain seafarers experienced elevated physical and psychological stress levels, correlating with a higher degree of fatigue. The distribution of ashore management factors was noted to be varied, with some members experiencing good management practices while others did not. Figure 4.1 below provides a visual representation of the distribution of these factors among seafarers.

This study introduces a Bayesian Network model to assess fatigue levels among ship crew members. It encompasses diverse factors, including health quality, sleep quality, ashore management level, physical stress, psychological stress, and ship design quality. The Bayesian model offers a comprehensive approach to comprehending the fatigue levels of Singapore bunker barge crew members, unraveling the intricate relationships between these influencing factors. The model underwent training and validation using extensive survey data collected from Singapore Bunker barge crew members. Table 4.1 shows the short form used for different factors.

Table 4.1 Different factors and their short form.

Factors	Short form
Health quality/Health condition	**HQ**
Caffeine/Coffee intake	CI
Medicine intake	MI
Alcohol intake	AI
Diet quality node	DT
Illness Frequency	IF
Age Node	Ag
Sleep and Rest quality	**SRQ**
Ship motion node	SM
Shift work intensity/Shift work schedule	SWI
Ship Vibration	SV
Accommodation temperature	AT
Ship Noise	SN
Sleep Quality	SQ
Circadian Rhythm s	CR
Jetlag	JL
Bunkering Schedule Regularity	BSR

Sleep disorder	SD
Length of Break	LOB
Rest Break	RB
Psychological stress	**PXS**
Performance demand	PD
Shore Leave	SL
Traffic density	TD
Family issues	FI
Personal Problem	PP
Workload	WL
Physical stress	**PS**
Age of vessel node	AOV
Vessel maintenance	VM
Roughness of Sea	RS
Overtime	OT
Singapore Port Humidity	SPH
Ashore Management	**AM**
Crew Selection	CS
Crew Training	CT
Crew complement	CC
Shore management assistance	SMA
Crew Contract Period	CCP
Paperwork Requirements	PR
Ship Design quality	**SDQ**
Automation	ATM
Equipment reliability	ER
Physical comfort at work	PCW
Equipment Redundancy Level	SR
Fatigue (Target)	**F**

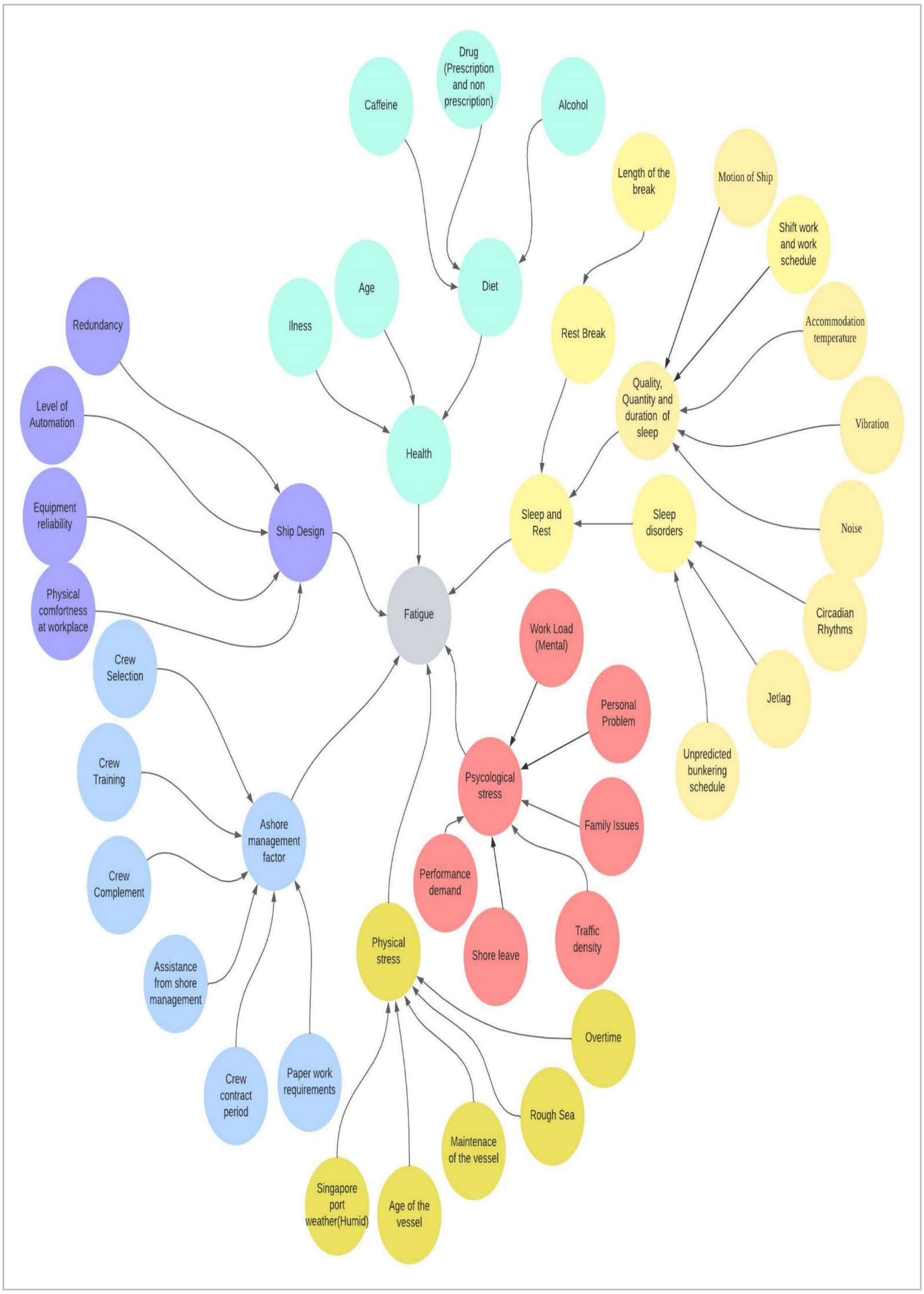


Figure 4.1 Visual representation of the distribution of these factors among seafarers.

4.2 Data Transformation

Data transformation from nominal to binary involves converting categorical variables into binary format, typically represented by 0s and 1s. In this specific case, where there are two scenarios, "Worst case scenario" and "Best case scenario," a simple nominal to binary conversion can be performed as follows:

Worst case scenario: Assign this category the binary value of 0.

Best case scenario: Assign this category the binary value of 1.

After applying this transformation, the data becomes binary, with 0 indicating the worst-case scenario and 1 indicating the best-case scenario. This conversion is commonly employed when dealing with categorical variables in machine learning or statistical analysis, where algorithms may require numerical input.

4.3 Structure of Bayesian model

The Bayesian Network model includes a wide range of nodes, each representing a different aspect of the complex system under discussion. Beginning with individual lifestyle considerations, nodes like Caffeine/Coffee Intake (CI), Medicine Intake (MI), and Alcohol Intake (AI) lay the groundwork for understanding individuals' physiological features. Moving on to health-related variables, nodes such as Illness Frequency (IF), Age (Ag), and the overall Health Quality/Health Condition (HQ) dive into the complex interplay between personal well-being and environmental circumstances.

Ship Motion (SM), Shift Work Intensity/Shift Work Schedule (SWI), Ship Vibration Level (SV), and other nodes give light on the particular issues faced by seafarers while navigating the marine milieu. Environmental factors such as Accommodation Temperature (AT), Ship Noise (SN), and Roughness of Sea (RS) are critical indicators of the impact of the maritime environment on persons. Sleep-related indicators like Sleep Quality (SQ), Circadian Rhythm (CR), and Jetlag (JL) help us appreciate the crucial importance of rest and the difficulties that irregular schedules offer. The operational parameters of Bunkering Schedule Regularity (BSR) and Length of Break (LOB) improve the model by emphasizing routine and rest times.

Psychological dimensions are addressed using nodes such as Psychological Stress (PXS), Workload (WL), and Family Issues (FI), providing insights into sailors' mental and emotional well-being. The maritime-specific variables provide context-specific information, such as Singapore Port Humidity (SPH), Age of Vessel (AOV), and Vessel Maintenance (VM). Overtime (OT), Physical Stress (PS), Crew Selection (CS), and Ashore Management (AM) are nodes that encapsulate work-related stressors and Shore Management Assistance (SMA). The latter, in particular, includes Crew Training (CT), Crew Contract Period (CCP), and Paperwork Requirements (PR), demonstrating shore management's varied role in assisting seafarers.

Ship Redundancy (SR), Automation (ATM), Equipment Reliability (ER), and Physical Comfort at Work (PCW) are technical elements that highlight the role of technology and infrastructure in seafaring. The Fatigue (F) node, in particular, encapsulates the study's core focus, functioning as the ultimate outcome measure influenced by a plethora of linked elements. The graphical depiction of the Bayesian Network vividly depicts the intricate web of relationships, giving a holistic framework for understanding and analyzing the numerous dynamics influencing seafarer fatigue. The Bayesian Network model is shown in Figure 4.2.

```
([('CI','HQ'), ('MI','HQ'), ('AI','HQ'), ('DT','HQ'), ('IF','HQ'), ('Ag','HQ'), ('SM','SRQ'), ('SWI','SRQ'), ('SV','SRQ'), ('AT','SRQ'), ('SN','SRQ'), ('SQ', 'SRQ'), ('CR', 'SRQ'), ('JL', 'SRQ'), ('BSR', 'SRQ'), ('SD', 'SRQ'), ('LOB', 'SRQ'), ('RB', 'SRQ'), ('PD', 'PXS'), ('S', 'PXS'), ('TD', 'PXS'), ('FI', 'PXS'), ('PP', 'PXS'), ('W', 'PXS'), ('SPH', 'PS'), ('AOV', 'PS'), ('VM', 'PS'), ('RS', 'PS'), ('OT', 'PS'), ('CS', 'AM'), ('CT', 'AM'), ('CC', 'AM'), ('SMA', 'AM'), ('CCP', 'AM'), ('PR', 'AM'), ('SR', 'SDQ'), ('ATM', 'SDQ'), ('ER', 'SDQ'), ('PCW', 'SDQ'), ('HQ','F'), ('SRQ','F'), ('PXS','F'), ('PS','F'), ('AM','F'), ('SDQ','F')])
```

Figure 4.2 Bayesian Network model nodes.

4.4 Nodal relationship based on Bayesian Network Structure

The nodal linkages inside the Bayesian Network structure reveal the complicated dependencies and probabilistic influences among many elements related to seafarer fatigue. Each node in the network represents a separate variable, and the directed connections between nodes indicate the probabilistic interactions that shape the intricate interplay within the maritime context. The framework describes how changes or variances in one feature might have a probabilistic impact on others, ultimately altering the overall end measure of Fatigue (F).

For example, the node 'Caffeine/Coffee Intake Degree' (CI) is linked to 'Health Quality/Health Condition Level' (HQ), meaning that the level of caffeine or coffee intake affects individuals' general health condition. Similarly, 'Medicine Intake Level' (MI) and 'Alcohol Intake Level' (AI) have probabilistic dependencies on HQ, demonstrating how these lifestyle habits contribute to mariners' overall health. The maritime-specific nodes, such as 'Ship Motion' (SM), 'Shift Work Intensity/Shift Work Schedule' (SWI), and 'Ship Vibration Level' (SV), are interconnected with 'Sleep Quality Level' (SQ), indicating that the conditions and challenges faced at sea have a probabilistic impact on the quality of sleep experienced by seafarers.

Psychological and workload-related nodes, such as 'Psychological Stress Level' (PXS), 'Workload Level' (WL), and 'Family Issues Level' (FI), are linked with 'Physical Stress Level' (PS), indicating a complex interplay between psychological and physical pressures. Furthermore, these psychological elements are linked to the 'Ashore Management Level' (AM), stressing the relevance of management practices in impacting seafarer well-being. The technical and operational nodes, such as 'Ship Redundancy Level' (SR), 'Automation Level' (ATM), and 'Equipment Reliability Level' (ER), share probabilistic relationships with 'Ship Design Quality Level' (SDQ). This demonstrates how the technical characteristics of a vessel can influence its overall design quality.

The structure also delineates dependencies between 'Health Quality/Health Condition Level' (HQ), 'Sleep Quality Level' (SQ), 'Psychological Stress Level' (PXS), 'Physical Stress Level' (PS), 'Ashore Management Level' (AM), and 'Ship Design Quality Level' (SDQ), with the ultimate outcome measure of 'Fatigue Level' (F). These dependencies highlight the multiple interactions and cumulative impacts of numerous influences on seafarer fatigue. Therefore, the Bayesian Network structure provides a comprehensive perspective of the probabilistic interactions among the diverse variables, providing significant insights into the nodal dynamics contributing to the seafarer tiredness phenomenon. Figure 4.3 provides the Nodal relationship based on the Bayesian network structure.

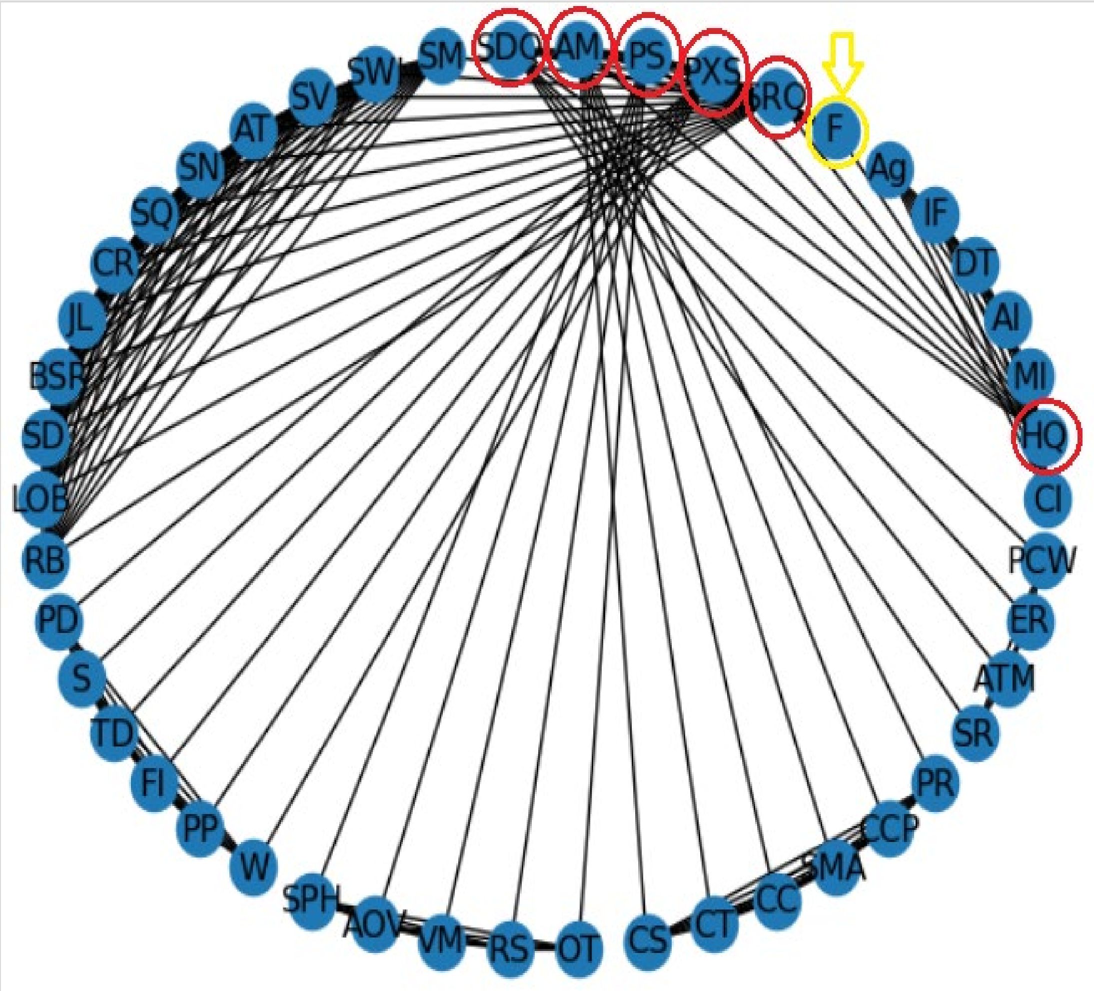


Figure 4.3 Nodal relationship based on Bayesian Network Structure.

4.5 Major Variable correlation matrix and heat map

The key variable correlation heat map becomes a critical tool in deciphering the complex web of relationships between critical components. The heat map helps us to discover patterns of correlation with variables influencing sleep quality, psychological stress, and general health issues when we delve into maritime-specific variables such as Ship Motion, Shift Work Intensity, and Ship Vibration Level. For example, the association between Ship Motion and Sleep Quality Level reveals the possible impact of maritime conditions on seafarers' rest. On the other hand, exploring the correlations between psychological stress levels and parameters such as workload levels and family issues levels provides insights into the connectivity of psychological well-being with work-related and personal components.

The heat map serves as a compass, drawing attention to data groups showing significant relationships. This is especially true given the multidimensional character of sailing, where environmental, psychological, and operational aspects all intersect. The implications go beyond identifying potential intervention areas or management techniques to minimize the effects of linked stressors on seafarer fatigue. Viewing these relationships with caution is critical, remembering that correlation does not indicate causation. The heat map serves as a jumping-off point for more in-depth investigations, guiding following analysis and contributing to a comprehensive understanding of the complex processes impacting seafarer weariness. Finally, the key variable correlation heat map becomes an invaluable tool, coinciding with the research goal of completely identifying and resolving the factors contributing to seafarers' weariness.

Figure 4.4 Correlation matric.

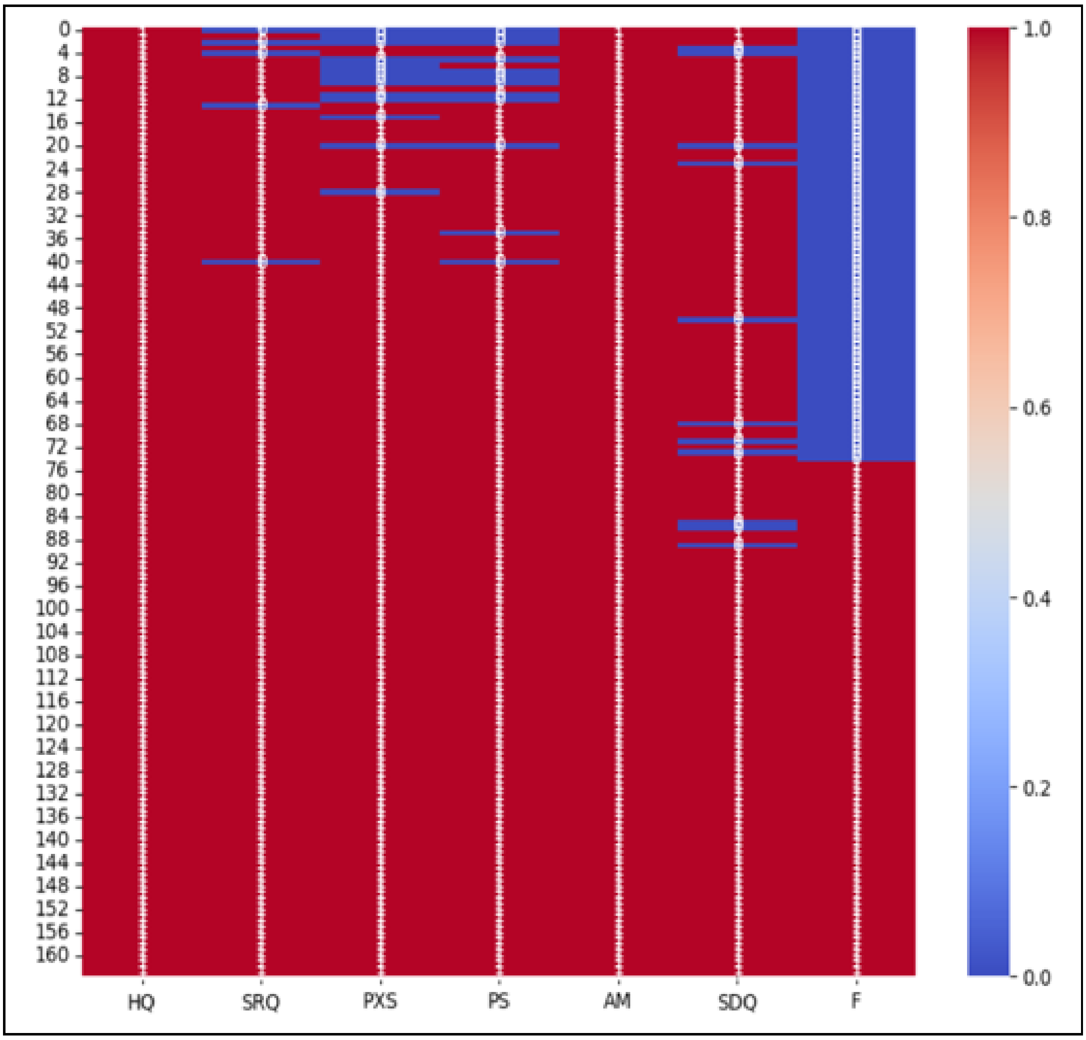


Figure 4.5 Heat map.

The correlation matrix, which emphasizes Psychological Stress Level (PXS) as having the greatest impact while implying zero impact for Ashore Management Level (AM) and Health Quality/Health Condition Level (HQ), as supported by the heat map, provides valuable insights into the potential contributors to seafarer fatigue. However, it is critical to recognize that these findings are dependent on the survey data.

The possibility of bias or data consistency within the survey's bounds raises serious concerns. The impact of variables like AM and HQ may look insignificant within the examined population, but this could be influenced by a variety of factors such as respondent demographics, survey design, or unique contextual characteristics during the researched era. Proposing additional studies with an emphasis on anonymity and respondent confidentiality to address this is a clever and sensible approach. Future surveys can give more candid insights into the impact of management practices (AM) and health conditions (HQ) on seafarer fatigue if respondents feel secure and comfortable delivering honest comments without fear of penalties. This method adheres to excellent principles in survey research by encouraging the collection of unbiased and honest replies. It also allows for a more in-depth knowledge of the complex links between management practices, health issues, and seafarer tiredness. The use of such methodologies improves the robustness and dependability of study findings, hence improving the overall quality of the examination into factors impacting seafarer well-being.

4.6 Feature Importance (Micro Level and Macro level)

The analysis of feature importance at both the micro and macro levels provides important understanding of the factors that influence seafarer fatigue. As seen in the figure 4.6, Bunkering Schedule Regularity Level (BSR) and Traffic Density Level (TD) emerged as key drivers at the micro level, coinciding with the broader categories of Sleep and Rest Quality Level (SRQ) and Psychological Stress Level (PXS), respectively. This micro-level comprehension emphasizes the importance of certain operational and environmental aspects in impacting seafarer well-being.

The second graph, which broadens the perspective to the macro level, emphasizes the importance of Psychological Stress Level (PXS) and Physical Stress Level (PS) as the top two drivers. This macro-level perspective encompasses broad pressures that may extend beyond specific operational situations. It confirms the importance of psychological and physical well-being in shaping overall fatigue in seafarers.

As a result of the convergence of results at both the micro and macro levels, the key determinants of fatigue are Sleep and Rest Quality Level (SRQ), Psychological Stress Level (PXS), and Physical Stress Level (PS). This correlation between survey data and real-life experiences underscores the analysis's robustness and places these parameters as major focal topics for interventions aimed at reducing seafarer fatigue.

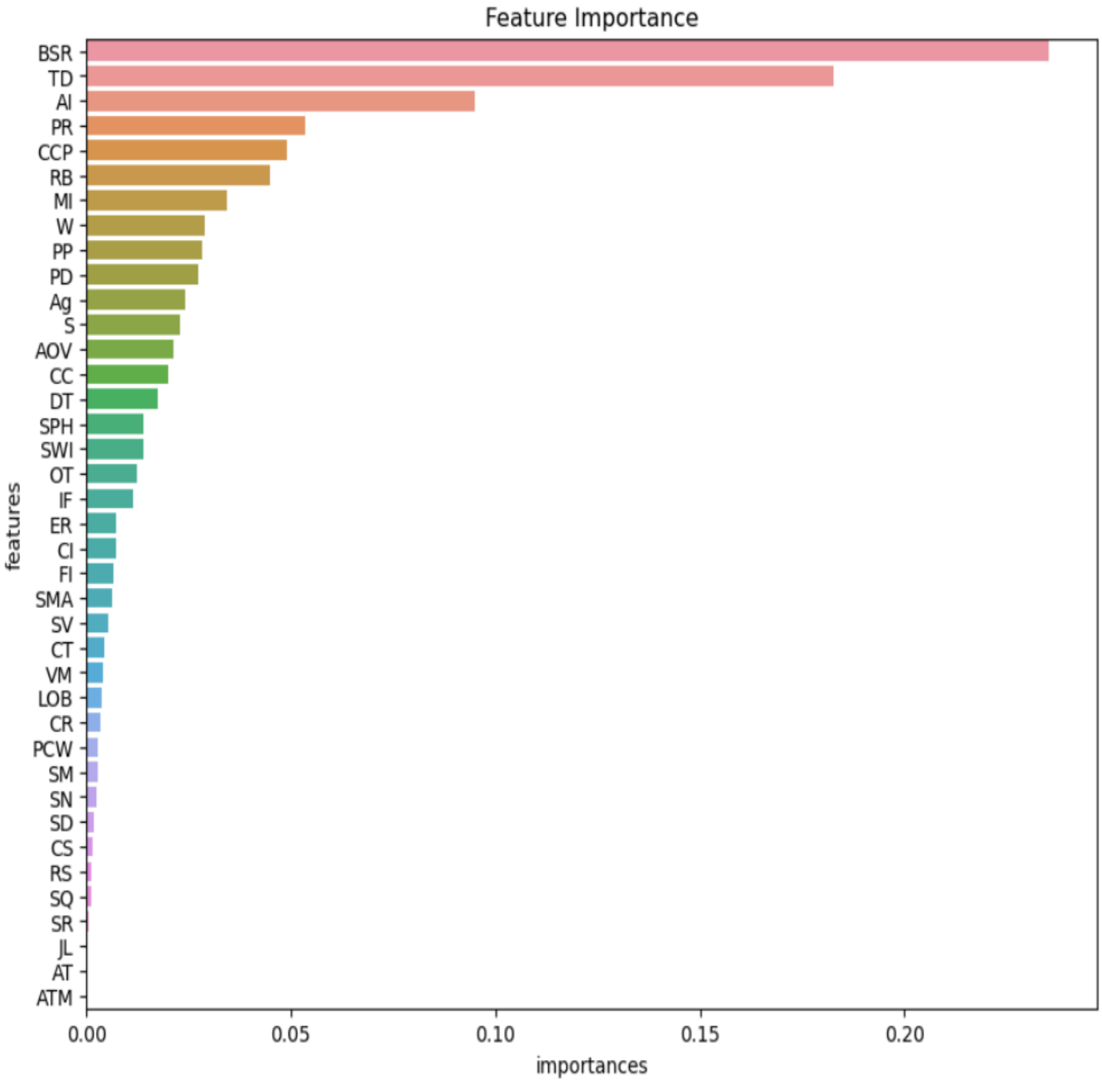


Figure 4.6 Micro features.

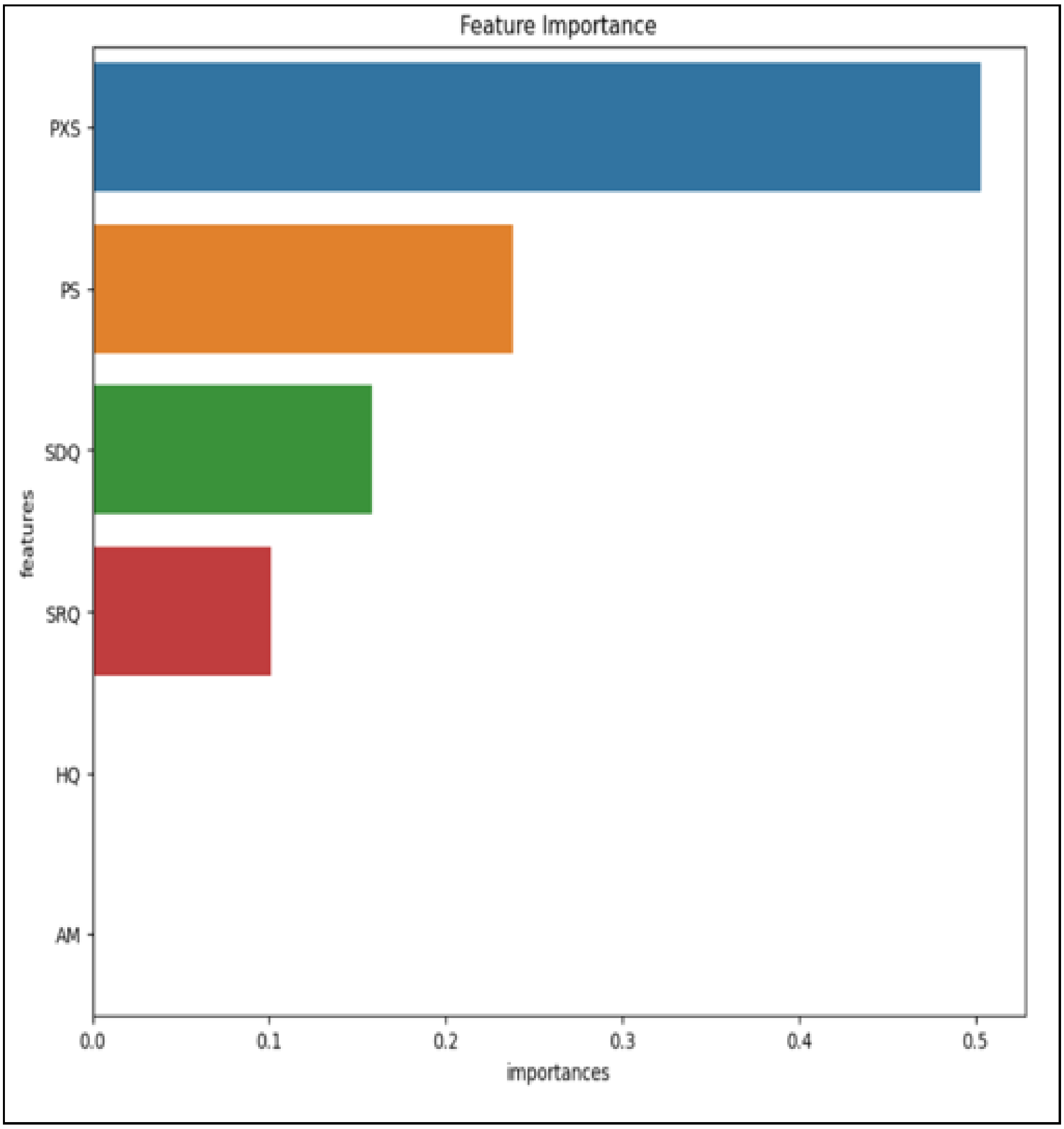


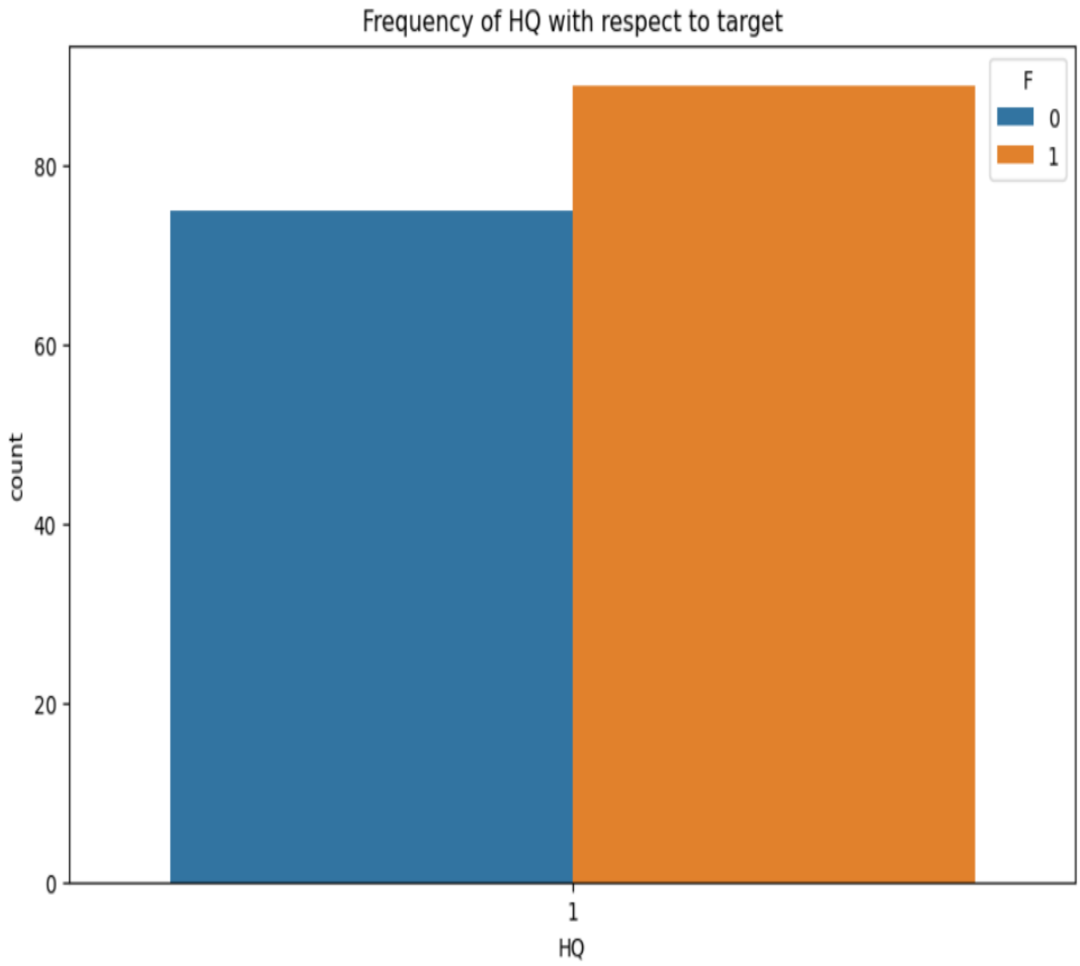
Figure 4.7 Macro features.

4.7 Frequency plot analysis

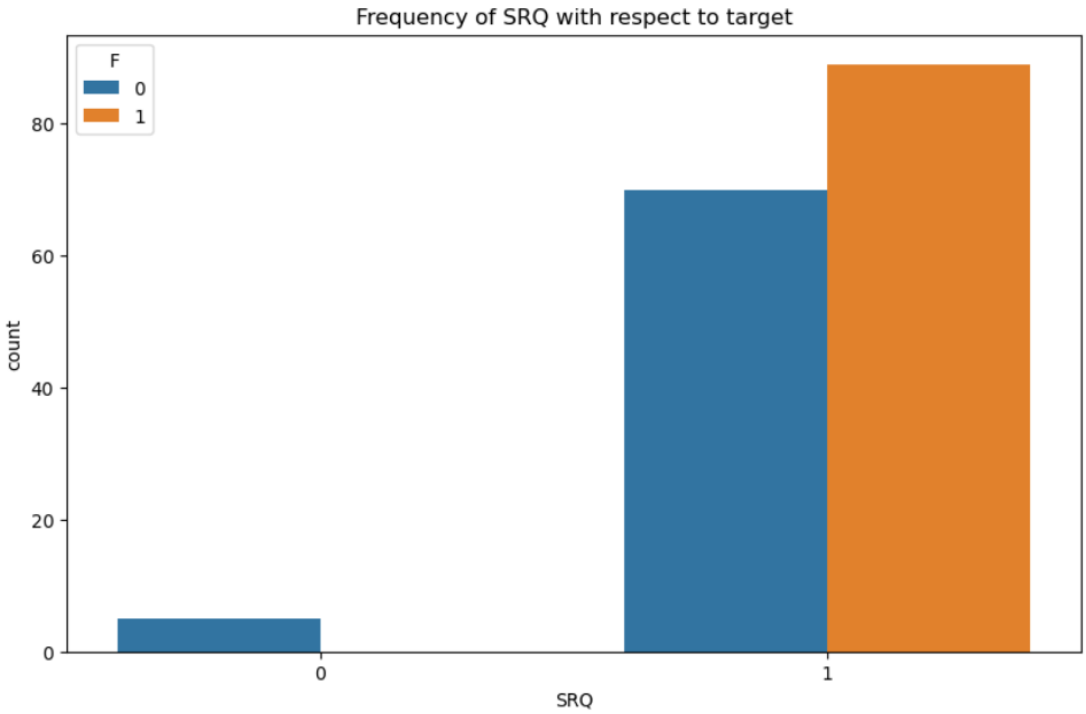
At the macro level, the frequency plot provides an interesting investigation into the correlations between major parent factors and tiredness levels among seafarers. The lack of worst-case scenarios for "AM" (Management Aspect) and "HQ" (Health Quality) replicates findings from the heat map and correlation matrix, indicating that these aspects may not be major contributors to severe fatigue based on the data collected. In contrast, the prevalence of "PS," "PXS," and "SDQ" (Ship Quality) in situations of fatigue level 0 (FL(0)) highlights their major influence on seafarer fatigue.

These variables emerge as critical drivers, correlating with real-life experiences and emphasizing their important roles in shaping seafarers' well-being.

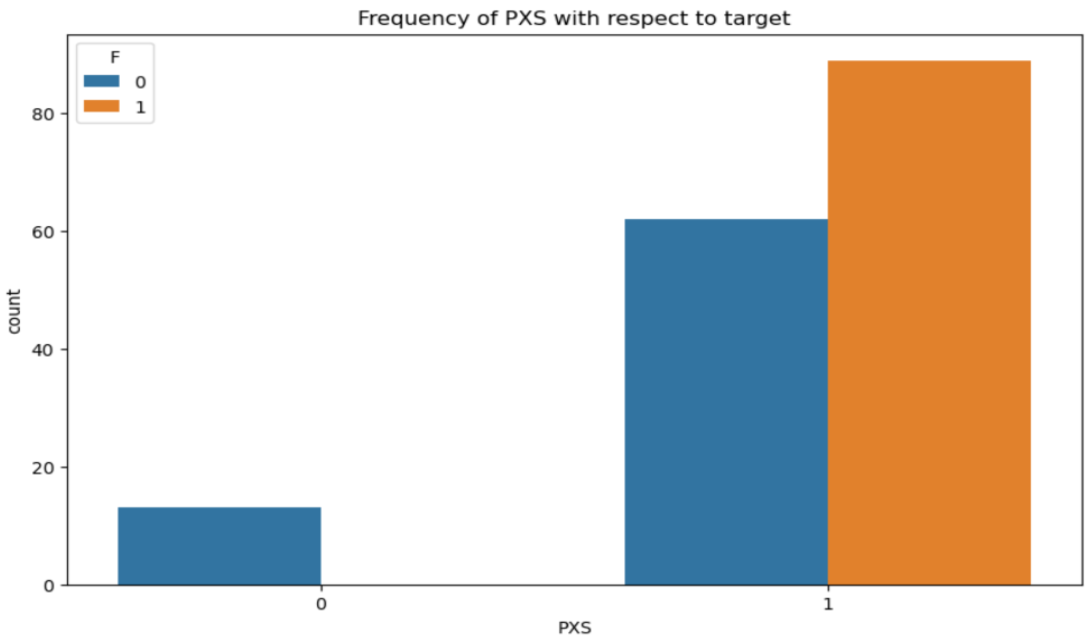
This discovery calls for more research into the complex dynamics of physical and psychological stress and the quality of the ship environment, all of which contribute to fatigue. The frequency plot graphically communicates the prevalence of these relevant elements and supports the need for focused treatments and management tactics in addressing specific stressors that are substantially associated with higher fatigue levels among seafarers.



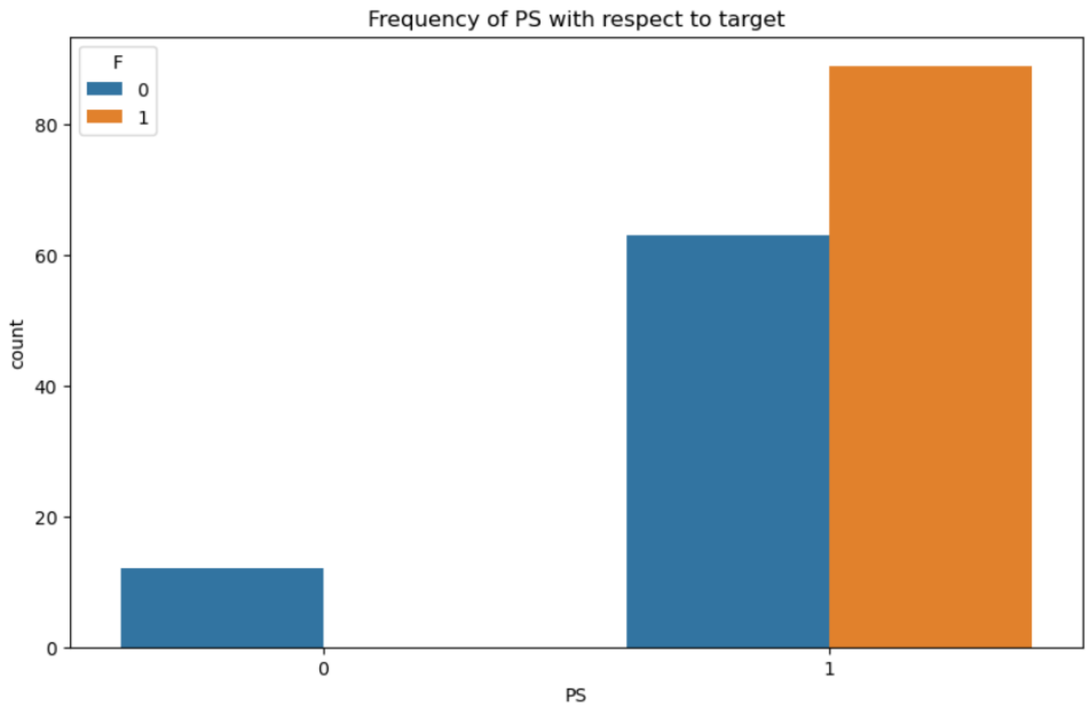
(A)


Frequency of SRQ with respect to target
F
0
1
count
0
20
40
60
80
0
1
SRQ

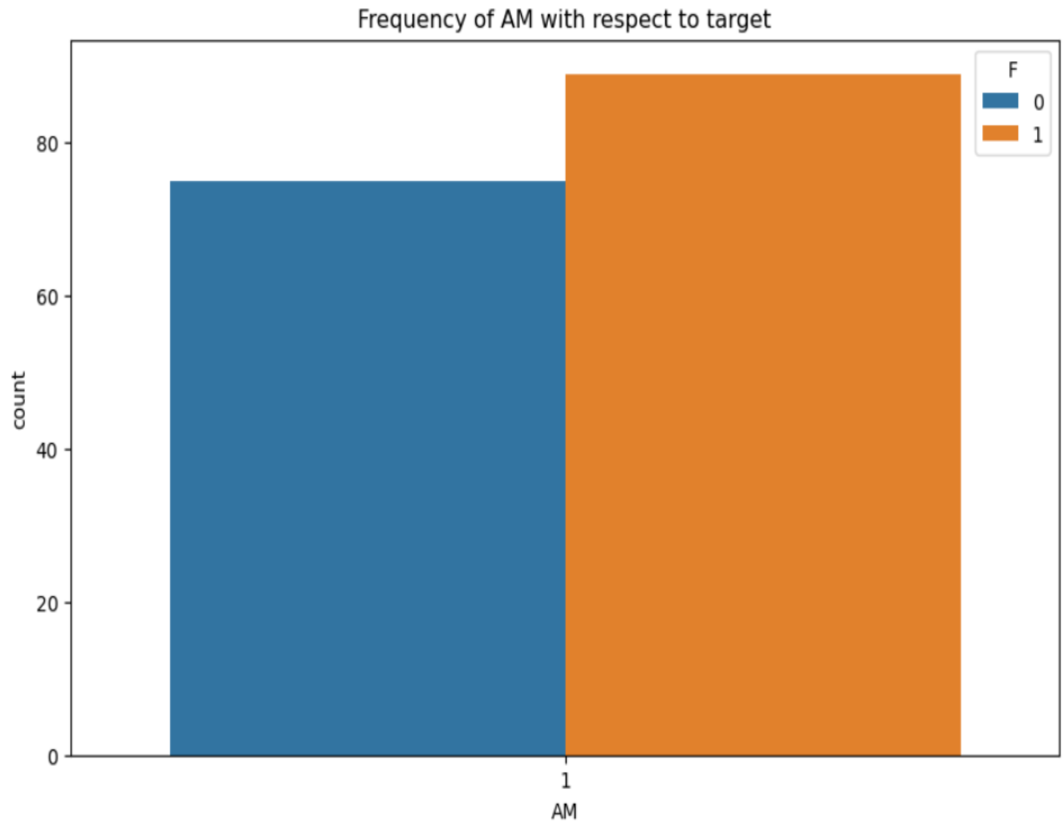
(B)


Frequency of PXS with respect to target
F
0
1
count
0
20
40
60
80
0
1
PXS

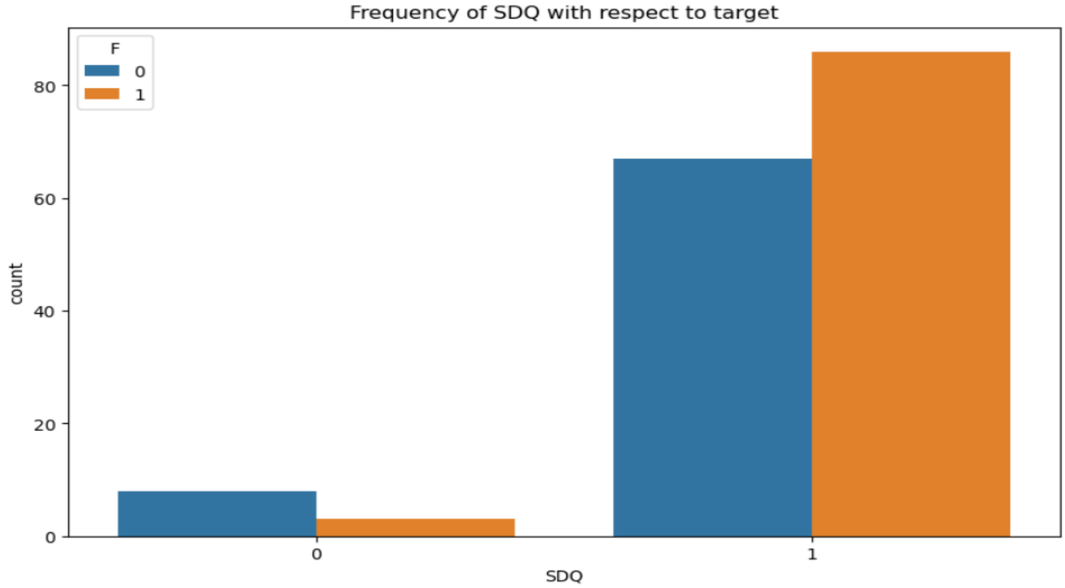
(C)


Frequency of PS with respect to target
F
0
1
80
60
40
20
0
count
0
1
PS

(D)


Frequency of AM with respect to target
F
0
1
80
60
40
20
0
count
1
AM

(E)



(F)

Figure 4.8 Frequency plot matrix (A, B, C, D, E and F).

4.8 Conditional Probability Distribution and dependency of the Bayesian Network model

The Conditional Probability Distribution (CPD) table (Appendix 1)for the variable F (Fatigue Level) shows the likelihood of various fatigue levels given specific conditions of its parent variables—AM (Alertness Level), HQ (Health Level), PS (Physical Strain Level), PXS (Psychological Strain Level), SDQ (Social Strain Level), and SRQ (Social Strain Level), SQ (Sleep Quality Level). The probability for F being at level 0 and level 1 are shown in pairs. Notably, when AM and HQ are all at level 1, and PS, PXS, SDQ, and SRQ are all at level 0, the likelihood of F being at level 0 is 1.0, whereas the likelihood of F being at level 1 is 0.0. When AM and HQ are both at level 1, as well as PS, PXS, SDQ, and SRQ, the probabilities are evenly divided between F levels 0 and 1. The CPD table (Appendix 1) captures the complex correlations between these variables and offers a thorough perspective of the probabilistic linkages within the given system.

4.9 Joint Probabilities with target

In a Bayesian Network, a joint probability distribution gives the probability of certain combinations of states across multiple variables. Figure 4.9 below shows the joint probability distributions for the target variable "F" (Fatigue Level) and each of the other variables in the network: "HQ" (Health Quality Level), "SRQ" (Sleep Quality Level), "PXS" (Psychological Stress Level), "PS" (Physical Stress Level), "AM" (Management Aspect Level), and "SDQ" (Ship Design Quality Level). Joint probabilities indicate the probability of different combinations of states across two variables. Here's what each table shows:

HQ and F: This joint distribution reveals how the Health Quality Level (HQ) influences the Fatigue Level (F). With HQ at level 1, there's a 45.73% probability that the crew experiences no fatigue (F=0) and a 54.27% probability of experiencing fatigue (F=1).

SRQ and F: Examining the Sleep Quality Level (SRQ) in conjunction with the Fatigue Level, it shows that when SRQ is at level 0, there's a 3.05% probability of no fatigue (F=0) and 0% probability of fatigue (F=1). However, at SRQ level 1, the probabilities shift, with a 42.68% chance of no fatigue and a 54.27% chance of experiencing fatigue.

PXS and F: Psychological Stress Level (PXS) and Fatigue Level exhibit a similar pattern. When PXS is at level 0, there's a 7.93% probability of no fatigue (F=0) and a 0% probability of fatigue (F=1). At PXS level 1, these probabilities change to 37.80% and 54.27%, respectively.

PS and F: Physical Stress Level (PS) in tandem with Fatigue Level demonstrates that at PS level 0, there's a 7.32% probability of no fatigue (F=0) and 0% probability of fatigue (F=1). When PS is at level 1, the probabilities are 38.41% for no fatigue and 54.27% for fatigue.

AM and FL: Analyzing the Management Aspect Level (AM) and Fatigue Level, when AM is at level 1, there's a 45.73% probability of no fatigue (F=0) and a 54.27% probability of fatigue (F=1).

SDQ and F: Ship Design Quality Level (SDQ) in relation to Fatigue Level demonstrates that at SDQ level 0, there's a 4.88% probability of no fatigue (F=0) and a 1.83% probability of fatigue (F=1). At SDQ level 1, the probabilities shift to 40.85% for no fatigue and 52.44% for fatigue.

The Bayesian model predicts the crew members' Fatigue Level (F) with a remarkable accuracy of 97.6 percent when tested on the available information. This high degree of accuracy demonstrates the Bayesian network's efficacy in capturing the intricate interactions and dependencies among the numerous variables driving weariness. The model's capacity to anticipate tiredness levels properly is critical in the maritime setting, where crew well-being is critical for safety and operational efficiency. As indicated by its high accuracy, the model's resilience shows that it might be useful in real-world applications, assisting decision-makers in executing targeted interventions to reduce crew tiredness and improve overall operational performance.

Joint probabilities for HQ and target:

F	No	Yes
HQ		
1	0.457317	0.542683

Joint probabilities for SRQ and target:

F	No	Yes
SRQ		
0	0.030488	0.000000
1	0.426829	0.542683

Joint probabilities for PXS and target:

F	No	Yes
PXS		
0	0.079268	0.000000
1	0.378049	0.542683

Joint probabilities for PS and target:

F	No	Yes
PS		
0	0.073171	0.000000
1	0.384146	0.542683

Joint probabilities for AM and target:

F	No	Yes
AM		
1	0.457317	0.542683

Joint probabilities for SDQ and target:

F	No	Yes
SDQ		
0	0.048780	0.018293
1	0.408537	0.524390

Figure 4.9 The joint probability distributions for the target variable "F" (Fatigue Level) and each of the other variables in the network.

CHAPTER 5

DISCUSSION

It can be said with a fair amount of certainty that to improve the seafarers' fatigue level, there is a need to address physical stress and sleep quality. Physical and psychological stress are the most important factors that impact the fatigue levels. In view of the above, the following interventions can be taken to manage the fatigue levels.

5.1 Physical stress

Physical stress continues to be an urgent concern for crew members onboard Singapore bulk carriers, necessitating implementing a holistic strategy to protect their well-being and maximise operating efficiency. The administration of overtime is a significant factor in physical strain. Seafarers frequently encounter prolonged work schedules, which results in heightened susceptibility to physical strain and fatigue. This burden can be substantially mitigated through the implementation and strong enforcement of laws such as the Merchant Shipping (Maritime Labour) Act 2014 part 4 section 16- Hours of Rest that restrict overtime and STCW 2010, as amended, thereby providing sufficient time for rest and recuperation between shifts.

The function of vessel maintenance in alleviating physical stress is of equal importance. Prompt and efficient reactions to equipment breakdowns are critical to mitigate extended periods of exposure to hazardous situations, guaranteeing a safer and healthier workplace. Sufficient maintenance of a vessel not only mitigates the likelihood of accidents but also enhances the physical welfare of the crew members at sea. The design of vessels is particularly significant when it comes to mitigating physical stresses. Adapting vessels to endure turbulent sea conditions plays a crucial role in mitigating the dangers and risks maritime personnel face. In addition to improving crew safety, a resilient vessel reduces the physical stress associated with navigating through difficult marine circumstances.

Furthermore, ensuring minimum exposure of the crew on board under sunny & humid weather on deck is critical for ensuring the general welfare of maritime personnel. Physical tension can be significantly intensified by elevated humidity levels, which can have adverse effects on comfort and health, especially when one is at sea. The adoption of humidity regulation measures signifies a dedication to establishing an atmosphere that places the physical welfare of seafarers first and promotes the development of a sustainable marine sector. Fundamentally, addressing physical stress necessitates an integrated strategy comprising regulatory interventions as strictly comply with the Merchant Shipping (Maritime Labour) Act 2014 part 4 section 16- Hours of Rest, maintenance methodologies- such as installing automation, electronic Periodical Maintenance System implementation, improvements in vessel design for example installing machinery redundancy, and environmental factors- limiting the exposure of the crew under sunny & humid weather. Implementing such a comprehensive approach ensures the protection of seafarers' health and enhances the effectiveness and robustness of maritime operations in Singapore.

5.2 Sleep and Rest Quality

Sleep and rest quality are crucial determinants of the health and productivity of seafarers. This feature is influenced by a multitude of factors, encompassing the frequency and duration of sleep, ship motion, shift work and schedules, accommodation weather, ship vibration, noise levels, and the incidence of sleep-related disorders.

It is critical to establish and enforce appropriate intervals for rest breaks. Enabling sailors to have adequate time for rest and relaxation between shifts serves to mitigate fatigue and positively impacts their general state of health. Rest break duration and frequency regulation are of utmost importance in ensuring crew members remain alert throughout strenuous marine activities. Various factors exert an influence on the quantity, quality, and duration of sleep. Seafarers' capacity to attain a satisfactory night's sleep may be adversely affected by the ship's motion, which is frequently exposed to turbulent sea conditions. It is imperative to pay close attention to shift work and timetables in order to maintain regular sleep patterns, taking into account the circadian cycles of the crew.

Lodging circumstances exert a significant influence on sleep quality, particularly temperature regulation. The provision of comfortable living circumstances has a favorable influence on the sleep environment of sailors, hence promoting their physical and mental well-being. Vibrations and noise levels aboard a vessel are further factors to consider. Sleep can be adversely affected by excessive noise and vibrations, resulting in fatigue and impaired cognitive function. The aboard environment can be more tranquil using strategies to mitigate these disruptions. Clock-related variations, jet lag, and irregular bunkering schedules are all potential contributors to sleep difficulties. Recognizing and effectively controlling these variables are crucial to mitigating and resolving sleep-related concerns among maritime personnel.

Building the ship from the reputed shipyard to ensure the high-quality design and supervision of the building can ensure the noise and vibration are within the tolerant limit. Also, the central aircon system in the accommodation block and crew quarter must effectively maintain a comfortable temperature. This can be ensured by installing an Air-con system with sufficient capacity for the area to be covered and a planned maintenance system to be maintained diligently. Crew duty schedule timing roster should not be changed frequently. However, due consideration is to be given for certain crew not to be left out with only night watches when people have a deep & sound sleep. The operator should maintain the bunkering schedule, and the same should be shared with the master of the vessel in advance for his planning. The ship’s motion can’t be controlled as it is a natural phenomenon, but the master should maintain enough deadweight by taking ballast to maintain the vessel's stability to reduce stiff & tender phenomenon of the stability.

5.3 Ashore management factors

Ashore management factors are crucial for ensuring the welfare and productivity of sailors employed onboard Singapore bulk ships. This category comprises many factors to be considered, such as crew selection, training protocols, crew complement size, shore management support, crew interaction duration, and documentation obligations.

Crew selection is an essential initial step. A harmonious and productive workplace is fostered by ensuring that employees are appropriately matched to the responsibilities of their positions. Comprehensive screening and selection procedures aid in the formation of a proficient and harmonious staff. Comprehensive crew training programs are important in order to adequately equip sailors to confront the various problems that may be encountered at sea. In addition to imparting technical expertise, training should encompass vital components such as stress coping mechanisms, fatigue management, and other critical elements essential for preserving mental and physical health at sea.

It is critical to optimize crew complement size in order to efficiently distribute duty. Maintaining a balanced crew size is crucial for optimizing task execution while preventing individual seafarers from being overburdened, hence mitigating stress and fatigue. Establishing efficient communication and support mechanisms between shore management and onboard crew is of utmost importance to effectively tackle obstacles and optimize operations. Consistent support, input tools, and transparent lines of communication all contribute to a management structure that is more responsive and encouraging.

Their health is affected by crew contact times, which refer to the time sailors spend at sea before returning to land. Establishing a harmonious equilibrium between work and rest intervals is critical to safeguard the crew's mental well-being and avert burnout. Streamlining the documentation required is an additional critical factor to contemplate. The presence of onerous administrative duties may impede seafarers' ability to concentrate and alleviate tension associated with their primary obligations.

5.4 Psychological stress

Psychological stress affects seafarers' mental health and overall job performance. An extensive range of variables causes it. A significant factor contributing to psychological stress is workload, as mariners frequently encounter arduous and uncertain timetables. Integrating stress management initiatives customized to tackle the distinct obstacles encountered in marine labour might furnish vital resources for resilience and coping.

Family and personal concerns contribute an additional stratum to psychological strain. When coupled with the pressure to meet familial obligations, the isolation of seafaring can cause emotional distress. Seafarers can navigate personal difficulties and foster an empathetic and helpful environment by providing counseling services and developing support networks ashore and onboard. Additionally, port traffic density exacerbates psychological strain, especially when navigating congested waterways. By reducing the cognitive load on seafarers, effective traffic management and navigational support systems can improve their capacity to navigate securely and efficiently.

Equally important is the modification of performance requirements. High-pressure work conditions and unrealistic expectations may further intensify psychological stress. Consistently evaluating and modifying performance expectations to ensure they align with attainable objectives fosters a more positive work environment and advances the psychological welfare of seafarers.

5.5 Health Condition

The physical and mental health of crew members on Singapore bulk carriers is a critical factor influencing both operational effectiveness and overall welfare. A variety of determinants impact health issues, such as dietary choices, disease, and age. It is critical to acknowledge the significance of these elements in order to develop and execute plans that effectively safeguard the well-being and vigour of seafaring personnel.

Systematic health assessments play a critical role in monitoring and managing seafarers' health issues. Regular medical screenings facilitate proactive healthcare interventions by recognizing prospective illnesses and addressing age-related health concerns. This strategy fosters a healthier and more resilient workforce by ensuring seafarers are provided with suitable medical care. Their diet significantly impacts the health of seafarers, as factors such as alcohol consumption, caffeine usage, and drug use can significantly affect their general state of being. Promoting and facilitating the adoption of nutritious dietary practices while at sea can benefit the physical well-being of maritime workers, enhancing their capacity to manage the rigors of their occupations.

5.6 Ship design

The performance and welfare of sailors on Singapore bulk carriers are directly influenced by the design of the vessel. This complex element comprises various factors, including but not limited to redundancy, automation degree, equipment dependability, and physical comfort in the work environment.

By incorporating backups for crucial systems, redundant ship design reduces the probability of equipment failures and potential safety risks. By implementing this measure, the seafaring crew not only bolsters the overall safety of the vessel but also reduces strain and workload. The degree to which ship systems are automated can substantially affect the workload and stress levels experienced by sailors. By streamlining operations, well-designed automated processes enable the crew to concentrate on responsibilities that demand human knowledge. Nevertheless, it is critical to strike a balance when integrating automation to preserve the crew's situational awareness and active participation in essential shipboard operations. Maintaining dependable equipment is critical for ensuring the crew's safety and the vessel's efficient functioning. Consistent upkeep and financial investment in cutting-edge technology enhance the dependability of aboard apparatus, diminishing the probability of malfunctions that may engender fatigue and stress among maritime personnel. Physical comfort in the workplace is an additional crucial element in the construction of ships. Optimal living facilities, noise reduction techniques, ergonomic considerations, and appropriate accommodation temperature substantially influence the crew's welfare throughout their prolonged sojourns at sea.

5.7 Summary

In summary, A comprehensive strategy is necessary to ensure seafarers' welfare on Singapore bulk carriers, encompassing a range of elements such as sleep and rest patterns, physical stress, and sleep deprivation. Every aspect contributes significantly to establishing a setting that safeguards maritime operations and ensures the crew's well-being. If we go back to the literature review of this study, we can find that all the factors such as Psychosocial stress, mental health (Stress, Loneliness, abuse, Regulations), working environment both operational & technical, Irregular sleep quality and quantity, are contributing to fatigue. Although ashore management and crew health factor are not a contributing factor according to the data analysis, but ashore management factor could not be properly justified. There might be a reason of crew afraid to speak up about their management. Crew are sent to undergo medical check up prior joining and only medically fit crew are allowed to join the vessel.

Commencing with physical strain, overtime laws assume paramount importance. Extended work hours may result in physical exhaustion and poor health. Mariners are protected and given adequate time to recuperate by enforcing policies restricting overtime. At the same time, vessel maintenance procedures assume a prominent position. In addition to reducing the physical strain caused by malfunctioning equipment, a consistently maintained vessel enhances the workplace's safety and productivity.

Concerning psychological stress, handling professional obligations, personal issues, and family concerns is essential. Implementing stress management programs equips mariners with the necessary resources to effectively manage the challenges inherent in their profession, hence fostering psychological fortitude. In a similar vein, the optimization of port traffic density and the evaluation of performance expectations both foster a psychologically sound work environment. Consistent health evaluations are crucial when considering health issues. Ensuring prompt medical interventions, such as those connected to age-associated health risks, promotes a proactive approach to healthcare through monitoring. In addition, the influence of factors such as consumption of alcohol, caffeine, and drugs on the overall health of seafarers can be mitigated by the promotion of nutritious meals and the provision of nutritional assistance.

The design of the ship becomes a critical determinant, incorporating elements such as equipment dependability, redundancy, physical comfort in the workplace, and automation degree. Increasing the resilience of vessels to adverse sea conditions improves their safety record, while ergonomic factors and noise reduction add to the crew's physical welfare. Sleep and rest quality constitute the final component of the comprehensive approach. It is essential to maintain adequate sleep circumstances and sufficient rest breaks in order to prevent fatigues. A conducive environment can be created onboard by effectively managing disturbances such as ship motion, vibration, and noise, and attending to sleep-related disorders.

Therefore, it is imperative to implement a holistic approach that incorporates physical and psychological stress management, health evaluations, optimal ship design, and careful deliberation regarding sleep and rest. By emphasizing these facets, the marine sector can cultivate a robust and in good health seafarer, ultimately augmenting the security and effectiveness of bunker tankers based in Singapore.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

The seafaring industry is vital to the global economy, with seafarers playing an essential role in facilitating international trade and impacting daily life worldwide. To sustain this crucial workforce, organizational structures within the industry must prioritize their employees' physical, mental, and emotional well-being. Recognizing the complexities associated with age and experience and treating crew members with empathy and respect are vital for maintaining motivation and performance.

Fatigue among seafarers is a multi-dimensional issue that extends beyond mere physical exhaustion. Emotional health, influenced by factors such as unstructured roles, demanding supervisors, and the challenges of balancing high personal standards with professional demands, significantly impacts fatigue levels. Extended periods away from home and inadequate working conditions exacerbate this issue, making rest and recovery more critical, especially in the post-COVID era, where the impacts on health, displacement, and job security have heightened these challenges.

This research identifies that seafarer fatigue is primarily driven by physical and psychological stress, poor sleep quality, and suboptimal ship design. To effectively manage and reduce fatigue, several recommendations are proposed for ship owners and managers within the Singapore bunker industry:

1. **Monitor Work and Rest Hours:** Implement weekly online monitoring of crew work and rest hours through the Crewing department and encourage the crew to record their rest periods daily.

2. **Scrap Aging Barges:** Retire older bunker barges (over 10 years old) that are challenging to maintain.
3. **Support Ship Maintenance:** Ensure timely provision of spare parts and support for maintaining vessel standards.
4. **Reduce Workload:** Adjust workloads to manageable levels by increasing crew numbers as needed.
5. **Set Realistic KPIs:** Avoid setting unrealistic Key Performance Indicators (KPIs) that place undue pressure on the crew.
6. **Enhance Training:** Provide targeted training to improve crew competency and reduce performance-related stress.
7. **Offer Mental Wellness Support:** Provide free access to mental health consultations and medication.
8. **Facilitate Shore Access:** Arrange regular shore leave and provide logistical support to refresh crew members.
9. **Improve Ship Design:** Design ships to minimize vibration and noise, ensuring restful conditions for the crew.
10. **Maintain Comfortable Conditions:** Regulate accommodation air temperature to ensure crew comfort.
11. **Optimize Bunkering Schedules:** Coordinate bunkering schedules to minimize unnecessary rest breaks and ensure compliance with Maritime Labour Convention requirements.
12. **Manage Jetlag:** Ensure that crew members have adequate time to recover from jetlag before resuming duties.

The study underscores the necessity for further research on seafarer fatigue, particularly in the context of the bunker tanker industry. Future research should focus on refining survey questions to capture a more accurate picture of crew experiences, especially regarding shore management, where current supportive responses may not always reflect practical realities. Addressing these gaps will be crucial for developing effective strategies to comprehensively manage and mitigate seafarer fatigue.

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APPENDIX

Appendix 1

Conditional probability distribution and dependency of the Bayesian network model

<table>
<tr><th>Variable</th><th>CPD</th></tr>
<tr><td>CI</td><td>+++
| CI(0) | 0.0381679 |
+++
| CI(1) | 0.961832 |
+++</td></tr>
<tr><td>HQ</td><td>+++++++++
| AI | AI(0) | AI(0) | AI(0) | ... | AI(1) | AI(1) | AI(1) |
+++++++++
| Ag | Ag(0) | Ag(0) | Ag(0) | ... | Ag(1) | Ag(1) | Ag(1) |
+++++++++
| CI | CI(0) | CI(0) | CI(0) | ... | CI(1) | CI(1) | CI(1) |
+++++++++
| DT | DT(0) | DT(0) | DT(0) | ... | DT(1) | DT(1) | DT(1) |
+++++++++
| IF | IF(0) | IF(0) | IF(1) | ... | IF(0) | IF(1) | IF(1) |
+++++++++
| MI | MI(0) | MI(1) | MI(0) | ... | MI(1) | MI(0) | MI(1) |
+++++++++
| HQ(1) | 1.0 | 1.0 | 1.0 | ... | 1.0 | 1.0 | 1.0 |
+++++++++</td></tr>
<tr><td>MI</td><td>+++
| MI(0) | 0.160305 |
+++
| MI(1) | 0.839695 |
+++</td></tr>
<tr><td>AI</td><td>+++
| AI(0) | 0.328244 |
+++</td></tr>
</table>

<table>
<tr><td></td><td>| AI(1) | 0.671756 |
+++</td></tr>
<tr><td>DT</td><td>+++
| DT(0) | 0.0534351 |
+++
| DT(1) | 0.946565 |
+++</td></tr>
<tr><td>IF</td><td>+++
| IF(0) | 0.229008 |
+++
| IF(1) | 0.770992 |
+++</td></tr>
<tr><td>Ag</td><td>+++
| Ag(0) | 0.450382 |
+++
| Ag(1) | 0.549618 |
+++</td></tr>
<tr><td>SM</td><td>+++
| SM(0) | 0.0305344 |
+++
| SM(1) | 0.969466 |
+++</td></tr>
<tr><td>SRQ</td><td>++++++++
| AT | AT(0) | AT(0) | ... | AT(1) | AT(1) | AT(1) |
++++++++
| LOB | LOB(0) | LOB(0) | ... | LOB(1) | LOB(1) | LOB(1)
|
++++++++
| BSR | BSR(0) | BSR(0) | ... | BSR(1) | BSR(1) | BSR(1) |
++++++++
| CR | CR(0) | CR(0) | ... | CR(1) | CR(1) | CR(1) |
++++++++
| JL | JL(0) | JL(0) | ... | JL(1) | JL(1) | JL(1) |
++++++++
| RB | RB(0) | RB(0) | ... | RB(1) | RB(1) | RB(1) |
++++++++
| SD | SD(0) | SD(0) | ... | SD(1) | SD(1) | SD(1) |
++++++++
| SM | SM(0) | SM(0) | ... | SM(1) | SM(1) | SM(1) |
++++++++
| SN | SN(0) | SN(0) | ... | SN(1) | SN(1) | SN(1) |</td></tr>
</table>

<table>
<tr><td></td><td>++++++++
| SQ | SQ(0) | SQ(0) | ... | SQ(1) | SQ(1) | SQ(1) |
++++++++
| SV | SV(0) | SV(0) | ... | SV(0) | SV(1) | SV(1) |
++++++++
| SWI | SWI(0) | SWI(1) | ... | SWI(1) | SWI(0) | SWI(1) |
++++++++
| SRQ(0) | 0.5 | 0.5 | ... | 0.0 | 0.5 | 0.0 |
++++++++
| SRQ(1) | 0.5 | 0.5 | ... | 1.0 | 0.5 | 1.0 |
++++++++</td></tr>
<tr><td>SWI</td><td>+++
| SWI(0) | 0.0534351 |
+++
| SWI(1) | 0.946565 |
+++</td></tr>
<tr><td>SV</td><td>+++
| SV(0) | 0.0381679 |
+++
| SV(1) | 0.961832 |
+++</td></tr>
<tr><td>AT</td><td>+++
| AT(0) | 0.00763359 |
+++
| AT(1) | 0.992366 |
+++</td></tr>
<tr><td>SN</td><td>+++
| SN(0) | 0.0305344 |
+++
| SN(1) | 0.969466 |
+++</td></tr>
<tr><td>SQ</td><td>+++
| SQ(0) | 0.0458015 |
+++
| SQ(1) | 0.954198 |
+++</td></tr>
<tr><td>CR</td><td>+++
| CR(0) | 0.0305344 |
+++</td></tr>
</table>

	| CR(1) | 0.969466 | +++
JL	+++ | JL(0) | 0.0152672 | +++ | JL(1) | 0.984733 | +++
BSR	+++ | BSR(0) | 0.267176 | +++ | BSR(1) | 0.732824 | +++
SD	+++ | SD(0) | 0.0458015 | +++ | SD(1) | 0.954198 | +++
LOB	+++ | LOB(0) | 0.0458015 | +++ | LOB(1) | 0.954198 | +++
RB	+++ | RB(0) | 0.59542 | +++ | RB(1) | 0.40458 | +++
PD	+++ | PD(0) | 0.137405 | +++ | PD(1) | 0.862595 | +++
PXS	++++++++ | FI | FI(0) | FI(0) | ... | FI(1) | FI(1) | FI(1) | ++++++++ | PD | PD(0) | PD(0) | ... | PD(1) | PD(1) | PD(1) | ++++++++ | PP | PP(0) | PP(0) | ... | PP(1) | PP(1) | PP(1) |

<table>
<tr><td></td><td>+++++++++
| S | S(0) | S(0) | ... | S(1) | S(1) | S(1) |
+++++++++
| TD | TD(0) | TD(0) | ... | TD(0) | TD(1) | TD(1) |
+++++++++
| W | W(0) | W(1) | ... | W(1) | W(0) | W(1) |
+++++++++
| PXS(0) | 1.0 | 0.5 | ... | 0.0 | 0.0 | 0.0 |
+++++++++
| PXS(1) | 0.0 | 0.5 | ... | 1.0 | 1.0 | 1.0 |
+++++++++</td></tr>
<tr><td>S</td><td>+++
| S(0) | 0.206107 |
+++
| S(1) | 0.793893 |
+++</td></tr>
<tr><td>TD</td><td>+++
| TD(0) | 0.267176 |
+++
| TD(1) | 0.732824 |
+++</td></tr>
<tr><td>FI</td><td>+++
| FI(0) | 0.0305344 |
+++
| FI(1) | 0.969466 |
+++</td></tr>
<tr><td>PP</td><td>+++
| PP(0) | 0.0305344 |
+++
| PP(1) | 0.969466 |
+++</td></tr>
<tr><td>W</td><td>+++
| W(0) | 0.145038 |
+++
| W(1) | 0.854962 |
+++</td></tr>
<tr><td>SPH</td><td>+++
| SPH(0) | 0.0839695 |
+++</td></tr>
</table>

<table>
<tr><td></td><td>| SPH(1) | 0.916031 |
+++</td></tr>
<tr><td>PS</td><td>+++++++
| AOV | AOV(0) | AOV(0) | ... | AOV(1) | AOV(1) |
+++++++
| OT | OT(0) | OT(0) | ... | OT(1) | OT(1) |
+++++++
| RS | RS(0) | RS(0) | ... | RS(1) | RS(1) |
+++++++
| SPH | SPH(0) | SPH(0) | ... | SPH(1) | SPH(1) |
+++++++
| VM | VM(0) | VM(1) | ... | VM(0) | VM(1) |
+++++++
| PS(0) | 0.5 | 0.5 | ... | 0.0 | 0.05172413793103448 |
+++++++
| PS(1) | 0.5 | 0.5 | ... | 1.0 | 0.9482758620689655 |
+++++++</td></tr>
<tr><td>AOV</td><td>+++
| AOV(0) | 0.450382 |
+++
| AOV(1) | 0.549618 |
+++</td></tr>
<tr><td>VM</td><td>+++
| VM(0) | 0.0152672 |
+++
| VM(1) | 0.984733 |
+++</td></tr>
<tr><td>RS</td><td>+++
| RS(0) | 0.00763359 |
+++
| RS(1) | 0.992366 |
+++</td></tr>
<tr><td>OT</td><td>+++
| OT(0) | 0.0610687 |
+++
| OT(1) | 0.938931 |
+++</td></tr>
<tr><td>CS</td><td>+++
| CS(0) | 0.0152672 |
+++</td></tr>
</table>

<table>
<tr><td></td><td>| CS(1) | 0.984733 |
+++</td></tr>
<tr><td>AM</td><td>++++++++
| CC | CC(0) | CC(0) | ... | CC(1) | CC(1) | CC(1) |
++++++++
| CCP | CCP(0) | CCP(0) | ... | CCP(1) | CCP(1) | CCP(1) |
++++++++
| CS | CS(0) | CS(0) | ... | CS(1) | CS(1) | CS(1) |
++++++++
| CT | CT(0) | CT(0) | ... | CT(1) | CT(1) | CT(1) |
++++++++
| PR | PR(0) | PR(0) | ... | PR(0) | PR(1) | PR(1) |
++++++++
| SMA | SMA(0) | SMA(1) | ... | SMA(1) | SMA(0) | SMA(1) |
++++++++
| AM(1) | 1.0 | 1.0 | ... | 1.0 | 1.0 | 1.0 |
++++++++</td></tr>
<tr><td>CT</td><td>+++
| CT(0) | 0.00763359 |
+++
| CT(1) | 0.992366 |
+++</td></tr>
<tr><td>CC</td><td>+++
| CC(0) | 0.709924 |
+++
| CC(1) | 0.290076 |
+++</td></tr>
<tr><td>SMA</td><td>+++
| SMA(0) | 0.0229008 |
+++
| SMA(1) | 0.977099 |
+++</td></tr>
<tr><td>CCP</td><td>+++
| CCP(0) | 0.587786 |
+++
| CCP(1) | 0.412214 |
+++</td></tr>
<tr><td>PR</td><td>+++
| PR(0) | 0.320611 |
+++</td></tr>
</table>

<table>
<tr><td></td><td>| PR(1) | 0.679389 |
+++</td></tr>
<tr><td>SR</td><td>+++
| SR(0) | 0.0305344 |
+++
| SR(1) | 0.969466 |
+++</td></tr>
<tr><td>SDQ</td><td>++++++++
| ATM | ATM(0) | ATM(0) | ... | ATM(1) | ATM(1) | ATM(1) |
++++++++
| ER | ER(0) | ER(0) | ... | ER(1) | ER(1) | ER(1) |
++++++++
| PCW | PCW(0) | PCW(0) | ... | PCW(0) | PCW(1) | PCW(1) |
++++++++
| SR | SR(0) | SR(1) | ... | SR(1) | SR(0) | SR(1) |
++++++++
| SDQ(0) | 0.5 | 0.5 | ... | 0.0 | 0.25 | 0.075 |
++++++++
| SDQ(1) | 0.5 | 0.5 | ... | 1.0 | 0.75 | 0.925 |
++++++++</td></tr>
<tr><td>ATM</td><td>+++
| ATM(0) | 0.00763359 |
+++
| ATM(1) | 0.992366 |
+++</td></tr>
<tr><td>ER</td><td>+++
| ER(0) | 0.0305344 |
+++
| ER(1) | 0.969466 |
+++</td></tr>
<tr><td>PCW</td><td>+++
| PCW(0) | 0.0458015 |
+++
| PCW(1) | 0.954198 |
+++</td></tr>
<tr><td>F</td><td>+++++++
| AM | AM(1) | AM(1) | ... | AM(1) | AM(1) |
+++++++
| HQ | HQ(1) | HQ(1) | ... | HQ(1) | HQ(1) |
+++++++</td></tr>
</table>

<table>
<tr><td></td><td>| PS | PS(0) | PS(0) | ... | PS(1) | PS(1) |
+++++++
| PXS | PXS(0) | PXS(0) | ... | PXS(1) | PXS(1) |
+++++++
| SDQ | SDQ(0) | SDQ(0) | ... | SDQ(1) | SDQ(1) |
+++++++
| SRQ | SRQ(0) | SRQ(1) | ... | SRQ(0) | SRQ(1) |
+++++++
| F(0) | 0.5 | 1.0 | ... | 1.0 | 0.3669724770642202 |
+++++++
| F(1) | 0.5 | 0.0 | ... | 0.0 | 0.6330275229357798 |
+++++++</td></tr>
</table>

Appendix 2

ANALYSIS OF FATIGUE AMONG SINGAPORE BUNKER TANKER SEAFARERS AND MITIGATION STRATEGIES

My name is Capt. Md. Ranakul Islam. I am perusing MSc in Nautical Science in UMT, Malaysia. The objective of this study is to assess the fatigue level among bunker tanker crew of Singapore. This is part of my thesis to accomplish my MSc degree. It will be highly beneficial for the Singapore bunker industry to understand the reason for fatigue. You can withdraw from the survey anytime if you wish to. Kindly assist me with completing the survey.

1. Kindly Enter/Write Your Name
   ………………………………………………………………………………
2. Please give your consent that by taking part in this survey you are consenting to use data for research. Data will not be disclosed for any other purpose except for the thesis.

   ☐ I consent

   ☐ I do not consent

3. Are you a Singapore Bunker Barge crew?

   ☐ Yes

☐ No

4. Kindly Enter/Write Your
   Rank.…………………………………………………………...

5. Please select your
   department……………………………………………………………..

6. Kindly Mark the below parameters (Caffeine/Coffee intake level)

   ☐ High

   ☐ Normal

7. Kindly Mark the below parameters (Prescribed and non-prescribed medicine intake level)

   ☐ High

   ☐ Normal

8. Kindly Mark the below parameters (Alcohol intake level)

   ☐ High

☐ Normal

9. Diet quality node

☐ Good

☐ Bad

10. Illness Frequency

☐ Frequent

☐ Infrequent

11. Age node

☐ Young (<40 years)

☐ Mid aged (>40 years)

12. Health quality/Health condition level

☐ Good

☐ Bad

13. Ship motion node

☐ Steady

☐ Fast

14. Shift work intensity/ Shift work schedule

☐ Regular

☐ Irregular

15. Ship vibration level

☐ Normal

☐ High

16. Accommodation temperature level

☐ Comfortable

☐ Uncomfortable

17. Ship Noise level

☐ Normal

☐ High

18. Sleep Quality level

☐ Good

☐ Rough

19. Circadian Rhythm Levels

☐ Poor

☐ Normal

20. Jetlag levels

☐ High

☐ Normal

21. Bunkering Schedule Regularity Level

☐ Poor

☐ Normal

22. Sleep disorder level (SDL) node

☐ Normal

☐ High

23. Length of break

☐ Sufficient

☐ Insufficient

24. Rest Break level

☐ More than three per day

☐ Three or less than three-per day

25. Sleep and rest quality level

☐ Good

☐ Bad

26. Performance demand level

☐ Regular

☐ Irregular

27. Shore leave level

☐ Sufficient

☐ Insufficient

28. Traffic density level

☐ Normal

☐ High

29. Family issues level

☐ Manageable

☐ Unmanageable

30. Personal problem level

☐ Manageable

☐ Unmanageable

31. Work load level

☐ Normal

☐ High

32. Psychological stress level

☐ Normal

☐ High

33. Singapore port humidity level

☐ Normal

☐ High

34. Age of vessel node

☐ Young

☐ Old

35. Vessel maintenance level

☐ Poor

☐ Normal

36. Roughness of Sea level

☐ Normal

☐ High

37. Overtime level

☐ Normal

☐ High

38. Physical stress level

☐ Normal

☐ High

39. Crew selection level

☐ Poor

☐ Normal

40. Crew Training level

☐ Poor

☐ Normal

41. Crew complement level

☐ Normal

☐ High

42. Shore Management assistance level

☐ Poor

☐ Normal

43. Crew contract Period level

☐ High

☐ Low

44. Paper work Requirements level

☐ Normal

☐ High

45. Ashore Management level

☐ Good

☐ Bad

46. Ship Redundancy level

☐ Sufficient

☐ Insufficient

47. Automation level

☐ Normal

☐ High

48. Equipment reliability level

☐ Normal

☐ High

49. Physical comfort at work level

☐ Normal

☐ High

50. Ship design quality level

☐ Good

☐ Bad

51. Fatigue level

☐ Yes

☐ No

Submit

Thanks for your participation.

BIODATA OF AUTHOR

Captain Md Ranakul Islam is a highly experienced Master Mariner with three years of commanding foreign-going vessels. He has accumulated 23 years of expertise in the maritime industry, specializing in maritime operations, ship management, and human resources. Captain Islam holds a Master of Business Administration (MBA) in Human Resource Management from Royal Roads University and a Bachelor's degree in Maritime Science from Bangladesh Marine Academy.

He has obtained his Master Mariner competency certificate from the Maritime and Port Authority (MPA) of Singapore. Captain Islam began his shore-based career as a Marine Superintendent at Stellar Ship Management, Singapore, a leading bunker supply company, where he managed a fleet of over 15 bunker vessels. Additionally, he has authored five articles published in various international journals, reflecting his extensive knowledge and contributions to the maritime field.

PUBLICATIONS

Islam, M. R., Ahmed, T., Suhrab, M. I. R., Billah, A., & Sayed, M. A. A. (2022). Relationship Between Fatigue and Work Performance of Malaysian Seafarers. Neuro Quantology, 20(6), 6942.

Islam, M. R., Suhrab, M. I. R., & Fuad, A. F. A. (2024). Unveiling Seafarer's Fatigue: An In-Depth Analysis of Fatigue among Singapore Bunker Tanker Seafarers and Mitigation Strategies. Journal of Harbin Engineering University, Vol 45(1), Page:452-470.

Md Ranakul Islam, Mohammed Ismail Russtam Suhrab, Ahmad Faizal Ahmad Fuad, and Rasyidah Mohd San, Assessment and Mitigation of Seafarer's Fatigue among Singapore Bunker Tanker Crew. International Conference on Marine and Advanced Technologies. Conference paper (Accepted for Publication)

Md. Ranakul Islam, Captain Mohammad Abdullah Abu Sayed, Mohammed Ismail Russtam Suhrab. Factors Affecting Ship's Stability due to Cargo Liquefication: Nickel ore and Bauxite. Specialusis Ugdyams. Vol.1 Issue 43, Pages: 3465-3475.

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