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Contents

COP28 Climate Change Conference of the Parties

Since the Industrial Revolution, the modern world has become dependent on fossil fuels. Almost all of our prosperity and technology has been based on cheap, easily obtained energy from fossil fuels. Getting everyone to agree on something so complicated was not easy. Developed countries were unwilling to bear the costs, while developing countries demanded the right to continue using fossil fuels for economic growth. There were disagreements over historical responsibility, burden-sharing, costs, and science and policy was affected by government changes in key countries – for example, Donald Trump withdrew the United States from the Paris Agreement. On the positive side, the cost of renewable energy and other green technologies has fallen in recent years, even becoming cheaper than fossil fuels in most parts of the world. Electric vehicle technology has also advanced rapidly, and new fuels such as hydrogen are being developed.

In September 2023, before the opening of COP 28, the United Nations published the first two-year assessment of global progress in slowing climate change, called the "Global Assessment". This type of overview was created during COP26 in Glasgow and is scheduled to be repeated every five years. The report says there is a need to phase out fossil fuels. Previously, the United Nations had avoided making similar statements. Among the report's 17 key findings:

- The Paris Agreement and the resulting climate actions have helped significantly reduce emissions. In 2011, the projected temperature rises by 2100 was between 3.7 and 4.8°C. After COP27, the temperature was 2.4-2.6°C and, in the best-case scenario, if all pledges are met, 1.7-2.1°C.
- As of September 2023, the world is not on track to reach the goals of the Paris Agreement. To have a greater than 50% chance of limiting temperature rise to 1.5°C, and a greater than 67% chance of limiting temperature rise to 2°C, global emissions would have to peak by 2025.
- Trillions of dollars are needed to limit temperature rise to no more than 1.5°C. Financial flows must change dramatically.
- More effective international cooperation and synergy is crucial to achieving the goals of the Paris Agreement.

The Chinese representative announced that China, the United States and the European Union agreed to cooperate to ensure the success of the conference. At the beginning of November, insiders cautiously expressed their hope that a climate agreement would be reached between China and the United States before the conference, similar to the 2014 agreement that paved the way for the Paris Agreement. China published a plan to reduce methane emissions before the conference, but there was expected disagreement over coal use in China. China has recently described coal as essential to its energy security, although others say energy security could be improved by modernizing the power grid and the domestic energy market.

On December 13, a final settlement agreement was reached between the countries involved, with the agreement "calling" on all countries to "transition away" from fossil fuels "in a fair, orderly and equitable manner." In order to prevent the worst outcomes of climate change, while "accelerating action in this critical decade, to achieve net zero by 2050 in line with science." The Global Compact was the first in the history of summits to explicitly mention the need to transition away from all fossil fuels, but it continues to receive widespread criticism for the lack of a clear commitment to any fossil fuels. COP 28 concluded with an agreement that signals "the beginning of the end" of the fossil fuel era by paving the way for a rapid, fair and equitable transition, supported by significant emissions reductions and increased financing.

Review of Reliquefication Plant System for Liquified Natural and Petroleum Gas Carriers

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المستخلص:
تؤثر كفاءة عملية تسييل الغاز الطبيعي والبترولي بشكل كبير على القدرة الإنتاجية الإجمالية لسلسلة التوريد، واستخدام الطاقة، والاقتصاد، والسلامة. طور العديد من الأكاديميين عددًا من الأساليب التقليدية وأجروا عددًا من الأبحاث حول مختلف عمليات الغاز الطبيعي المسال/غاز البترولي المسال. تم تلخيص ومناقشة تصميم وتحسين عمليات تسييل الغاز الطبيعي والبترولي خلال السنوات القليلة الماضية في هذه الدراسة ومقارنة وبيان فوائد وعيوب طرق التسييل المختلفة. علاوة على ذلك، تم تسليط الضوء على التطورات السريعة الأخيرة في تكنولوجيا التسييل المضغوط وتطبيقاتها المتوقعة.

Abstract:
The effectiveness of the liquefaction process for natural and petroleum gas is crucial to the supply chains overall production capacity, energy use, economics, and safety. Many academics have developed several traditional methods and undertaken a lot of research on various LNG/LPG processes. The optimization and design of petroleum and natural gas liquefaction processes during the last few years are summarized and discussed in this study. Comparing and contrasting the benefits and drawbacks of various liquefaction methods. Furthermore, highlighted are the recent fast advancements in pressurized liquefaction technology and its anticipated applications.

Keywords: liquefied natural and petroleum gas (LNG/LPG); liquefaction processes; liquefaction plant.

1. Introduction

Due to the rising demand for alternative fuels, the marine transport industry for liquefied gases has grown in importance and the number of gas carriers has increased. Because of the greater material costs associated with transporting the resulting amounts of compressed gases, the gas supply in a liquefied condition is more profitable (Lee et al., 2014).

The energy potential of liquefied petroleum gases (LPG) is substantial. LPG shipping circumstances might change based on the needs of the client and the thermo-physical characteristics of the cargo. The most typical cargoes are butane ($C3H8$) and propane ($C4H10$). Charterers and other parties with business interests are increasingly asking ship-owners to mix LPG before entering the destination nation's territorial waters. In this instance, the International Maritime Organization (IMO) criteria might be followed by mixing the components either during unloading or loading or in tanks aboard the ship itself during transit. The majority of the containers used for component mixing are typically chilled vessels (Rossios, 2015).

Due to a variety of variables, including population expansion and rising living standards, there is an apparent rise in energy consumption. By 2040, it is projected that the world's energy consumption will have increased by nearly one-third, with fossil fuels serving as the primary energy source (Lim et al., 2013). Nevertheless, the burning of these fuels would result in significant emissions of greenhouse gases (GHG), particularly carbon dioxide (CO2). Natural gas (NG) decreases CO2 emissions per unit of energy by about 29% to 44% when compared to coal and oil (Howarth et al., 2011). In addition, because of its reduced air pollution emissions, natural gas is sometimes referred to be a "bridge fuel" for future renewable energy. It has grown to be a desirable energy source and is regarded as one of the cleanest fossil fuels. As a result, NG now supplies approximately 24% of the world's energy, contributing much more to the total demand for primary energy (Nawaz et al., 2019).

The key aspects and most recent findings of the NG/PG liquefaction process will be presented in detail in this review, along with a summary of the state of the science, an analysis of the difficulties in designing and optimizing the process, and recommendations for future study. NG/PG liquefaction process is examined from 2 perspectives: traditional liquefaction process and pressured liquefaction process. As is well known, the liquefaction pressure and temperature have a significant influence on the structure of liquefaction process. The traditional liquefaction procedure is examined. The pressurized liquefaction process' most current developments, application prospects, and some recommendations are displayed. To encourage future study and optimization of the LNG/LPG process, several key results are outlined to assist designers in the LNG/LPG business in making better judgments.

2. Review of literature

Typically, pipelines or liquefied natural gas are the two major alternatives for transporting NG from producing sites to consumers (LNG). Pipelines provide little transportation loss, good security, and are simple to operate. They are also appropriate for continuous operation. Yet, the transit of long-distance pipelines frequently goes via several locations. There are several drawbacks for pipelines in the face of varied geological conditions and barriers, such as the complexity of construction, the rising construction and maintenance cost with the lack of flexibility, and increased transit distance. The usage of pipelines is prohibited in several nations and areas, such as Korea, Taiwan, and a few European nations. Because of the tremendous challenges involved in building pipelines, LNG has emerged as the standard method for resolving all issues related to the storage and shipping of NG across the world (Song et al., 2019).

On the other hand, the abundance of NG in the ocean has sped up the rate of its excavation and consumption in order to satiate the expanding need for natural gas. The Offloading and LNG-Floating Production Storage (FLNG for short or LNG-FPSO), integrates the NG storage, offloading function units, and production. Given the severe offshore circumstances, the limited space, and the high costs associated with transferring natural gas from an offshore extraction platform to an onshore liquefaction facility, may be the best option (Wang et al., 2014). The long-distance transport option that decreases the amount of delivered NG by around sex hundred times through liquefaction is more dependable for reasons related to economics, technology, politics, and security. The "Liquefied Natural Gas (LNG) Forecast Report" from Shell projects that by 2040, there will be 700 million tons of LNG in use worldwide. The quantity of LNG-fueled cargoes is also rising concurrently. By 2021, it is predicted that there will be 45 LNG bunkering boats operating worldwide (Shell LNG Outlook, 2021).

The sector is anticipated to reach an all-time competitive level as a result of the worldwide development of LNG production and rising environmental concerns. Roman-White et al. (2021) ooks at all of the new technologies that have been added to the LNG production line. The writers talk about the need for creativity throughout the full LNG supply chain, from production and liquefaction to shipping, regasification, and sales. They talk about new technologies, such as improvements to gas turbines, floating storage and regasification units (FSRUs), and digitalizing and automating LNG ports.

The study shows how important innovation is for lowering energy use, boosting efficiency, and making the LNG business more profitable. The writers also talk about the possibilities of new technologies like small-scale LNG, carbon capture and storage (CCS), and making hydrogen from natural gas. Up to 60% of the reservoir's capacity may be extracted using such techniques, which include steam, chemical, and water injection. Following extraction, natural gas (NG) is transported to a treatment facility to remove impurities like carbon dioxide, water, nitrogen, oxygen, and hydrogen sulfide to avoid equipment damage or internal corrosion brought on by particulates created during the cooling process. NG may be liquefied using a variety of processes after pretreatment. NG is carried to the receiving station after being liquefied, where it is then gasified once again and brought to the user side (Mazyan et al., 2016).

Refrigeration and liquefaction technologies account for forty-two percent of the total LNG supply chain cost. This is primarily due to the fact that the liquefaction process is carried out in cryogenic temperatures and requires sophisticated refrigeration systems and other equipment. The consumption of large energy caused by the refrigeration cycle compressed power entry has an additional influence on the cost and consumption of high energy of LNG liquefaction production. Hence, if the cost and consumption of the compression power of the liquefaction process can be decreased, the increase in trade growth rate and global competitiveness for LNG would be greatly boosted (Gao et al., 2022).

Operational improvements at various supply chain points can result in significant benefits. For instance, increasing energy efficiency to lower the quantity of fuel needed for conversion of NG in various supply chain activities, resulting in more LNG output with little additional resource use and environmental effect. In addition to being one of the most important thermodynamic processes in the cryogenic natural gas business, NG liquefaction is also the most energy-intensive and expensive link in the supply chain. Gas expansion cycles and Vapor compression cycles are typically the cycles involved in the liquefaction process. The primary difference between these two cycles is that the refrigerant changes phases during the vapor compression cycle, but the refrigerant does not change states during the gas expansion cycle (Katebah et al., 2020).

Aside from the heat burden being distributed over the temperature range from room temperature to LNG's low temperature, the cycle in this operation is essentially comparable to a closed refrigeration cycle. Also, an exergy study demonstrates that temperature difference is the main cause of cryogenic heat exchanger's exergy damage, as it is the factor that determines the larger compression stress in the LNG main heat exchanger. To minimize such differences, refrigerant composition, flow rate, and operating pressure may all be optimized in LNG cryogenic heat exchangers. Various liquefaction methods need varied energy-using machinery, operations, and financial investments. Several academics have examined the fundamental theories and operating principals of numerous NG liquefaction technologies, along with diverse refrigeration cycle characteristics, and produced several NG liquefaction methods (Wang et al., 2014).

These procedures are broken down into three groups based on the types of refrigeration cycles and equipment that are now on the market: expander liquefaction, cascade liquefaction, and mixed refrigerant liquefaction. The three refrigeration cycles that make up the cascade liquefaction process often have different temperatures. The most common refrigerants are ethylene, methane, and pure propane. In the mixed refrigerant liquefaction process, there is just one refrigerant cycle made out of a light hydrocarbon combination. Moreover, the refrigerant in the expander liquefaction process is often pure nitrogen or methane. Although these refrigerants can achieve the low temperature needed for single-loop LNG, they are less efficient than cascade liquefaction and mixed refrigerant liquefaction processes. In general, these three types of liquefaction processes are improved upon or combined in actual liquefaction operations. Based on their features, several NG liquefaction methods are applied in various NG liquefaction unit types (Zhang et al., 2020). Here are some of the most commonly used NG liquefaction methods and the unit types in which they are applied:

Cascade liquefaction: In this method, the natural gas is cooled in a series of heat exchangers where it is cooled by a refrigerant, usually nitrogen or methane, which is itself cooled in a separate cycle. This method is commonly used in large-scale liquefaction plants, such as those used for baseload LNG production.

Mixed refrigerant liquefaction: This method uses a mixture of refrigerants, typically propane, ethylene, and methane, to cool the natural gas. The refrigerant mixture is cooled in a separate cycle and then circulated through the heat exchangers to cool the natural gas. This method is commonly used in medium-sized to large-scale LNG plants.

Single mixed refrigerant liquefaction: In this method, a single refrigerant, such as methane or ethylene, is used to cool the natural gas. This method is suitable for small to medium-sized LNG plants.

Expander liquefaction: In this method, the natural gas is expanded through a turbo-expander, which cools it to produce LNG. This method is commonly used in small-scale LNG plants, such as those used for peak-shaving or remote power generation.

Nitrogen cycle liquefaction: This method uses a nitrogen refrigeration cycle to cool the natural gas. This method is typically used in small-scale LNG plants.

LNG hybrid liquefaction: This method combines two or more of the above liquefaction methods to optimize efficiency and reduce costs. For example, a hybrid liquefaction plant may combine a nitrogen cycle with a mixed refrigerant cycle to produce LNG.

The choice of liquefaction method and unit type depends on various factors such as the scale of production, the location of the plant, and the availability of refrigerants. By selecting the most appropriate NG liquefaction method and unit type, LNG producers can optimize efficiency, reduce costs, and meet the growing demand for natural gas.

Onshore production and offshore production are two categories for natural gas liquefaction units based on the manner of production. They may also be divided into peak-shaving type, base-load type, and other small-scale liquefaction units, depending on the application. The drastically varying operating conditions, production capacities, and operating procedures result in different requirements for the liquefaction process depending on the production method and application. The mature cascade liquefaction procedure was mostly employed in the early 1960s for building NG liquefaction units. It changed to a much-streamlined mixed refrigerant liquefaction technique in the 1970s. Following the 1980s, the APCI-proposed propane pre-cooled mixed refrigerant liquefaction technique was primarily used in the newly constructed and extended base-load NG liquefaction facilities. The subsequent development of small-scale NG liquefaction units, peak-shaving liquefaction units, offloading units and offshore FLNG production storage, etc., has focused on all the requirements of NG liquefaction aspects, continuously challenging the optimization and design of NG liquefaction processes. According to the literature, few research have investigated the safety of the liquefaction process, with most LNG supply studies concentrating on lowering energy usage and increasing economics. The optimization of the liquefaction process, the recovery of heavy hydrocarbons, a comparison of the proportioning content of refrigerants, a safety study of LNG and FLNG leaks, and other difficulties may be classified as the major concerns in the LNG supply chain **(Gao et al., 2022).**

3. Data collection

The key aspects and most recent findings of the NG/PG liquefaction process will be systematically presented in detail in this review, along with a summary of the current state of the research, an analysis of the difficulties in designing and optimizing the process, and recommendations for future study. The compressive search was conducted by using the databases: MEDLINE/PubMed and the following free keywords e.g.: liquefied natural and petroleum gas (LNG/LPG), liquefaction processes, liquefaction plant.

4. Comparative review based on traditional and advanced liquefaction techniques

Several review papers have examined the progress of NG liquefaction technologies, with varying review emphases **(He et al., 2018; Zhang et al., 2020; Katebah et al., 2020)**. **Ros-Mercado et al. (2015)**, for example, addressed the NG transportation system. Chang (2015) investigated how to improve the structural efficiency of refrigeration cycles using NG liquefaction technology. Similarly, Lim et al. (2013) focused on the commercial refrigeration cycles of the LNG process. Other evaluations, such as those on FLNG technology or the mixed refrigerant liquefaction process, only summarized one kind of LNG process.

The extensive categorization and explanation of the LNG process by **Khan et al. (2017)** neglected the application variations between onshore and offshore liquefaction as well as their respective optimization needs. **Mazyan et al. (2016)** also highlighted emerging technologies like solar energy, NG solidification, and thermoacoustic that improve the efficiency of the liquefaction and regasification processes. The significance of LNG technology optimization was not addressed in **Zhang et al.'s (2020)** recent in-depth examination of the condition of numerous LNG process types. Several scientific groups from several countries have conducted research on the methods used in gas reliquefication systems.

Saputra and Supramono considered the LPG carrier reliquefication facility with a capacity of 20 tons per day in 2019. The ship carries cryogenic liquids as well as LPGs (butane and propane) and ethane, ethylene, and methane. A cascade refrigeration machine is used in the refrigeration system. The thermodynamic analysis of a reliquefication plant utilizing the exergy technique has been explored experimentally. Nanowski (2013) published the results of an investigation of the butane reliquefication plant in order to evaluate the probable loading rate.

Gómez et al. (2013) investigated numerous BOG reliquefication processes on the LNG ships' board based on economic factors and energy efficiency. Many technologies were described, analyzed, and discussed. This enabled the operational and technical elements, as well as the selection criteria for the reliquefication plant, to be highlighted. Several re-liquefaction facilities have been compared based on their effectiveness and performance, as well as other technical facts. Kwak et al. (2018) investigated the Boil-Off Gas (BOG) reliquefication facility, which decreases methane losses on small-scale LNG carriers. The gas turbine is a closed-cycle model using nitrogen as the operating fluid.

Tan et al. (2018) proposed an upgraded BOG reliquefication system for LNG ships. Two mixed refrigerant cascade cycles (also known as dual mixed refrigerant cycles, or DMR) are used to provide the reliquefication of BOG cooling capacity. The energy efficiency of the new system is assessed using the exergy approach of thermodynamic analysis for stationary modeling in Aspen HYSYS. It is recommended that any changes to operating parameters that affect system performance be considered. To improve the performance of LNG BOG reliquefication units on gas carriers, Kochunni and Chowdhury (2021) proposed adding a 2-stage transcritical CO2 refrigerating machine to LNG reliquefication systems powered by the Claude and Brayton thermodynamic cycles. Their efficiency is equivalent to that of reliquefication systems, which compress flammable refrigerant gases such as ethylene or propylene while operating in cascade cycles. The researchers discovered that the new technology reduces weight and size while enhancing energy efficiency and providing reliable fire protection.

A review of the aforementioned studies revealed that while there aren't many articles on the subject of systems for the study of reliquefication of petroleum gas, researchers concentrate on LNG transportation systems because they believe they are the most in demand.

4.1 Reliquefication plants

4.1.1 LNG reliquefication plants basics

The evaporated gas circle and the nitrogen cooling circuit are the two primary circles of a reliquefication facility. The LPG separator, LNG pump, evaporated gas cooler, compressors, heat exchangers, and evaporated gas circle are all parts of the evaporating gas system (when the system pressure is lower than the pressure in the cargo tanks, pump is used in these special circumstances). The circle of nitrogen cooling is made up of heat exchangers, a nitrogen dryer, a nitrogen booster compressor, a compressor, a nitrogen receiver, and nitrogen.

The main purpose of an evaporated gas cooler is to keep the gas entering a heat exchanger at a consistent temperature. The efficiency of the compressor is increased by the gas cooling, which raises gas density and increases the gas mass flow by the compressor. A cargo tank recirculating and cooling pump is used to pump liquefied natural gas into the evaporated gas cooler for cooling purposes ("spray"). The capacity of a centrifugal two-stage compressor for evaporating gas is often modified by rotating the first and second stage's blades. In this manner, the pressure on the compressor discharge side is maintained while only the capacity changes.

Maintaining the default cargo tank pressure and raising the gas pressure before it enters the heat exchanger are the major duties of the evaporated gas compressor. The temperature of condensation rises with increased pressure, enhancing the plant's total efficiency. By exchanging heat with cool nitrogen, the heat exchanger's primary job is to de-liquefy evaporated gas. A three-stage radial compressor, the compressor is powered by an electric motor through a gear or gear box.

4.1.2 Natural gas reliquefication plant main characteristics

The LNG reliquefication facility of ship needs to adhere to the following standards (Mokhatab et al., 2013):

•The capacity of the reliquefication plant is typically designed to handle a certain percentage of the cargo boil-off, rather than 100% of the boil-off gas, particularly in cases where the boil-off rate is high or the size of the reliquefication plant would be prohibitively large.

•Installing a gas combustion unit (GCU) is a necessary alternative for reliquefication plants.

•Since the nitrogen in evaporated natural gas cannot be deliquefied, the nitrogen concentration in natural gas decreases. Combustion in the gas combustion unit removes non-condensed nitrogen,

•The system must be capable of stopping the reliquefication when the cargo pumps are operating, eliminating the need for extra generators, and it must have automated capacity management.

• Mokhatab et al. (2013) use a nitrogen generator to produce the nitrogen, which is employed as a refrigerant and maintains its gaseous form during the whole cooling operation.

4.1.3 Natural gas liquefaction Thermodynamic basics and optimization

The typical components of the liquefaction system installed aboard ships for the transportation of natural gas include:

– closed refrigeration cycle and

– Cargo cycle.

Mixed Refrigerants (MR) in the Joule-Thomson circle (JT) in a closed refrigeration cycle may often reduce the temperature difference with a minimal number of built-in components. Nevertheless, because such mixes are difficult to install on board ships, only pure cooling media are present in the systems on board for the liquefaction of natural gas. Pure media are simple to use, but they require more cooling in terms of degrees. The reverse Brayton nitrogen cycle has been shown to be the best option for a closed refrigeration cycle for ship systems. The benefits include the capability of manufacturing nitrogen in a ship's nitrogen generators, cheap acquisition costs, safe operation, and non-flammability at pressures more than hundred bar (Vorkapić et al., 2016).

One drawback is that an expansion turbine cannot function in a two-phase environment (gaseous and liquefied phase). The turbine may sustain irreparable damage in the event of partial liquefaction when droplets penetrate the blades, which are rotating at a periphery speed of 200–300 m/s. Thus, it is important to take precautions while developing a process to make sure the liquid phase never reaches the turbine.

As a result, the Brayton cycle is unable to create liquid; as a result, the cycle's cooling impact is constrained, and boil-off temperature control is diminished. Another issue is that the turbine demands a large amount of coolant flow even with the lowest rotor diameter, which lowers the system's cooling capacity to just approximately 500 W. The shipboard installations are unaffected by this restriction, though. It is crucial to lessen the entropy produced by the difference in temperature (T) in a cryogenic heat exchanger since natural gas is mostly a combination of hydrocarbon gases, and the specific heat varies with temperature at different times in the liquefaction process. As in the T-s diagram in Figure 1 Nitrogen refrigeration cycle (Vorkapić et al., 2016):

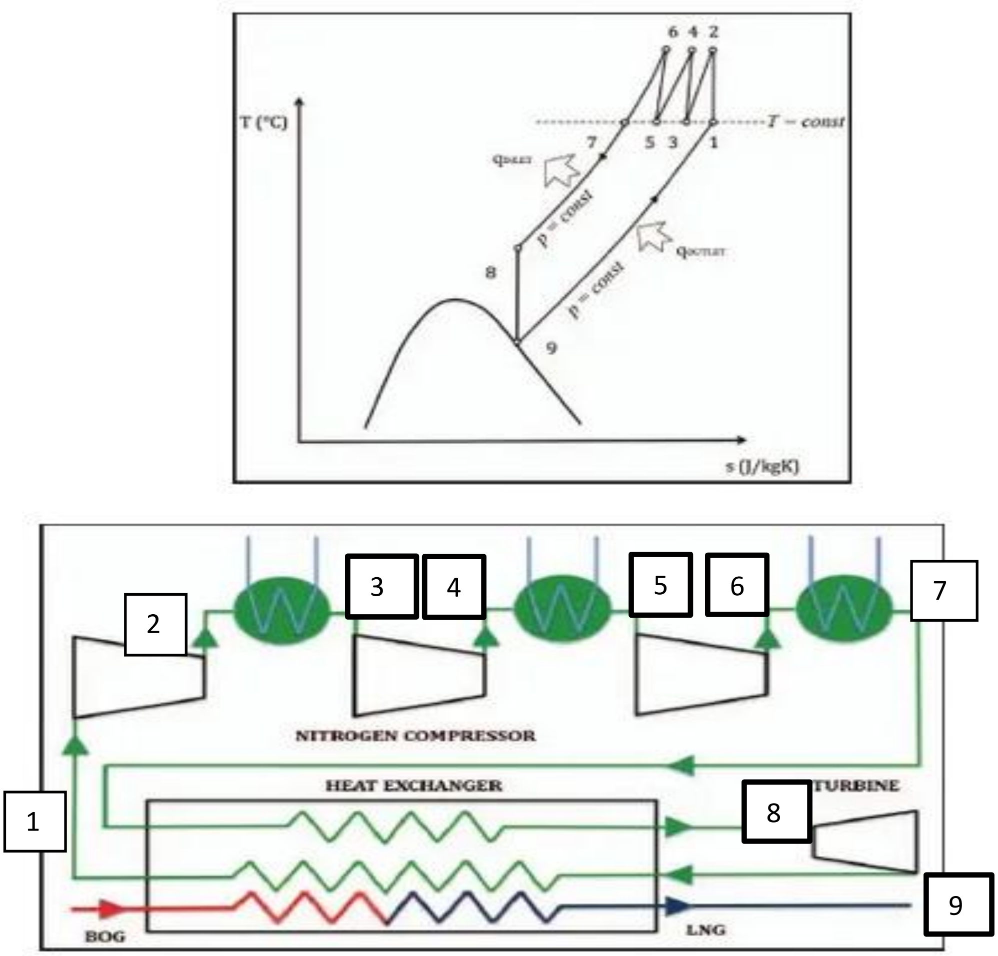

Figure (1): Refrigeration cycle of Brayton closed nitrogen.

Three-stage adiabatic compression of nitrogen with heat removal in coolers between stages one–seven, further cooling of gas at constant pressure between stages seven-eight, adiabatic expansion in the cryogenic expansion turbine between stages eight–nine, and cargo expansion at constant pressure between stages seven-nine. Once the first and second compression stages are completed, the gas goes through intermediate coolers (two-three; four-five), and the 3rd compression stage is completed with a cooler (six-seven). The compressor consists of a 3-stage compressor that is powered by an electric motor mounted on the same axis as the cryogenic turbine. When gas expands, some of the energy it has already used is partially recovered, which lowers the amount of electricity needed to run the compressor. A cascade refrigeration cycle using ethylene and propylene is an alternative to the Brayton nitrogen refrigeration cycle.

Three cycles make up the liquefaction process: natural gas, propylene (C3), and ethylene (C2). To lessen the temperature disparity in the exchanger, natural gas is compressed in 3 Stages as opposed to the two stages used in closed ethylene and propylene cycles. The closed refrigeration cycles C2 and C3 are shown in **Figure 2**, and they include adiabatic compression in 2 stages (one-two and three-four), intermediate cooling at constant pressure (two-three) and condensation (four-five at C3), expansion in the valve-Joule Thompson (five-six) along the heat transfer, and constant enthalpy curve at constant pressure in the primary heat exchanger (six-one). The Brayton cycle's thermodynamic efficiency can be increased by adding an extra pre-cooler and expansion turbine **(Vorkapić et al., 2016).**

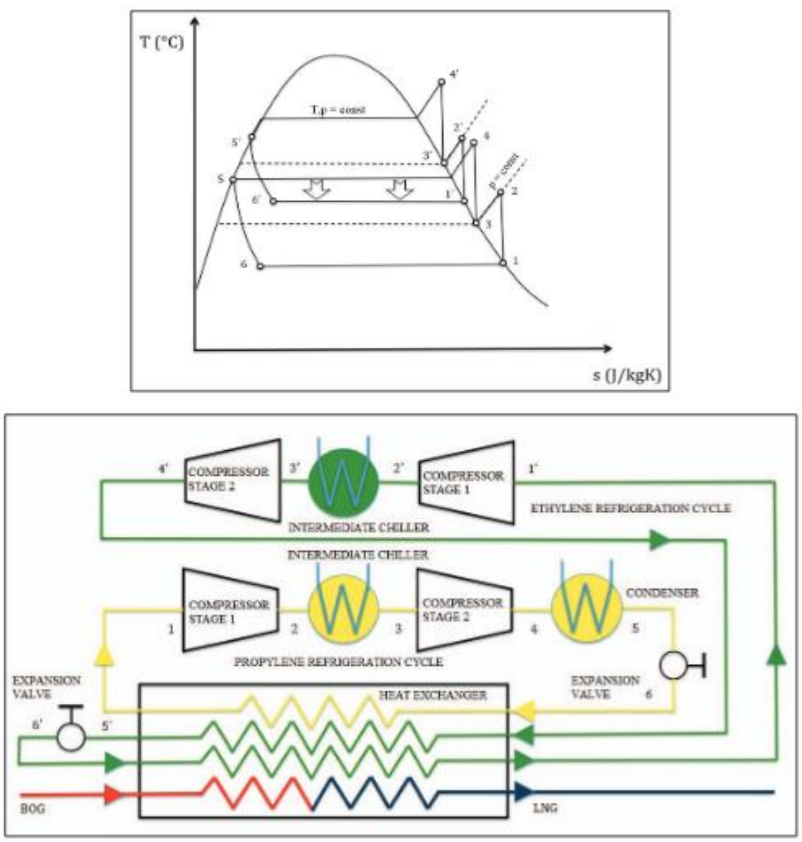

Figure (2): ethylene and propylene Cascade refrigeration cycle

While the Brayton concept with the expansion turbine is thermodynamically more effective, Joule-Thomson expansion is useful for cycles when it is important to produce lower temperatures. The Claude cycle, which liquefies natural gas with outstanding results, combines turbine expansion with damping. The Kapitza cooling cycle, which is characterized by lower costs and better operability, is created when the 3rd heat exchanger is removed after the nitrogen compressor (Vorkapić et al., 2016).

4.1.4 Liquefaction systems

While developing the ship's liquefaction systems, the following factors should be considered when selecting an appropriate system:

- Possibility of use in certain navigational situations (rolling, pitching)
- The liquefaction technology previous experience
- Restricted installation space
- Possibilities of stopping and sudden starting up
- Simplicity of installation
- Simple to use
- crew, cargo, environment, and ship Safety
- Cost
- recommended redundancy

There are still 4 more operational criteria that have an impact on the choice in addition to the primary requirements mentioned above:

- Boil-off cargo Liquefaction pressure
- Cargo system
- Boil-off gas Temperature
- capacity of System

4.2 Pressurized Liquefied Natural Gas Process

In comparison to traditional liquefaction technology, the idea of pressurized liquefied natural gas (PLNG) technology has been put forth. In order to raise the LNG storage temperature and sustain greater pressures across the whole LNG transportation transport chain, it is necessary to chill natural gas (NG) to an intermediate temperature for liquefaction. The purification and liquefaction of natural gas using PLNG technology is both technically and economically advantageous, although storage and transportation cost more money. The entire project cost can be decreased, the benefits of PLNG technology can be completely utilized, and the application scope can be increased by planning and optimizing transportation costs and production costs through a suitable PLNG process.

4.2.1 PLNG Process and traditional LNG Process Comparison

NG that has been cooled to around one hundred eleven K is transformed into products of LNG for storage at a pressure of about 0.1 MPa using the conventional LNG process. With a pressure range of 1.0–7.6 MPa, the PLNG process can produce products of LNG with a temperature range of 150–211 K, which is roughly thirty-nine–hundred K higher than that of traditional LNG products.

When considering the storage and liquefaction as well as overall costs technical requirements, it is more appropriate to use a pressure of one-two MPa for pressurized liquefaction, where the comparable temperature of natural gas liquefaction is around 153-173 K (Xiong et al., 2016). When pressurized NG is cooled to an intermediate temperature for conventional liquefaction, the goal of liquefaction storage may be realized, which allows for a considerable reduction in liquefaction operation costs and energy consumption for the PLNG process. When compared to traditional liquefaction, the PLNG method requires less pretreatment of the input gas and offers a novel way to lower CO2 emissions throughout the LNG process. The CO2 concentration in LNG products should be kept below fifty ppm because, in the case of the traditional liquefaction process, CO2 must be rigorously eliminated from input gas in the event that it solidifies at low temperatures and causes blockages (Lee et al., 2018). Temperature greatly affects CO2 solubility in methane. As the increase in temperature dramatically increases the solubility of CO2 in LNG products. The higher temperature also makes aromatics and other heavy hydrocarbons more soluble in LNG products, enhancing the PLNG process's tolerance for these elements in input gas (Xiong et al., 2016). By lowering the required CO2 content in the input gas, the PLNG method helps to eliminate the necessary auxiliary equipment for traditional liquefaction, such as CO2 removal equipment and heavy hydrocarbon scrubbing towers, which streamlines the manufacturing process and uses less energy. The process structure can be made simpler by raising the liquefaction and storage temperatures. And because there are fewer pieces of equipment, the accompanying expenses are around half those of a traditional LNG facility. Also, the PLNG process is crucial in preserving occupied parts of the LNG production system, opening the door to LNG production in a constrained space. The increase in product storage pressure in the PLNG process creates more demands on the transportation and storage linkages than does the traditional liquefaction process. Small, thick-walled storage tanks are typically used for PLNG storage in order to provide appropriate pressure-bearing capability; however, because these tanks are carried in clusters, their weight and production costs are increased. Moreover, after being heated and pressurized, LNG loses density, necessitating greater storage space in order to carry goods of the same quality while also raising the cost of transportation. The economic benefits of the PLNG process in liquefaction and purification, as well as their impact on costs of transportation, should be carefully considered when comparing and weighing the advantages and disadvantages of various pressure liquefaction methods.

5. Conclusion

The robust growth of LNG/LPG production has been encouraged by the high demand in the market for natural and petroleum gas consumption on a worldwide scale. The level of liquefaction technology has a direct impact on both the commercial profitability of natural gas providers and the cost of usage for customers. The potential for using LNG/LPG processes has expanded due to related advancements including boosting onshore LNG/LPG production capacity, enhancing the exploitation of sporadic small gas sources, and researching novel methods to transition from shallow to deep waters. This paper examines the discrepancy between liquefaction process research and practical operating needs based on current liquefaction process development. It also defines the primary issues encountered as well as potential future development paths. This makes it possible for the next researchers to produce better optimization and design outcomes for real-world projects and advance LNG/LPG applications.

6. Recommendations

- The production of LNG involves many feed gas liquefaction components. Attention must be given to both the overall improvement in combination with BOG cycle re-liquefaction process and the NGL recovery process as well as consumption of energy at all stages of the natural gas cooling process to increase the liquefaction process's energy efficiency.

- The author suggests conducting more searches of best evidence, current contents, and previous reviews, personal contact and examination of cited reference sources, and discussion with several experts in the field.

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Ranking Seafarers' Duties towards Unmanned and Autonomous Ships in Prospective of STCW

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المستخلص

تشهد صناعة النقل البحري تحولاً جذرياً في أدوار و قدرات العاملين في البحار بسبب الإبتكار التكنولوجي السريع نحو السفن غير المأهولة والمسيّرة ذاتيًا. تُعد هذه التطورات تحولًا أساسيًا يؤثر بشكل جوهري على الطريقة التي يشارك بها البحارة في أدوارهم ومهامهم ومسؤولياتهم على متن تلك السفن. لذلك، أحدثت التقنيات الناشئة والأتمتة والرقمنة ثورة في العمليات البحرية التقليدية، مما أدى إلى ضرورة إعادة تقييم الكفاءات والمهارات اللازمة للبحارة. تمتاز هذه السفن بأنها مجهزة بأنظمة تحكم معيارية متقدمة وتكنولوجيا اتصالات عن بُعد متطورة؛ لم تستحوذ هذه السفن على خيال المجتمع البحري العالمي فحسب ، بل إستدعت أيضًا أعتبارات تنظيمية عاجلة من قبل المنظمة البحرية الدولية (IMO). بالإضافة إلى ذلك، تحمل الأتفاقية الدولية لمعايير التدريب والإجازة (إصدار الشهادات) والخفارة (النوبات الملاحية) للملاحين علي ظهر السفن (STCW) أهمية مركزية وموقرة تضمن أمتلاك البحارة المعرفة والمهارات والكفاءات اللازمة لأداء واجباتهم بشكل مؤثر وأكثر فعالية.

ومع ذلك، تنبثق نقص المعايير النموذجية الخاصة باتفاقية STCW والمصممة بشكل دقيق لمعالجة السفن غير المأهولة والمسيّرة ذاتيًا، مما يدفع إلى إجراء فحص نقدي وتحليل عميق لأدوار وقدرات البحارة في هذا السياق المتطور. وبالتالي، يُهدف هذا البحث إلى تصنيف واجبات البحارة تجاه السفن غير المأهولة والمسيّرة ذاتيًا في ظل غياب الإرشادات ضمن اتفاقية STCW وذلك من خلال تحليل AHP حيث تظهر النتائج أن إدارة تلك السفن تُعتبر العامل الأكثر أهمية.

ABSTRACT

The maritime industry is experiencing a transformative shift in seafarer roles and capabilities due to rapid technological innovation towards unmanned and autonomous ships. This evolution is fundamentally altering the way seafarers engage with their roles, tasks, and responsibilities onboard ships. Therefore, emerging technologies, automation, and digitalization have revolutionized traditional maritime operations, leading to a reevaluation of the competencies and proficiencies required of seafarers. These ships are equipped with sophisticated modular control systems and cutting-edge remote communication technology; these vessels have not only captured the global maritime community's imagination but have also necessitated urgent regulatory considerations by the International Maritime Organization (IMO). In addition, the Standards of Training, Certification, and Watchkeeping (STCW) Convention holds a central and time-honored significance to ensure that seafarers possess the necessary knowledge, skills, and competencies to perform their duties effectively.

However, the lack of specific STCW guidelines precisely tailored to address unmanned and autonomous ships prompts a critical and introspective examination of the roles and capabilities of seafarers in this evolving context. Hence, this paper aims to rank the duties of seafarers towards unmanned and autonomous ships in the absence of guidelines within STCW through AHP analysis. The results show that ship management is deemed the most important factor.

Keywords: Unmanned ships, Autonomous ships, STCW, Seafarers

1. Introduction

The maritime sector is experiencing a significant rise in automation and digitalization, with a growing focus on the development and interest in unmanned, remotely controlled, and autonomous vessels (Porathe et al., 2018). This wave of technological advancement is closely tied to the ongoing reevaluation of the STCW convention. The evaluation is essential to delineate the competencies and capabilities skills that will be essential for seafarers in future ship operations within the realm of autonomous shipping. It necessitates careful consideration of how seafarers' roles and duties will be shaped and enhanced in the context of unmanned and autonomous vessels (Ringbom, 2019).

Simultaneously, the introduction of autonomous ships presents legal challenges and questions regarding how seafarers' duties will be redefined and what adaptation will be required in international and national regulations. As these ships become a reality, understanding how the legal framework can effectively accommodate and regulate their use while upholding the rights and responsibilities of seafarers is paramount. Moreover, integrating safety measures and ensuring compliance with conventions like the Convention for Safety of Life At Sea (SOLAS) are vital elements in aligning the deployment of autonomous ships with seafarers' duties and maintaining a high standard of maritime safety.

Each state must effectively exercise its authority over administrative, technical, and social issues and take the required steps for ships flying their flag to maintain maritime safety. A law stipulates that every vessel must have a master and officers who are trained in maritime, navigation, communications, and engineering. These specifications were acknowledged by flag nations for conventional ships. These flag states responsibilities were undoubtedly established for traditional ships with a master and his crew. However, in the context of Maritime Autonomous Surface Ships (MASS), these criteria may pose significant challenges regarding seafarers' duties and capabilities, demanding a reevaluation within the framework of STCW. There are some issues with how these clauses are interpreted in relation to unmanned ships. The most severe view would be that unmanned ships are prohibited because there is no qualified master and officers present, making them unlawful. Then, it is up to the flag state to forbid the unmanned ships. It would not be advisable to accept this interpretation because it is the most antiquated (Boviatsis et al., 2022). This integration of legal perspectives and evolving technologies necessitates a careful examination of how seafarers' roles align with the changing landscape of maritime autonomy under the context of STCW.

Because there is no longer a need for the master and officers to be in command of an autonomous ship, this might be a potential resolution. As a result, the clause referring to this particular responsibility would no longer be applicable. For unmanned and autonomous ships in particular, this interpretation would be the most intriguing. Another option is for the Shore Control Center (SCC) to interpret these responsibilities by analogy. According to this view, the ship's operator would be regarded as the master, and he would be required to fulfill the obligations and responsibilities of a master. However, a shore-based vessel controller's duties will likely differ from those of the ship's master. Additionally, given the radically different working environment and circumstances, it would not be the ideal approach to merge the shore-based ship controller with the ship's master when considering the various responsibilities in other conventions (Van Hooydonk, 2014).

The significance of Maritime Autonomous Surface Ships (MASS) concerning the competence criteria of seafarers at a global level should not be underestimated. As we transition towards highly automated, remotely controlled, or autonomous solutions, the established routines of ship operations and the roles, duties, and responsibilities of key shipboard senior staff will undergo radical transformation compared to traditional shipboard organization (Kitada et al. 2018). The continuation of these roles might even be at risk (Sharma et al. 2019). The manner in which ships and their seafarers adapt to these evolving work dynamics holds critical implications for the safety and dependability of ship operations. The knowledge, skills, and ability (KSA) as stipulated in the STCW, which have historically ensured safe and efficient operations, may not retain the same relevance or effectiveness with increased automation (Sharma et al. 2019). Thus, it is imperative to re-identify and ranking the STCW duties in this new context to effectively harness the potential of autonomous shipping.

Based on the demonstrated deficiency in STCW guidelines regarding unmanned and autonomous ships, the current study aims to rank the duties and capabilities of seafarers towards unmanned and autonomous ships in view of STCW by applying AHP analysis.

2. The Legal Status of an Unmanned and Autonomous Merchant Ship

First, the IMO disclosed the results of the regulatory scope research for using maritime autonomous surface ships (MASS), which were released on June 3, 2021, and which defined Degrees of Autonomy to be four degrees, namely (IMO, 2021)

1. **Degree One**: despite some operations being automated and unattended, seafarers remain present on board and in charge of the vessel's operation and navigation.
2. **Degree Two**: crew staff aboard remotely operated ships have the ability to operate the ship entirely from an SCC, giving them complete control.
3. **Degree Three**: ships that can be remotely operated but have no crew members aboard—operation of the ship from an SCC without workers.
4. **Degree Four**: without the aid of an SCC, a fully autonomous ship's operating system is suitable for independent navigation and operation.

On November 21, 2021, the IMO published the fifth iteration of the MASS UK Industry Conduct Principles and Code of Practice. This version divided six degrees of automation into the same levels amount (UK INDUSTRY, 2021):

- **Level 0**: When a crew on board controls each phase of navigation, including vessel command, monitoring and reacting to the navigational environment, and executing dynamic navigation tasks as a backup, there is no need for automation. Because of this, there is no remote control of any type, and all mechanical parts, including radar, are used to facilitate navigation, which is only done by the ship's master.
- **Level 1**: the ship's master is in charge of the remaining navigational responsibilities and is predicted to watch for and respond to any threats while the steering automation system steers the vessel with steering assistance.
- **Level 2**: In the case of partial automation, a navigation automation system directs the automation and steering of the ships. The remaining navigating duties and keeping an eye on the system are the shipmaster's responsibility. Up to this level, the ship's navigation is not done using remote controls (incorporating Degree 1 of the IMO's previous study).
- **Level 3**: When a navigation system, like as collision avoidance, is used conditionally, the shipmaster is still available to intervene and address any issues that may occur. After this level, installing remote-control systems is viable with no change to the minimum labor or qualification requirements (incorporating Degree 2 of the IMO's previous study).
- **Level 4**: High automation, where the navigation automation system performs all dynamic navigational activities, including backup procedures, immediately and without awaiting the shipmaster's response. Only specific navigational elements require human involvement (incorporating Degree 3 of the IMO's previous study).
- **Level 5**: whereby the navigation automation system handles and fully automates all dynamic navigation duties (incorporating Degree 4 of the IMO's previous study).

The navigation automation system aids the ship's navigation in the first three stages of automation because it is obvious that the vessel does not have a remote control fitted (Poornikoo, 2022). Any navigational mistakes are therefore solely the ship's master's fault. Because the ship's master is eventually accountable for responding to system issues, the third degree of automation is necessary even though the navigation is performed by the installed navigation automation system. When a ship is automated to Level 4, the navigation automation system is accountable, and the master is solely responsible for the specific navigational tasks that have been assigned to them. At this point, responsibility is only transferred to the SCC. At Level 5, there is also no risk related to the human element. Only those automated systems that are specifically designed for ships (Choi, 2022).

3. Adapting Seafarer Roles in the Era of Evolving Maritime Operations

The maritime industry is witnessing a transformative shift in the dynamics of seafarer roles and responsibilities within the realm of maritime operations. Traditionally, seafarers have been the linchpin of ship operations, responsible for a multitude of tasks vital for safe and efficient maritime transportation. However, with the integration of advanced technologies and the emergence of autonomous shipping, the nature of seafarer roles is evolving. Automation and digitalization are reshaping the functions aboard ships, challenging the conventional reliance on a significant human presence for operation. Seafarers are now expected to adapt to and integrate with automated systems, necessitating a shift in their competencies and skill sets. They are becoming operators of sophisticated technologies, coordinators of autonomous systems, and overseers of safety measures. This evolution demands a proactive approach to revising training, certification, and operational frameworks, as outlined by the STCW convention. The STCW needs to reflect these changing dynamics, ensuring that seafarers are adequately prepared and capable of navigating this new era of maritime operations (Shahbakhsh et al., 2022)

4. Duties and Capabilities of Seafarers

The ship's master carries significant legal responsibilities in both private and navigational realms. Primarily, they are tasked with crew management, navigation, and crucial safety decisions for the vessel. Their authority involves various obligations, with ensuing responsibilities in case of non-compliance. Furthermore, the ship's master holds a legal duty to represent the ship owner, albeit with diminishing scope due to evolving regulations and technological advancements. The rise of unmanned and autonomous ships has altered the landscape, enabling direct task commissioning and contractual agreements between the shipowner and the SCC manager, reducing the former captain's once-essential role. These transformations highlight the evolving nature of seafarers' duties and responsibilities in the maritime industry.

Granting the SCC manager equal authority to the ship's master may not be wise. The employment contract between the shipowner and the SCC could restrict urgent situation handling, aligning with the new Belgian Maritime Code's suggestions (Van Hooydonk, 2014). The ship's master also acts as the cargo owners' agent, with the authority to seek court permission for cargo sale if the consignee rejects delivery. However, determining responsibility without a captain on board and an uncooperative consignee is complex. Delegating this to a local agency could be more suitable, considering the SCC manager's likely distance from the ship, cargo, and consignee and limited involvement in cargo handling.

In the realm of unmanned and autonomous ships, there's a growing concern surrounding the traditional roles of ship captains. Existing mandates, like the requirement for a captain's physical presence during port or river entries according to Article 64 M.C., pose challenges for unmanned vessels where no onboard presence is expected. Similarly, Article 74 of the Merchant Marine Code, emphasizing the captain's responsibility for a voyage, might shift to the (SCC) due to their critical role in ensuring safe and timely arrivals, necessitating legal provisions to define their criminal culpability. Regulations like Article 77 M.C. regarding passenger and crew evacuation lose relevance without a physical onboard presence, presenting a shifting landscape of duties and capabilities. Additionally, assisting mariners and vessels in need, a vital duty outlined in Articles 62 and 63 of the Criminal and Disciplinary Code, requires reevaluation and potential new rules when unmanned and autonomous ships encounter vessels in distress. These changes underscore the evolving duties and responsibilities of seafarers in the context of advancing maritime technology and autonomous vessels.

5. Maritime Security in the Age of Unmanned and Autonomous Ships

In maritime law enforcement, seafarers hold critical responsibilities in verifying suspect ships' nationality and conducting inspections as per Article 110(2) UNCLOS regulations. However, when dealing with suspicious unmanned vessels, their roles become more challenging due to the absence of a crew or a master to assist in vital procedures and ensure safety during boarding (Allen, 2018). The emergence of unmanned ships raises questions about the possibility of utilizing remote or virtual methods to establish nationality and inspect cargo without physically boarding. While remote identification of a ship's nationality is feasible through hull marks, the legal implications of determining the nationality of ships using digital means need careful consideration (Schmitt, 2017).

In this evolving landscape, automated technologies enable remote inspections, presenting possibilities for both unmanned and traditional manned ships. However, the legality of remote or virtual exercises depends on adherence to specified safeguards (Article 8bis of the SUA Convention, 2005). Challenges arise when verifying unmanned ships due to the absence of personnel to verify essential credentials, potentially affecting the validity of remote exercises (Schmitt, 2017). Careful consideration of these aspects is crucial for maritime law enforcement actions involving unmanned ships. In this evolving landscape, seafarers' roles must adapt and align with advancements to ensure effective compliance and enforcement.

6. Research Methodology

The Analytic Hierarchy Process (AHP) is used to rank the duties and capabilities of seafarers towards the unmanned and autonomous ships within the view of STCW. AHP is a method that establishes priority scales based on expert judgment and measurements through pairwise comparisons. It has been one of the methods for multiple criteria decision-making that is most frequently used (Russo and Camanho, 2015).

In conducting the AHP with pairwise comparisons completed through a questionnaire distributed to 25 experts, the cumulative session making process is unfolded through a structured sequence. Initially, a comprehensive questionnaire is meticulously designed based on the hierarchy of criteria and sub-criteria, encompassing paired comparisons for each element. A panel of 25 experts, selected based on their subject expertise, is then invited to partake in the AHP analysis by having their insights provided through the questionnaire. This questionnaire, along with clear, understandable, and unambiguous instructions, is shared with the experts through online electronic means, and the criteria and sub-criteria are independently evaluated and compared in pairs, with numerical values denoting the relative importance of one item over the other being assigned.

The judgments/evaluations will then be made on a scale with the values 1, 3, 5, 7, and 9, i.e., criterion A versus criterion B (Saaty 1980; Podvezko 2009). The more important the corresponding criterion, the higher the value. Once the completed questionnaires are collected, the aggregated results of pairwise comparisons were meticulously analyzed to compute the relative weights for each criterion and sub-criterion using the mathematical eigenvector method, and a consensus set of weights is derived.

The measured criteria and sub-criteria are approved for unmanned and autonomous vessels by (Kim and Mallam, 2020 and Lim and Shin, 2022), which are;

Table 1: Criteria of AHP Analysis

Main Criteria	Sub-criteria
Ship Operation	**SO1**: General voyage
	SO2: Caution and Dangerous Voyage
	SO3: Determine position and navigation route
	SO4: Emergency Response
	SO5: Search and rescue
Ship Management	**SM1**: Maintain stability
	SM2: Deck and engine equipment management
	SM3: Management of shipping supplies and medicines
	SM4: Life-saving equipment and life-saving fire extinguishing management
	SM5: Compliance with international conventions
Cargo Management	**CM1**: Cargo Handling
	CM2: Care cargoes
	CM3: Cargo area hull inspection
Ability to apply task and workload management	**AAWM1**: Planning and coordination
	AAWM2: Personnel assignment
	AAWM3: Time and resource constraints
	AAWM4: Prioritization
Knowledge and ability to apply effective resource management	**KARM1**: Allocation, assignment, and prioritization of resources
	KARM2: Effective communication on board and ashore
	KARM3: Decisions reflect consideration of team experience
	KARM4: Assertiveness and leadership, including motivation
	KARM5: Obtaining and maintaining situation awareness
Knowledge and ability to apply decision-making techniques	**KADM1**: Situation and risk assessment
	KADM2: Identify and generate options
	KADM3: Select course of action
	KADM4: Evaluation of outcome effectiveness

7. Results and Finding

In this section, AHP analysis is done to rank the duties and capabilities of seafarers towards the unmanned and autonomous ships within in view of STCW, where data are collected from 25 experts in the maritime industry consisting of senior ship's captains, navigational and machinery specialists, technical superintendents, automation experts, fleet operations managers, and maritime industry association representatives. Their experience ranges from 12 to 25 years. The following part introduces the results concluded pairwise comparison methodology, a fundamental aspect of the AHP, to assess the relative importance of criteria and sub-criteria. Experts compared items in pairs to derive their judgments on importance.

Ranking of the Main Six Criteria

A pairwise comparison matrix is done through identifying the decision matrix and the weight of each criterion. This comparison is shown in Table 2.

Table 2: Values of Main Criteria

Criteria	SO	SM	CM	AAWM	KARM	KADM
SO	1.00	0.62	0.70	0.83	1.01	1.07
SM	1.62	1.00	1.09	1.37	1.60	1.79
CM	1.42	0.92	1.00	1.14	1.47	1.42
AAWM	1.20	0.73	0.88	1.00	1.19	1.21
KARM	0.99	0.63	0.68	0.84	1.00	0.99
KADM	0.93	0.56	0.70	0.83	1.01	1.00
Sum	7.170	4.448	5.058	6.007	7.276	7.482

From Table 2 the criteria weight (CW) and weighted sum vector (WSV) are calculated, where their values are shown in Table 3;

Table 3: Criteria Weight and Weighted Sum Vector of Main Criteria

Criteria	CW	WSV
SO	0.872217	5.23
SM	1.412329	8.45
CM	1.22704	7.39
AAWM	1.03505	6.22
KARM	0.854586	5.14
KADM	0.83887	5.02

From the above table, the ʎmax Random Consistency value (RC), Consistency Index (CI), and Consistency Ratio (CR) are calculated.

ʎmax= ((5.23/0.87) + (8.45/1.41) + (7.39/1.23) + (6.22/1.035) + (5.14/0.85) + (5.02/0.84)) /6 = 6.002404802

CI= (6.002404802 - 6)/5 = 0.00048096

CR= 0.00048096/1.24 = 0.000387871

It is concluded that CR value is < 0.05. Thus, the values are acceptably consistent.

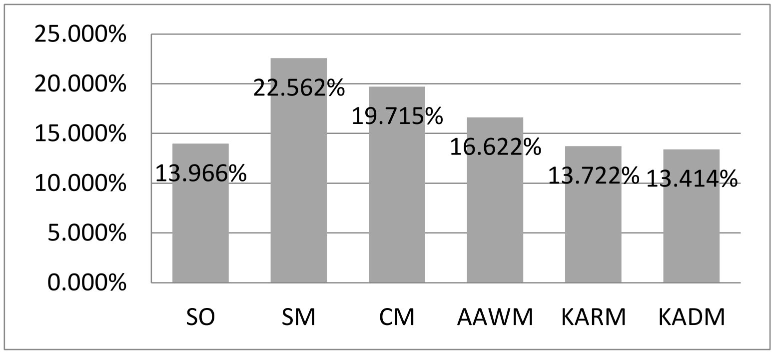
Finally, the ranking is identified, where the ship management has the first ranking with a percentage of 22.562%, followed by cargo management with 19.715%, and the third rank is the ability to apply task and workload management with a percentage of 16.622%. Finally, it is noticed that the other three criteria have close percentages, which are 13.966, 13.722, and 13.414

respectively. These results are concluded after calculating the geometric mean of the criteria, which are shown in Table 4 and Figure 1:

Table 4: Pairwise Comparison Matrix for the Main Criteria

Criteria	GM	W
SO	0.8549	13.966%
SM	1.38109	22.562%
CM	1.206856	19.715%
AAWM	1.017495	16.622%
KARM	0.83997	13.722%
KADM	0.821128	13.414%

Figure 1: Weight of the Main Criteria



Ranking of Ship Operation

A pairwise comparison matrix is done through identifying the decision matrix and the weight of sub- criteria of ship operation. This comparison is shown in Table 5.

Table 5: Values of Ship Operation

Criteria	SO1	SO2	SO3	SO4	SO5
SO1	1.00	0.35	0.50	0.72	1.15
SO2	2.84	1.00	1.09	1.94	2.85
SO3	1.99	0.92	1.00	1.34	2.31
SO4	1.39	0.52	0.75	1.00	1.54
SO5	0.87	0.35	0.43	0.65	1.00
Sum	8.093	3.139	3.768	5.646	8.851

From Table 5 CW and WSV are calculated, where their values are shown in Table 6;

Table 6: Criteria Weight and Weighted Sum Vector of Ship Operation

Criteria	CW	WSV
SO1	0.744634	3.69
SO2	1.944171	9.60
SO3	1.511685	7.70
SO4	1.038491	5.22
SO5	0.660584	3.32

From the above table, the ʎmax, CI, and CR are calculated.

ʎmax= ((3.69/0.74) + (9.60/1.94) + (7.70/1.51) + (5.22/1.04) + (3.32/0.66)) /5 = 5.009181484

CI= (5.009181484 - 5)/4 = 0.002295371

CR= 0.002295371/1.12 = 0.002049438

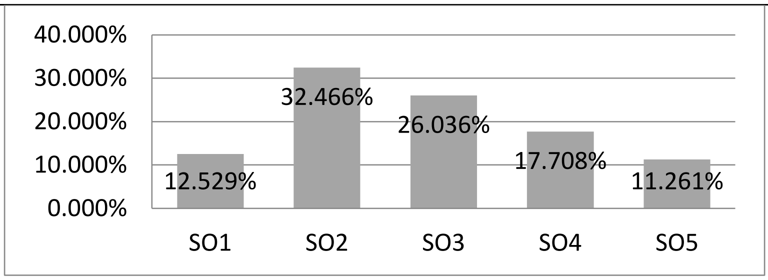
It is concluded that CR value is < 0.05. Thus, the values are acceptably consistent.

Finally, the ranking is identified, where SO2 has the first ranking with a percentage of 32.466%, followed by SO3 with 26.036%, and the third rank is SO4 with 17.707%. The fourth rank is SO1 with 12.529%. Finally, the fifth rank is SO5 with 11.261%. These results are concluded after calculating the geometric mean of ship operation, which are shown in Table 7 and Figure 2:

Table 7: Pairwise Comparison Matrix for Ship Operation

Criteria	GM	W
SO1	0.680725	12.529%
SO2	1.763965	32.466%
SO3	1.414637	26.036%
SO4	0.962146	17.708%
SO5	0.61186	11.261%

Figure 2: Weight of Ship Operation



Ranking of Ship Management

A pairwise comparison matrix is done through identifying the decision matrix and the weight of sub- criteria of ship management. This comparison is shown in Table 8.

Table 8: Values of Ship Management

Criteria	SM1	SM2	SM3	SM4	SM5
SM1	1.00	0.91	0.82	0.80	1.26
SM2	1.10	1.00	0.77	0.83	1.25
SM3	1.22	1.31	1.00	0.98	1.51
SM4	1.25	1.20	1.02	1.00	1.49
SM5	0.79	0.80	0.66	0.67	1.00
Sum	5.351	5.223	4.271	4.282	6.513

From Table 8 the (CW) and (WSV) are calculated, where their values are shown in Table 9;

Table 9: Criteria Weight and Weighted Sum Vector of Ship Management

Criteria	CW	WSV
SM1	0.959952	4.80
SM2	0.988656	4.93
SM3	1.202081	6.01
SM4	1.192317	5.98
SM5	0.785062	3.93

From the above table, the ʎmax RC, CI, and CR are calculated.

ʎmax= ((4.80/0.96) + (4.93/0.99) + (6.01/1.20) + (5.98/1.19) + (3.93/0.785)) /5 = 5.002471738

CI= (5.002471738 - 5)/4 = 0.000617934

CR= 0.000617934/1.12 = 0.000551727

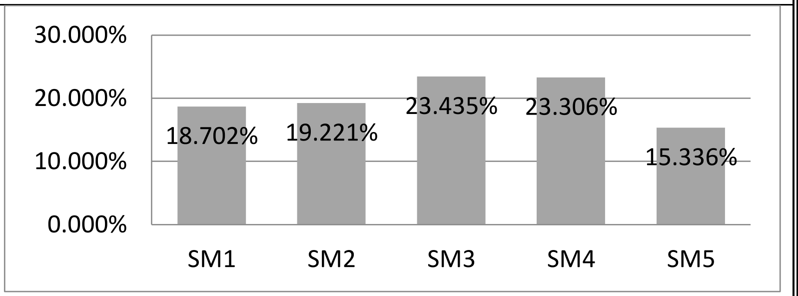
It is concluded that CR value is < 0.05. Thus, the values are acceptably consistent.

Finally, the ranking is identified, where SM3 has the first ranking with a percentage of 23.435%, followed by SM4 with a very close percentage that equals 23.306%, and the third rank is SM2 with a percentage of 19.221%. The fourth rank is SM1 with a percentage of 18.702%. Finally, the fifth rank is SM5 with a percentage of 15.336%. These results are concluded after calculating the geometric mean of ship management, which are shown in Table 10 and Figure 3:

Table 10: Pairwise Comparison Matrix for Ship Management

Criteria	GM	W
SM1	0.946544	18.702%
SM2	0.97285	19.221%
SM3	1.186109	23.435%
SM4	1.179584	23.306%
SM5	0.776173	15.336%

Figure 3: Weight of Ship Management



Ranking of Cargo Management

A pairwise comparison matrix is done through identifying the decision matrix and the weight of sub- criteria of cargo management. This comparison is shown in Table 11.

Table 11: Values of Cargo Management

Criteria	CM1	CM2	CM3
CM1	1.00	1.08	1.92
CM2	0.92	1.00	1.69
CM3	0.52	0.59	1.00
SUM	2.44	2.68	4.61

From Table 11 the (CW) and (WSV) are calculated, where their values are shown in Table 12;

Table 12: Criteria Weight and Weighted Sum Vector of Cargo Management

Criteria	CW	WSV
CM1	1.334162	3.99
CM2	1.203304	3.62
CM3	0.704629	2.11

From the above table, the ʎmax, CI, and CR of cargo management are calculated.

ʎmax= ((3.99/1.33) + (3.63/1.20) + (2.11/0.70)) /3 = 3.000291016

CI= (3.000291016 - 3)/2 = 0.000145508

CR= 0.000145508 /0.58 = 0.000250876

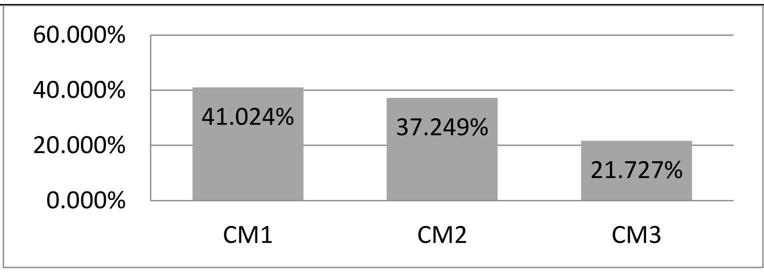
It is concluded that CR value is < 0.05. Thus, the values are acceptably consistent.

Finally, the ranking is identified, where CM1 has the first ranking with 41.024%, followed by CM2 in the second rank with 37.249%, and the third rank is CM3 with 21.727%. These results are concluded after calculating the geometric mean of cargo management, which are shown in Table 13 and Figure 4:

Table 13: Pairwise Comparison Matrix for Cargo Management

Criteria	GM	W
CM1	1.276425	41.024%
CM2	1.158953	37.249%
CM3	0.675998	21.727%

Figure 4: Weight of Cargo Management



Ranking of Ability to Apply Task and Workload Management

A pairwise comparison matrix is done through identifying the decision matrix and the weight of sub- criteria of ability to apply task and workload management.

This comparison is shown in Table 14.

Table 14: Values of Ability to Apply Task and Workload Management

Criteria	AAWM 1	AAWM 2	AAWM 3	AAWM 4
AAWM 1	1.00	0.38	0.48	0.60
AAWM 2	2.60	1.00	1.08	1.73
AAWM 3	2.08	0.93	1.00	1.06
AAWM 4	1.67	0.58	0.94	1.00
Sum	7.35	2.89	3.50	4.39

From the above table, the criteria weight (CW) and weighted sum vector (WSV) are calculated, where their values are shown in Table 15;

Table 15: Criteria Weight and Weighted Sum Vector of Ability to Apply Task and Workload Management

Criteria	CW	WSV
AAWM 1	0.617367	2.48
AAWM 2	1.601356	6.38
AAWM 3	1.267991	5.15
AAWM 4	1.047545	4.20

From the above table, the ʎmax Random Consistency value (RC), CI, and CR are calculated.

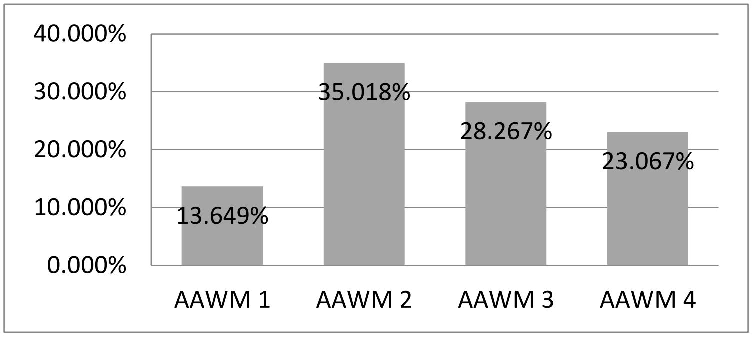
ʎmax= ((2.48/0.62) + (6.37/1.60) + (5.15/1.27) + (4.20/1.05)) /4 = 4.01689892
CI= (4.01689892- 4)/3 = 0.005632973
CR= 0.005632973/0.9 = 0.006258859
It is concluded that CR value is < 0.05. Thus, the values are acceptably consistent.

Finally, the ranking is identified, where AAWM2 has the first ranking with 35.018%, followed by AAWM3 in the second rank with a percentage of 28.267%, and the third rank is AAWM4 with a 23.067%. Meanwhile, the fourth rank is AAWM 1 with 13.649%. These results are concluded after calculating the geometric mean of the ability to apply task and workload management, which are shown in Table 16 and Figure 5:

Table 16: Pairwise Comparison Matrix for Ability to Apply Task and Workload Management

Criteria	GM	W
AAWM 1	0.578023	13.649%
AAWM 2	1.483018	35.018%
AAWM 3	1.197094	28.267%
AAWM 4	0.976886	23.067%

Figure 5: Weight of Ability to Apply Task and Workload Management



Ranking of Knowledge and Ability to Apply Effective Resource Management

A pairwise comparison matrix is done through identifying the decision matrix and the weight of sub- criteria. This comparison is shown in Table 17.

Table 17: Values of Knowledge and Ability to Apply Effective Resource Management

Criteria	KARM1	KARM2	KARM3	KARM4	KARM5
KARM1	1.00	1.28	1.04	1.29	1.26
KARM2	0.78	1.00	0.79	1.03	0.92
KARM3	0.96	1.26	1.00	1.22	1.15
KARM4	0.78	0.97	0.82	1.00	0.91
KARM5	0.79	1.09	0.87	1.10	1.00
Sum	4.309	5.594	4.525	5.638	5.244

From Table 17 the (CW) and (WSV) are calculated, where their values are shown in Table 18;

Table 18: Criteria Weight and Weighted Sum Vector of Knowledge and Ability to Apply Effective Resource Management

Criteria	CW	WSV
KARM1	1.174359	5.87
KARM2	0.905657	4.53
KARM3	1.118079	5.59
KARM4	0.894994	4.48
KARM5	0.969197	4.84

From the above table, the ʎmax Random Consistency value (RC), CI, and CR are calculated.

ʎmax= ((5.87/1.17) + (4.53/0.91) + (5.59/1.12) + (4.48/0.89) + (4.87/0.97)) /5 = 5.000816767
CI= (5.000816767- 5)/4 = 0.000204192
CR= 0.000204192/1.12 = 0.000182314

It is concluded that CR value is < 0.05. Thus, the values are acceptably consistent.

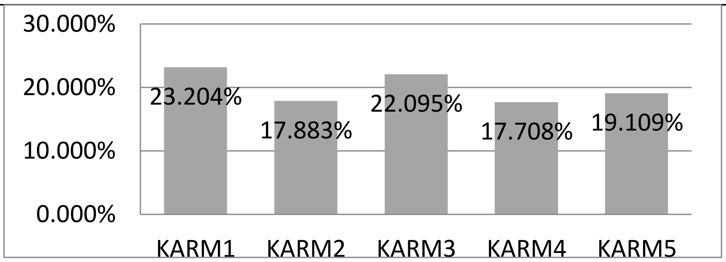
Finally, the ranking is identified, where KARM1 has the first ranking with a percentage of 23.204%, followed by KARM3 in the second rank with 22.095%, and the third rank is KARM5 with 19.109%. Meanwhile, the fourth rank is KARM2 with 17.883%, ending with the fifth rank, which is KARM4 with 17.708%.

These results are concluded after calculating the geometric mean of knowledge and ability to apply effective resource management, which is shown in Table 19 and Figure 6:

Table 19: Pairwise Comparison Matrix for Knowledge and Ability to Apply Effective Resource Management

Criteria	GM	W
KARM1	1.167419	23.204%
KARM2	0.899708	17.883%
KARM3	1.111582	22.095%
KARM4	0.890907	17.708%
KARM5	0.961386	19.109%

Figure 6: Weight of Knowledge and Ability to Apply Effective Resource Management



Ranking of Knowledge and Ability to Apply Decision-Making Techniques

A pairwise comparison matrix is done through identifying the decision matrix and the weight of sub- criteria of knowledge and ability to apply decision-making techniques. This comparison is shown in Table 20.

Table 20: Values of Knowledge and Ability to Apply Decision-Making Techniques

Criteria	KADM1	KADM2	KADM3	KADM4
KADM1	1.00	0.63	0.96	1.32
KADM2	1.59	1.00	1.21	1.92
KADM3	1.04	0.83	1.00	1.22
KADM4	0.76	0.52	0.82	1.00
Sum	4.39	2.98	3.99	5.46

From Table 20 the (CW) and (WSV) are calculated, where their values are shown in Table 21;

Table 21: Criteria Weight and Weighted Sum Vector of Values of Knowledge and Ability to Apply Decision-Making Techniques

Criteria	CW	WSV
KADM1	0.978715	3.89
KADM2	1.428627	5.70
KADM3	1.022041	4.17
KADM4	0.775777	3.10

From the above table, the ʎmax Random Consistency value (RC), Consistency Index (CI), and Consistency Ratio (CR) are calculated.

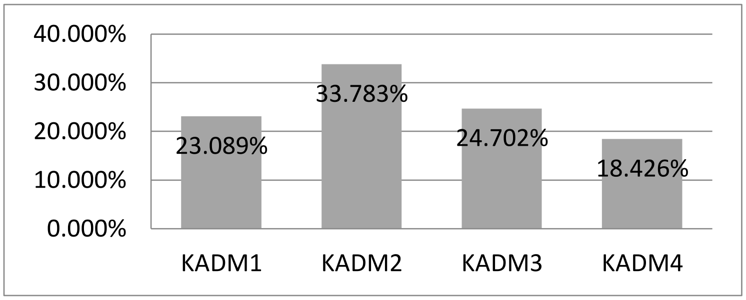
ʎmax= ((3.89/0.98) + (5.70/1.43) + (4.17/1.02) + (3.10/0.776)) /4 = 4.011801312
CI= (4.011801312- 4)/3 = 0.003933771
CR= 0.003933771/0.9 = 0.004370856
It is concluded that CR value is < 0.05. Thus, the values are acceptably consistent.

Finally, the ranking is identified, where KADM2 has the first ranking with 33.783%, followed by KADM3 in the second rank with 24.702%, the third rank is KADM1 with 23.089%, and the fourth rank is KADM4 with 18.426%. These results are concluded after calculating the geometric mean of knowledge and ability to apply decision-making techniques, which are shown in Table 22 and Figure 7:

Table 22: Pairwise Comparison Matrix for Values of Knowledge and Ability to Apply Decision-Making Techniques

Criteria	GM	W
KADM1	0.946431	23.089%
KADM2	1.384751	33.783%
KADM3	1.012526	24.702%
KADM4	0.75527	18.426%

Figure 7: Weight of Values of Knowledge and Ability to Apply Decision-Making Techniques



8. Research Discussion

After applying the AHP analysis, this section discusses the most important concluded results from the analysis. Firstly, ship management has proved to be the most important factor among the other five factors, this pointed out the importance of ship management and how it represents the initial factor that affects the unmanned and autonomous ships. Another important matter is that three of the six factors; ship operation, knowledge, and ability to apply effective resource management and knowledge and ability to apply decision-making techniques, have a very close ranking, which means they have the same importance according to the experts or the variation between them is very small.

In the absence within STCW, prioritizing ship management is vital to uphold regulatory compliance, safety measures, environmental responsibility, and international cooperation. It necessitates effective training of seafarers, compensating for the lack of STCW guidance and ensuring lawful and responsible operations of unmanned and autonomous ships.

Looking for the analysis of each criterion, in ship operation it is noticed that caution and dangerous voyage have the highest rank, which means that it is the most important factor, while the least important factor is search and rescue, where it has the least rank.

In ship management criteria, the significance varies based on the degree / level of autonomy. The management of shipping supplies and medicines represents the most important factor with the highest ranking, followed by life-saving equipment and life-saving fire extinguishing management with a very small difference in the percentage compared to the first factor, which means that they have a very close importance. This underscores the criticality of these factors, particularly in autonomy degrees one and two, where seafarers are present on board, readily available to assume control over shipboard systems (MSC.1/Circ.1638). In contrast, compliance with international conventions ranks lowest among the other sub-criteria.

Ship management gains importance. Emphasizing shipping supplies and life-saving equipment underscores the critical role ship management plays in safety. However, the low rank of compliance with international conventions highlights the challenge of maintaining standardized practices without STCW. Seafarers bear the responsibility of ensuring safety and adherence to best practices within this ambiguous legal and regulatory environment.

In cargo management criteria, cargo handling has the first rank, followed by care cargoes, and finally the cargo area hull inspection has the least rank with the least importance. In the ability to apply task and workload management criteria, personnel assignment has the highest rank among all sub-criteria, while planning and coordination have the least ranking.

Allocation, assignment, and prioritization of resources are found to be the most crucial sub-criteria in terms of KARM criteria, while assertiveness and leadership, including motivation, and effective communication on board and ashore are the lowest two with very little variation in their percentages.

In KADM, identify and generate options represents the most important dimension, while evaluation of outcome effectiveness has the least importance with the least ranking.

From the above concluded points, the importance of each criterion has been identified, which can help experts in making decisions, which can enhance the operation of unmanned and autonomous ships navigation.

Moreover, it is important to refer that although the current study had depended on previous literature to rank its criteria and way of measuring them, as this is adopted from (Kim and Mallam, 2020 and Lim and Shin, 2022), the current study makes its analysis for different perspective as well as the current study had gathered different factors that are not gathered from before.

9. Conclusion

STCW outlines the duties and capabilities for the seafarers. However, the convention was not initially created with unmanned ships in consideration, resulting in a lack of specific provisions addressing the competencies standing of unmanned ships. Despite this, there is an ongoing debate regarding whether unmanned ships should be acknowledged as "ships" and be exempt from the rights and obligations typically attributed to flag and coastal nations. With a distinction between remotely controlled unmanned ships and autonomous ships without human supervision, compliance with the current IMO regulatory framework is essential. While modest amendments or clarifications may be needed for remote-controlled ships, important amendments are needed for unsupervised autonomous unmanned ships. With a distinction between remotely controlled unmanned ships and autonomous ships without human supervision, compliance with the current IMO regulatory framework is essential.

IMO and MASS guidelines outline liability levels for navigational and operational errors at different levels. Levels 0, 1, and 2 fall to the shipmaster, while Level 3 involves remote operation and monitoring of navigation. Level 4 transfers liability to the shipmaster and SCC, while Level 5 involves fully automated vessels acting independently. Specific procedures may be used in times of system faults, such as terminal operators guiding ships in coastal zones or response teams boarding unmanned vessels. However, these precautions might not be helpful for unmanned seagoing vessels. Unmanned merchant ships are viable up to Level 3 of automation despite implementation difficulties. However, as human elements will still be used to partially manage or monitor oceangoing vessels, man-to-machine contact will still be relevant.

The analysis presented in this study emphasizes ship management as the most critical factor influencing the duties and capabilities of seafarers concerning unmanned and autonomous ships in view of STCW. This underscores the need for prioritizing ship management, enhancing its development, and aligning practices with STCW standards to ensure its effective operation while upholding seafarers’ duties. Given the pivotal role of ship management, connecting this discussion to ongoing debates regarding the classification of unmanned ships as "ships" and their implications for seafarers’ duties and capabilities among seafarers are deemed imperative. Accordingly, more attention must be directed towards this factor, its development, and alignment with STCW standards to guarantee its proper operation.

10. Research Recommendations

As the current study aims to identify the duties and capabilities of seafarers towards the unmanned and autonomous ships from the prospective of STCW, the current study collected data from experts to identify the most important factors that can affect the navigation of unmanned and autonomous ships. From the concluded results, this paper offered some recommendations for decision-makers.

First recommendation is that experts and decision-makers should examine the accountability and moral challenges related to the creation of unmanned and autonomous operating systems to propose moral and legal norms and regulations that suit the technological development.

Decision makers should also work on developing the necessary skills and awareness of seafarers through retraining and reskilling them for the aim of guaranteeing safety and dependability in ship operations. Moreover, provides suitable training to seafarers to stay updated with the changing risk profile associated with new technology.

The inclusion of larger samples in future research to obtain more reliable results is suggested by the researcher. Limitations related to a lack of time, which hindered the adoption of a small research sample size, were encountered in this paper.

Considering that ship operations and team composition would be modified by autonomous and unmanned ships, it is naive to believe that they will still be safe solely based on the knowledge gained from investigating prior systems. In light of this, it is recommended that future research should focus on management and leadership issues affecting all organizational levels and effective leadership models for managing autonomous ship operations should be examined.

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Impact of the Offshore Oil and Gas Working Environment on the Mental Health and Safety Behaviour of Workers

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المستخلص

يتزايد معدل الحوادث المرتبطة بالعمل في صناعة النفط والغاز العالمية، مع الاشارة الى وجود خطأ العنصر البشري الناتج في المقام الأول عن السلوك غير الآمن في بيئة عمل خطرة ومعزولة ومرهقة تنطوي على مزيج فريد من المخاطر النفسية والاجتماعية. ومن هذا المنطلق يمكن أن تصبح بيئة العمل هي اليد الخفية التي يمكن أن تؤثر سلباً على سلوكيات السلامه لدى العاملين مما يؤدي إلى ارتكاب الأخطاء. وللتخفيف من مخاطر الحوادث الناجمة عن السلوك غير الآمن في هذه الصناعة، تم التحقيق في التأثير المحتمل للمخاطر النفسية الاجتماعية لبيئة العمل والمتمثلة في البعد والعزلة، على الصحة النفسية للعمال، وتم تقييم التأثيرات المرتبطة والذي يمكن تفسيره بانخفاض مستويات المشاركة والتواصل في مجال السلامة بشكل ملحوظ على الرغم من التزامهم العالي بقواعد السلامة. ومن ثم يوصي الباحث بأن يقوم منظمو ومشغلو الصناعة بالبدء في تدخلات الصحة النفسية، بما في ذلك رفع وعي العمال بهذا الامر، وتخفيف العزلة، والسيطرة على أعباء العمل العالية، وتحسين الظروف المعيشية، وتوفير وسائل الاتصال الكافية، والخصوصية ، والمرافق الترفيهية حيث أن اعتماد هذا النهج يمكن أن يضع الأساس للسلامة والأداء الأمثل للقوى العاملة في مجال النفط والغاز.

Abstract

The rate of work-related accidents is rising in the global Oil and Gas industry, with a significant contribution of human error driven primarily by unsafe behaviour in a hazardous and isolated work environment involving a unique mix of psychological and social risks. From this standpoint, the working environment could be the hidden hand that can negatively affect workers' behaviour, leading to errors. To mitigate the risks of accidents and incidents caused by unsafe behaviour, the potential impact of the working environment's psychosocial hazards, represented by remoteness and isolation, on workers' mental health, was investigated, and the associated influences on safety behaviour were assessed. The study proposed a research model in which characteristics of the offshore working environment negatively affect workers' mental health and safety behaviour. Stress, Anxiety and Depression were chosen to represent mental health disorders due to their significant prevalence among work-related mental illnesses as per recent reports of the International Labour Organization (ILO) and multiple other studies. The methods used included a review of relevant literature and the quantitative research approach, where data was obtained from a survey involving a sample of (409) Egyptian workers in the oil and gas industry. The descriptive analysis was employed, and the results, according to the study sample, indicated a "high" level of psychosocial hazards in the work environment. The results also revealed a "moderate" level of worker safety behaviour, which can be explained by significantly lower safety engagement and communication levels despite their high adherence to safety rules. Hence, the researcher recommends that industry regulators and operators initiate mental health interventions, including raising worker awareness, alleviating isolation, controlling high workloads, improving living conditions, providing adequate means of communication, reasonable privacy, and recreational facilities as the adoption of The approach can lay the foundation for safety and optimal performance for the oil and gas workforce.

Key Words: Offshore, Safety, Working Environment, Hazards, Behaviour, Workforce

1. Introduction

Workers in the Oil & Gas industry are vulnerable to specific stressful work conditions with the highly demanding nature of their work environments that involve multiple psychosocial hazards. In this regard, the European Agency for Safety and Health at Work demonstrated that the adverse characteristics of the working environment induce various effects on workers' mental health (EU-OSHA, 2014). Similarly, the ILO revealed that offshore oil and gas exploration and production operations entail remote and isolated locations of most offshore installations, imposing physical and psychological barriers between workers and their social support network (ILO, 2022).

Furthermore, working in an oil and gas field entails long working hours with less time for rest, a high load of work, and stressful day and night shift schedules when rotation patterns are affected or constrained by transport schedules. Additionally, several other perceived risks associated with the nature of offshore jobs, such as the proximity of the living and working environments, do not offer privacy nor separation from the characteristics of the working environments. The problem is that such a working environment might harm the worker's mental well-being, while research has proved that mental illness negatively affects people's behaviour at work.

The investigation outcomes of the Allianz Group pointed to Human Element Errors as the primary causes contributing to the majority of accidents and incidents (Allianz, 2019). Therefore, there is increased attention toward investigating the factors causing human element error. In this regard, unsafe human behaviour was the main factor behind workplace injuries and accidents (Zhang et al., 2020). This is consistent with previous studies of Choudhry (2014), who revealed that worker poor safety behaviour is the primary cause of workplace accidents.

Given these concerns, this study aimed to provide a comprehensive understanding of the potential causes behind human behaviour, the primary leading factor to most of the industry's incidents and accidents. The contribution is that it can form the basis for decision-makers in the Oil & Gas industry in developing counter-measures that can effectively contribute to boosting the workers' safety behaviour, thus eliminating or at least mitigating the risk of those causes in the future.

This study presented two hypotheses as follows;

H_1. The psychosocial hazards of the Oil & Gas working environment have an effect on the presence of workers' mental health disorders.

H_2. The workers' Mental Health Disorders have an effect on the worker's safety behaviour

2. Literature Review

2.1 Incidents & Accidents in the Oil & Gas Industry

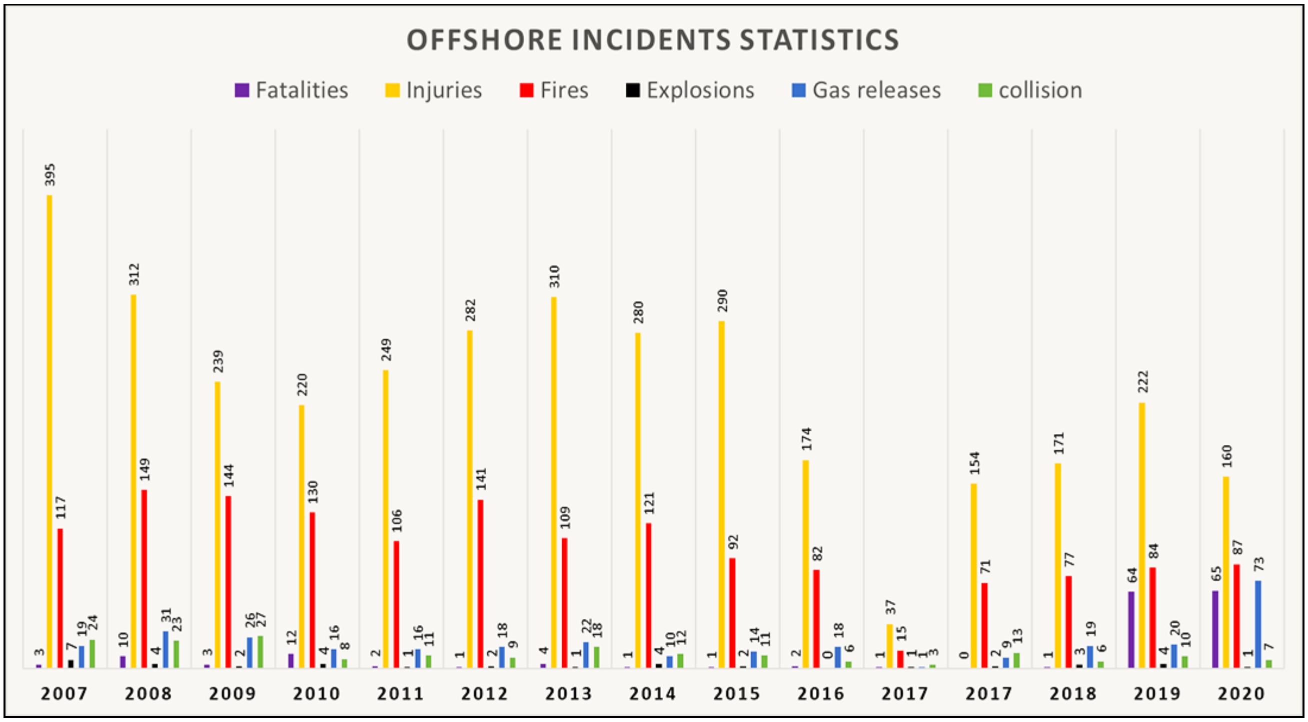
In the oil and gas industry, "Safety" is widely defined as a secure setting where workers are maintained safely on their work tasks and where the likelihood of accidents or incidents is eliminated while limiting the potential consequences of administrative retribution (Fernandez-Muniz et al., 2014). Okoye (2016) asserted that safety is simply the combination of behaviour intended to either increase or decrease the risk of harm, where the term "Safe" denotes the absence of danger and "Unsafe" implies the presence of a high probability of danger.

This concern is essential in managing work activities in hazardous working environments, such as the oil and gas industry, where accidents and incidents could have disastrous consequences. This was agreed by Mearns & Yule (2009), who asserted the importance of safety in the oil and gas industry and referred to it as a crucial operational requirement since the industry is regarded as a high-risk domain due to its associated hazardous nature and challenging work conditions.

Incidents and accidents confront all industries with multiple complications and generate community concerns, commonly leading to additional regulations to reshape the parameters under which those requirements are implemented. Regarding the oil and gas industry, hazards pose significant challenges in managing the safety of such complicated operational activities. According to Almeida & Vinnem, (2020), the complex operations of the Oil and Gas industry, which involves various exploration and production processes, entail a significant potential of enormous risks involving fires, explosions, and releasing toxic gases. Those unfavourable events could escalate, due to several factors, into significant incidents and accidents, leading to a substantial number of injuries and fatalities in the workforce.

The United States BSEE, (2021) revealed that the offshore oil and gas sector is significantly demanding and stressful due to its high potential risks and work-related accidents. Figure (1) illustrates the annual records of incidents across the USA offshore oil and gas sector based on data collected relevant to all reported fatalities and injuries, in addition to all incidents involving fire, explosions, gas release and collision from 2007 to 2020. Although the graph demonstrates a drop in injuries, collisions, fires and explosions over the last few years, a single significant incident in this industry could be greatly catastrophic, and its consequences could seriously impact lives, the environment and property.

Figure (1): Incidents in Offshore Oil & Gas Industry (USA)

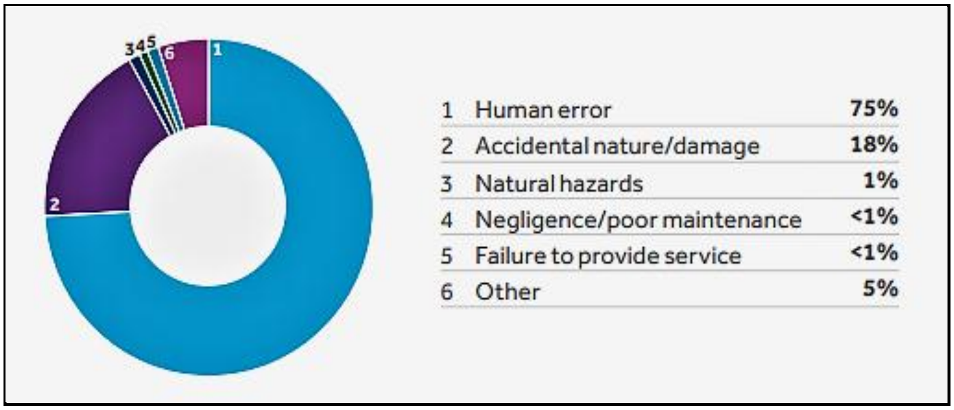


Source: BSEE, (2021)

The annual number of fatalities, as illustrated in Figure (1), shows a recent increase, which poses serious concerns regarding the safety of operation and management of risks and hazards in the industry. A high rate of fatalities associated with incidents could be viewed as the worst-case scenario; therefore, all potential causes should be considered when performing risk analysis for the daily drilling and production processes (BSEE, 2021).

Intending to gain a better understanding of how accidents and incidents have been caused in the offshore oil and gas industry, Ismail et al. (2014) examined 219 case studies of accidents and incidents which took place over 56 years and involved several offshore installations, such as drilling ships, jack-up rigs, semi-submersible rigs, and production platforms. Based on collected data, the study findings revealed that all the studied accidents and incidents were mainly caused or escalated by the integration of adverse factors, including human error, incompetence, and equipment failures. Nevertheless, human error was found to be the most contributing factor among all other causes. This argument was backed up by Allianz Global Corporate & Specialty, which investigated all the potential causes of accidents and incidents related to a recorded 14,828 cases of liability insurance claims raised between 2011 and 2016 (Allianz, 2019). The Allianz's report findings indicated that among all identified causes of accidents and incidents, human error was found to be the primary factor with a significantly high contribution ratio of up to 75% of the studied cases, followed by other causes, including accidental nature that was up to 18%.

Figure (2): Causes of Accidents & Incidents



Source: Allianz, (2019)

While the safety criteria for regulating the oil and gas industry are mainly known for their comprehensive approach towards risk analysis, it could be noted that the scope of accident investigation is commonly identifying physical and apparent reasons while giving less attention to hidden risks such as the involvement of mental health disorders in shaping the worker's behaviour. Multiple factors were indicated as potential reasons behind the human failure in 34 accidents and incidents that occurred during the period from 2011 to 2013. Several factors, including non-compliance with the procedures, poor competency and low management commitment, excessing environmental factors like heat stress, skill-based mistakes and errors, defective equipment and instruments, poor planning and communication issues, overload and fatigue, were identified as factors contributing to human failure causing accidents (UK Essays, 2018).

2.2 Workers' Safety Behaviour

Safety behaviour is the absence of an undesirable act involving an accidental and unacceptable loss (Dartey & Addo, 2018). According to Frazier et al. (2013), safe and unsafe behaviour could fluctuate depending on the company, its administration, and its workforce, as well as the difficulty level and conditions of work activities. Furthermore, Kvalheim and Dahl (2016) revealed that safety behaviour depends on how workers perceive their performance in terms of safety, keeping in view all acts and specific actions that improve the application of safety regulations and policies.

In a study investigating the relationship between the organizational safety culture and individual safety behaviour, Uryan (2010) emphasized the significance of positive safety behaviour at work and stated that employees' attitudes toward safety might influence how they conform to the safety standards. As a result, when workers exhibit a positive mentality toward safety, they maintain a safe work system, minimizing workplace risks (Wallace, 2016). Evidence from several previous research has demonstrated that enhancing the safety behaviour of individuals at work requires integrating safety involvement, safety compliance, and safety mindfulness into account as essential components of safety behaviour (Dahl & Kongsvik, 2018). Workers' safety commitment, engagement, and communications are the main components in assessing safety behaviour in the workplace (Saedi et al., 2021).

2.2.1 Safety Commitment

Safety commitment is significantly related to employees' safety behaviour and is regarded as a means of promoting a safe workplace. This is supported by Ehiaguina & Moda (2020), who revealed the value of safety commitment as a constructively vital component of workers' safety behaviour that reduces workplace accidents and injuries within hazardous industries.

2.2.2 Safety Engagement

An essential component of positive safety behaviour at any workplace is the worker's effective engagement in safety. Thus, when it comes to workplace safety, workers need to get vigorously involved (Tear et al., 2020). The workers' engagement in safety enables the development of practical approaches and methods for resolving safety concerns. It is confirmed that the workers' high level of safety engagement would help decrease potentially unsafe behaviour that leads to workplace incidents (Bayram, 2019). In line with this view, safety engagement is vital for enhancing the workers' ability to respond to work threats or emergencies and significantly contributes to positive and safe behaviour (Freitas et al., 2019).

2.2.3 Safety Communication

Safety management depends on workers reporting accidents, compliance with policies, awareness of possible risks, and safe work practices. In this regard, workers cannot enhance safety by themselves. They need management to define priorities, create guiding safety rules and procedures, provide funding for essential resources, and carry out necessary corrective measures. Thus, communication is a crucial component of safety behaviour, which could be enhanced when workers view safety as a group interaction where each of them plays a vital role as a team member with the same aim of achieving success (Schwatka et al., 2019). Effective communication must be purpose-driven, simple, dependable, and advantageous to both management and the workforce to motivate workers to report incidents and near misses and perform their responsibilities toward safety (Verroen et al., 2013).

2.3 Role of Mental Health in Shaping Human Behaviour

The significant role of mental health has gained widespread awareness worldwide. In this context, the implications of work on mental health and how it impacts workers' performance and safety is becoming a global public health concern. Researchers are still investigating mental health and frequently debate the significance of its role in interpersonal and practical aspects. In this regard, psychological and physical health are remarkably consistent. This was revealed by Palumbo et al. (2020), who also explained that being able to think, feel, and behave according to one's desired lifestyle is often a sign of good mental health. However, when a person goes through a period of poor mental health, it could be challenging or even unachievable for him to confront everyday thoughts, feelings, or reactions, resulting in emotional distress and physical illness.

Furthermore, Galderisi et al. (2017) indicated that the environment, culture, and social and economic factors contribute to the paradigm that determines how healthy an individual might become. As a result, each person's health reflects their capacity to face and overcome social and environmental challenges. Therefore, ensuring a person's mental well-being should be emphasized for achieving the highest level of functional ability.

2.3.1 Definition of Mental Health

Literature provides multiple definitions describing mental health, yet most of which are based on a foundational component which is beyond being just free of mental illnesses; instead, it is a state of mental well-being that promotes the ability of a person to deal with everything in his life and manage its demands properly. Such capacity enables the individual to accomplish his assigned duties and enhances the achievement of his tasks to better results (Galderisi et al., 2017).

As a globally recognized definition, the World Health Organization (WHO) officially described mental health as: "*The state of well-being in which people realize their potential, and can cope with common life stresses; learn well; work productively and fruitfully, and are capable of contributing to the community*" (WHO, 2022a).

2.3.2 Mental Health Components in the Working Environment

The term "working environment" refers to integrating internal and external factors of the surroundings and circumstances associated with the workplace in which a person carries on his work activities. The workplace encompasses the working environment where workers execute their duties (Ajala, 2012). In the context of work, mental health can be analyzed based on considering two fundamental components; the first is associated with the individuals themselves and is referred to as the "Personal Factors", while the second is related to the work aspects they perform and is described as the "Organizational Factors". This was revealed by Ouellet & Gratton (2013), who further explained that personal factors involve the distinctive characteristics of each person, such as personality and social life. Some people have coping mechanisms that enable them to manage Stress, gain self-awareness, and overcome obstacles to adaptation. At the same time, their positive emotions reduce their likelihood of experiencing mental issues.

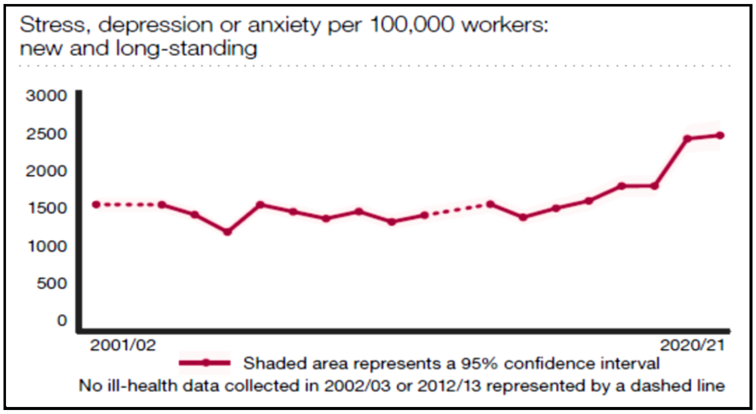
2.3.3 Mental Health Issues in the Oil & Gas Industry

The presence of mental health disorders in the Oil & Gas working environment presents a fundamental challenge to managing this hazardous industry. A workplace accident, severe injury, and even fatality can result from an offshore worker's inability to manage daily job stress due to the risky nature of his work environment. The offshore workers endure hazardous and challenging living and working conditions with prolonged separation from their friends and family, considerable lack of socialization, living in enclosed spaces, and spending days with minimum time for resting, which can eventually lead to emotions of isolation, loneliness, frustration, and dissatisfaction. Such feelings would induce mental health disorders (Xiu-li et al., 2020).

This finding is supported by the Health and Safety Executive (HSE), the UK's national occupational health and safety authority. The resulting figures derived from the Labour Force Survey (LFS) showed increased work-related Stress, Depression, and Anxiety among workers, with 822000 cases and a prevalence rate of 2480 cases per 100,000 workers (HSE, 2021). According to the HSE report, there has been a notable increase in annual rates of occupational

Stress, Depression and Anxiety among workers in Great Britain from 2001/02 to 2020/21, as illustrated in Figure (2.4). The rate in 2020/21 was substantially higher than estimated in 2018/19 by an additional number of 451000 new cases.

Figure (4): Work-Related Cases of Stress, Depression and Anxiety



Source: HSE, (2021)

2.3.4 Effect of Mental Health Disorders on Safety Behaviour

The critical role of worker safety behaviour in effectively implementing safety measures within the offshore petroleum industry was investigated by Gro et al. (2022), who showed that psychosocial factors substantially impacted safety behaviour. The study demonstrated a correlation between safety behaviour and personal injury cases in the offshore oil industry and explained the framework through which work practices affect safety.

According to Kang et al. (2016), the inevitable exposure to stressors in the offshore working environment may eventually cause mental health disorders, which raise the work-related risks of accidents and incidents and substantial financial losses. This fact depicts a crucial need to develop, implement and enhance a comprehensive approach to risk analysis and safety measures besides raising awareness of workplace stressors and their impact on performance among workers and operators. Ultimately, the Det Norske Veritas (DNV), (2022) pinpointed that it is essential to understand that one of the most critical aspects of minimizing human errors and improving safety is managing the contextual elements that could influence human behaviour.

2.4 The Psychosocial Hazards of the Working Environment

Psychosocial hazards are work-related factors that can cause harm to people psychologically, socially and physically, which could be categorized into three levels: individual, job, and organization. The psychosocial hazards at each level can interact, increasing the psychosocial risks in the workplace (NOPSEMA, 2021). Recognizing the importance of this issue, the ILO has referred to the psychosocial hazards of the working environment as the interactions between the characteristics of work, its organization, management, and environmental elements on the one hand, with the needed skills and capacity of employees on the other hand. Those interactions might harm workers' health to certain degrees based on their perceptions and experiences (ILO, 2016).

Psychosocial risks refer to the probability and severity of psychological or physical harm brought by the individual's exposure to psychosocial hazards. These psychosocial risks may be related to the nature of the work undertaken and the workplace's physical, social or cultural characteristics, among other things (WHO, 2022b).

Psychosocial hazards can be found in almost all industries, but some workers get exposed to them more significantly than others because of what, where, and how they perform their work. Subsequently, those workers confront a higher risk of being impacted by various adverse events and conditions due to the characteristics of their working environment (WHO, 2022c). In this view, Oil & Gas workers are vulnerable to complex and challenging work conditions associated with various physical stressors such as extended shifts, stressful duties, and repetitive night shifts.

From an academic standpoint, the correlation between multiple psychosocial risks of the working environment and workers' mental health has been discussed in previous studies. Cox & Griffiths (2005) defined the psychosocial hazards of the workplace as: "*The aspects of work's design and management, as well as its organizational and social environment that has the potential to cause psychological or physical harm"*. The psychosocial hazards in the working environment and how they might impact workers' mental health are gaining growing attention, especially for industries with isolated and stressful workplace conditions, such as the oil and gas industry.

2.4.1 Remoteness and Isolation of the Workplace

According to the Queen Land Government (QLD), (2022), the term "remote work" describes the working environment that, due to its location, timing, or nature, cannot be supported with the prompt aid of others, such as workplaces where receiving emergency assistance or attaining rapid rescue is significantly challenging. It may also include working in regions with poor access to communications resources and extended travel periods. On the other hand, work that requires workers to spend an extended period far from home or when there are few other people nearby is considered an isolated workplace. A worker may suffer physical or psychological harm due to regular, extended, or extreme emotional Stress from remote or isolated employment. While remote and isolated jobs might present a risk by themselves, it frequently occurs in conjunction with other psychological workplace risks, which may increase the risk of harm if combined (QLD, 2022).

The remote and isolated locations of most oil and gas offshore installations are among the psychosocial work risks associated with the offshore work environment. Anwar & Sherief, (2018) conducted a comprehensive study based on a literature review of all previous research studies investigating the direct or indirect effects of working in remote and considerably isolated workplaces on workers' safety behaviour.

3. Research Methodology

The researchers adopted the deductive approach to reach the research aim and employed quantitative methods to collect the data: a literature review and questionnaires. The research variables included psychosocial hazards in the Oil & Gas working environment as independent variables, mental health disorders as mediating variables, and workers' safety behaviours as dependent variables.

The study's population included all Egyptian Oil & Gas workers. The questionnaires were available to workers at working sites or when on leave while attending mandatory safety courses at the Arab Academy for Science Technology & Maritime Transport (AASTMT) to ensure that all workers in the industry could be included in the study sample.

After selecting the sample, the measurement tools and the development of questionnaires, the statements were pretested and modified to remove any discernible flaws. In this regard, the pilot study was significantly beneficial in reconstructing and adequately reshaping the questionnaire.

The hard copies of the questionnaires were distributed to classroom participants, and the digital formatting was utilized for workers at the working sites using an online survey.

After completing the fieldwork for the survey, the researchers obtained 409 complete responses, and then the collected data were statistically analyzed after being coded, edited, and processed. The research analysis techniques included Descriptive Analysis, Correlation Analysis, and Multiple Linear Regression Analysis.

4. Results and Discussion

The descriptive statistics results showed a "high" level of isolation and remoteness, in addition to a "mild" level of Anxiety and "moderate" levels of Depression and Stress. The results indicated a "moderate" level of safety behaviour reasoned by participants' high commitment to regulations but less safety engagement and communication.

The results of utilizing the Pearson correlation coefficient to study the correlation between the Psychosocial Hazards of the Oil & Gas Working Environment and Workers' Mental Health Disorders showed a positive and statistically significant correlation between the working environment's psychosocial hazards and mental health disorders as demonstrated in Table (1)

Table (1): Correlation between the Psychosocial Hazards and Mental Health Disorders (n =409)

<table>
<tr><th colspan="3" rowspan="2">Variables</th><th colspan="3">Worker's Mental Health (Disorders)</th></tr>
<tr><th>Depression</th><th>Anxiety</th><th>Stress</th></tr>
<tr><td rowspan="4">Working Environment (Psychosocial Hazards)</td><td rowspan="2">Remoteness</td><td>Pearson Correlation</td><td>0.54</td><td>0.42</td><td>0.50</td></tr>
<tr><td>Sig.</td><td>0.00</td><td>0.00</td><td>0.00</td></tr>
<tr><td rowspan="2">Isolation</td><td>Pearson Correlation</td><td>0.54</td><td>0.46</td><td>0.52</td></tr>
<tr><td>Sig.</td><td>0.00</td><td>0.00</td><td>0.00</td></tr>
</table>

The Pearson correlation coefficient was used to study the correlation between mental health disorders and workers' safety behaviour, and the results in Table (2) show a negative and statistically significant correlation at the level of significance (0.01) between the level of safety behaviour and workers' mental health disorders. Correlation coefficients were (-0.54) to (-0.50) and (-0.51) for Depression, Anxiety and Stress, respectively.

Table (2): Correlation between Mental Health Disorders and Worker's Behaviour (n =409)

Variables			Safety Behaviour
Worker's Mental Health (Disorders)	Depression	Pearson Correlation	-0.54
		Sig.	0.00
	Anxiety	Pearson Correlation	-0.50
		Sig.	0.00
	Stress	Pearson Correlation	-0.51
		Sig.	0.00

In light of previous results, multiple linear regression analysis was used to study the effect of mental health disorders on worker's behaviour, as demonstrated in Table (3).

Table (3) Regression model for the effect of Mental Health Disorders on Safety Behaviour (n=409)

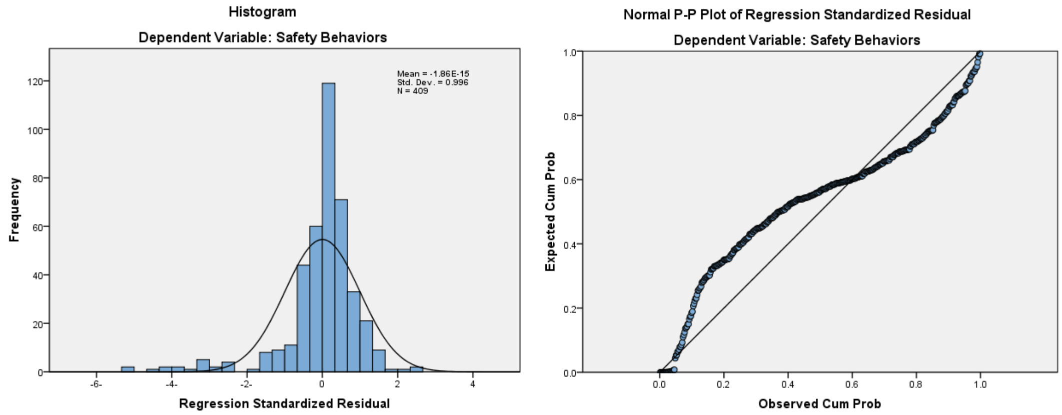
Dependent Variable	Predictors	Unstandardized Coefficients		Standardized Coefficients	t	P-value/ Sig.	F	P-value/ Sig.	R Square
		B	Std. Error	Beta					
Safety Behaviour	(Constant)	3.38	0.14	—	24.89	0.00	60.67	0.00	0.31
	Depression	-0.05	0.01	-0.34	-3.95	0.00			
	Anxiety	-0.01	0.01	-0.06	-0.69	0.49			
	Stress	-0.02	0.01	-0.19	-2.49	0.01			

Table (3) shows that the value of F is (60.67), with (P-value < 0.01), meaning that the regression model is significant at the level of significance (0.01). The coefficient of determination (R^2) equals (0.31), which means that (31%) of the variance in the level of safety behaviour can be explained by the variance of mental health disorders.

It was found that Depression had the most significant impact on the level of Safety behaviour, followed by Stress, whereas the standardized regression coefficient (β) values reached (-0.34) and (-0.19), respectively, indicating the importance of the effect of these variables on safety behaviour.

In contrast, Anxiety had an insignificant impact on safety behaviour in the presence of other variables (P-value > 0.05). Figure (4) shows the distribution of the standard residuals of the regression model, where it is clear that the distribution of the standard errors of the Model is close to the normal distribution.

Figure (4): Distribution of the Standard Residuals of the Regression Model between Mental Health Disorders and Safety Behaviour



Based on these findings, neglecting the working environment's impact on workers' mental health could eventually compromise a worker's safety behaviour. Mental health disorders can become overwhelming, leading to unsafe behaviour, which puts their safety and the safety of others at risk while ultimately harming the interest and sustainability of this vital sector.

Therefore, workers' interactions with the working environment psychosocial hazards must be recognized to comprehend better the various associated health threats, including stress, anxiety and depression disorders that might result from these interactions. The main concern is that every occurrence of a responsive interaction between a worker and his working environment affects his perception and behaviour.

In this manner, addressing Stress, Anxiety and Depression in the Oil & Gas industry is critically important since such a distinct working environment could be physically, psychologically and socially stressful, adversely affecting workers' mental well-being and consequently influencing their safety behaviour and performance.

5. Conclusion

The researchers of this study argued that human error should not be entirely regarded as the root cause of incidents and accidents in the Oil & Gas industry but rather should be viewed from a broader scope as a consequence of multiple personal-environmental interactions in the working environment, which could adversely affect the workers' mental well-being leading to disrupting their safety behaviour. In this view, psychosocial hazards in the Oil & Gas working environment could impose substantial risks by affecting the workers' behaviour, changing their ability to maintain positive safety behaviour. This could be reasoned by the hidden nature of mental health disorders since they cannot be easily diagnosed compared to other occupational safety risks. As an illustration, Stress, Anxiety and Depression, among other mental health disorders, could be unrecognized in a workplace unless reported by workers, which is unlikely to happen due to discrimination. Subsequently, the relationship between the psychosocial hazards of the working environment and the workers' mental health cannot be easily linked to the workers' behaviour unless a comprehensive investigation is carried out. These findings stipulate the necessity for corrective measures to mitigate remoteness, high workload and adverse living conditions since they significantly impact workers' mental health. Based on this argument, the industry's regulators and operators should initiate rapid interventions to address mental health disorders, including a primary framework for the Egyptian Oil & Gas sector, to raise awareness for frontline workers and management in all capacities with the significant impact of the psychosocial hazards of the working environment.

Furthermore, increasing the number of workers and incorporating further automation in operation activities might seem a reasonable approach towards tackling high workloads. Also, providing a means of communication like high-speed internet to allow video calls with families could decrease workers' perceptions of isolation and remoteness, especially for offshore workers. In addition, allowing workers' privacy in accommodation, especially on offshore installations, and providing recreational and entertainment facilities are highly recommended to mitigate the perception of adverse living conditions. On the other hand, operators should demonstrate a culture of safety engagement and safety communication by listening to workers, making them feel valued for their contributions and supporting them to enhance their contextual performance. Working towards this aspiration lays the foundation for the daily delivery of safety and performance; it will enable an engaged and empowered workforce and allow the industry to gain optimal productivity.

Area for Further Research

Future research is suggested to examine the relationship between workers' educational backgrounds and safety culture dimensions for assessing attitudes and perceptions towards workplace safety climate in the Egyptian Oil & Gas gas sector since it might be a crucial individual component influencing workers' behaviours.

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NUMERICAL ANALYSIS OF WAVE ENERGY POINT ABSORBERS BUOY SHAPE

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المستخلص:
لقد زاد الطلب على الطاقة بشكل كبير هذه الأيام مما أدى إلى تزايد استهلاك الكهرباء، والتي يتم توفير معظمها عن طريق الوقود الأحفوري، مما أدى إلى زيادة تكاليف الطاقة وكذلك الانبعاثات الضارة الناتجة عن احتراق الوقود. وقد أدى ذلك إلى التقدم في استخدام مصادر الطاقة المتجددة لتلبية الطلب الحالي على الطاقة. وتشمل هذه المصادر استخدام الطاقة الشمسية وطاقة الرياح والأمواج لتوليد الطاقة بطريقة خضراء. يعرض هذا البحث استخدام ممتصات نقاط الطاقة الموجية بأشكال مختلفة لتقييم أدائها عند تعرضها للموجات. تم تصميم أربعة أشكال من العوامات وتحليلها باستخدام برنامج Ansys Aqwa لملاحظة حركتها وكذلك استجابتها للقوى غير المتوازنة التي تتعرض لها. أظهرت النتائج أن العوامة ذات الشكل الأسطواني يمكنها تحقيق حركة أكبر بنسبة ٥٢.٨% في الاتجاه الرأسي مقارنة بمتوسط حركة تصميمات العوامات المختلفة. وهذا يدل على أن العوامة الأسطوانية هي الخيار الاقتصادي لامتصاص طاقة الأمواج بشكل أفضل.

ABSTRACT:
Energy demands have increased dramatically nowadays giving rise to the growing consumption of electricity, most of which is provided by fossil fuels, which has increased energy costs as well as the harmful emissions resulting from fuel combustion. This has resulted in advancements in the use of renewable energy sources to satisfy the current energy demands. These sources include the use of solar, wind, and wave power to generate energy in a green manner. This paper presents the use of wave energy point absorbers with various shapes to assess their performance when exposed to waves. Four buoy shapes are modelled and analyzed using Ansys Aqwa to observe their motion as well as their responsiveness to the out of balance forces subjected on them. The results show that the cylindrically shaped buoy can achieve around 52.8% more motion in the vertical direction when compared to the average motion of the different buoy designs. This shows that a cylinder buoy is the economic option for optimized wave energy absorption.

Keywords: Wave Power, Green Energy, Point absorbers, Numerical Simulation

1. INTRODUCTION

Given the harmful impacts of fossil-based energy sources and the growing consumption of electricity, governments have taken considerable steps towards sustainable development and the application of renewable sources of energy in their various forms such as solar, wind and wave power to reduce environmental pollution (Viet et al., 2016). Among the commonly used renewable sources of solar and wind energy, wave energy has the highest power density and provides the most availability through 90% of the time which increases its reliability when compared to other renewables (Beirão & Malça, 2014). Therefore, great efforts were made to utilize wave energy through various technologies of wave energy converters (WEC) which include point absorbers, oscillating water columns, and overtopping devices (Khojasteh & Kamali, 2016). A point absorber (PA), however, is considered the most effective technique in terms of power absorption and feasibility; both economically and technically (Guo et al., 2022). It is characterized by a small dimensional floating buoy relative to its surrounding wavelength, and a mooring system to keep the buoy supported at the seabed. The objective of a PA system is to absorb the maximum energy from different wave frequencies which is harnessed by a power take off (PTO) system (Shadman et al., 2018).

Although PA systems can take various configurations, a two-body WEC can also be used to harness the wave energy through the relative motion between the two moving buoys thus creating a better cost-effective solution (Li et al., 2023).

Despite its advantages, a PA is not efficient in harnessing the slow-speed oscillations of the waves which encouraged many studies to design PTO devices that can convert the buoy's mechanical energy into electrical energy with high efficiency to improve the PA's performance in rough wave and weather conditions which increased the manufacturing, implementation, and maintenance costs (Piscopo et al., 2017). Also, the use of PA systems in irregular wave conditions is affected by wave frequencies which cannot be considered (Liang et al., 2023).

In 2012, Guedes Soares et al. in Review and classification of wave energy converters, studied various WECs to determine the most effective technologies for offshore implementation in terms of theory of operation and power conversion steps. They found out that converters should be classified according to the power delivered cost which requires geographic and economic factors that are susceptible to change (Guedes Soares et al., 2012).

In 2018, Chen et al. in Performance evaluation of a dual resonance wave-energy convertor in irregular waves, introduced a dual resonance wave-energy convertor. The performance of the converter was studied using the linear wave theory and spectral analysis under different mechanical factors such as internal mass, PTO system damping, and spring stiffness (Chen et al., 2018).

In 2020, Li et al. in Optimum power analysis of a self-reactive wave energy point absorber with mechanically driven power take-offs, studied two types of PTO systems: mechanical motion rectifier (MRR) and non-MMR with dynamic models in conjunction with the WEC system. They created a numerical simulation to analyse the performance of the two systems. The obtained results showed that the MRR system better absorbs power for small wave periods (Li et al., 2020).

This research aims to compare the behaviour of several buoy shapes in waves. The parameter in the proposed analysis is the geometrical shape of the buoy; alterations in which will be made to study the efficiency of the buoy in absorbing wave power which will be assessed based on the buoy's movement in response to the incident waves. In this paper, various buoys will be designed and built in a 3D numerical simulation with a fixed radius. The models will then be subjected to wave conditions. Finally, the results will be analyzed to determine the buoy shape that achieved the most movement in response to the incident waves.

2. METHODOLOGY

Numerical models of four buoy shapes are built, namely cube, cylinder, cone, and pyramid shapes and used in a computational fluid dynamics software (Ansys) in the hydrodynamic diffraction system (Aqwa) to run simulations with a fixed radius to determine the buoy shape with the most displacement in response to the incident waves.

The theory of Ansys Aqwa in the frequency domain is solving the equations of motion to calculate the response X of a structure in waves for unit wave amplitude as shown in Eq. (1):

$$[-\omega^2 \left(M_s + M_a(\omega)\right) - i\,\omega\, B(\omega) + C]\, X(\omega) = F(\omega) \quad \#(1)$$

where: ω is frequency

M_s is structure's mass

M_a is added mass (frequency dependent)

B is damping (frequency dependent)

C is hydrostatic stiffness

F is wave force (incident and diffracting forces)

The methodology is composed of the following four stages highlighted in Figure 1:

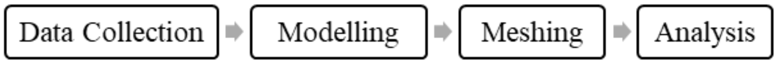

Figure 8: Research Methodology Layout

The simulation is done in a water domain size of 2.5 m × 1.5 m with a depth of 35 m using Ansys Aqwa as shown in Figure 2.

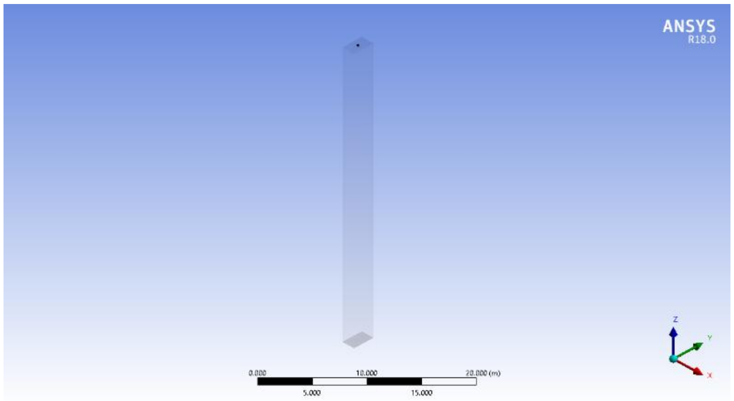

Figure 9: The Water Domain Used in Simulation

In the study, four buoy shapes, cube, cylinder, cone, and pyramid, are 3D modelled and analyzed with a fixed mass of 0.138 kg and a radius of 0.1 m to yield the optimum shape for wave energy harvesting.

The buoys' inertia values are defined through their radius of gyration as shown in Table 1.

Table 23. Radius of gyration of the proposed buoy shapes

Buoy shape	*Radius of gyration*	*Value (m)*
Cube	$k = \frac{l}{\sqrt{6}}$	0.04082
Cylinder	$k = \frac{R}{\sqrt{2}}$	0.07071
Cone	$k = \sqrt{\frac{3\,r^2}{10}}$	0.05477
Pyramid	$k = \frac{l}{\sqrt{10}}$	0.03162

Figure 3 shows the different geometries of the proposed buoys with a radius or characteristic dimension of 0.1 m which signifies the length of the cube, radius the cylinder, cone, and side length of the pyramid where the radius equals the height of the buoy as well.

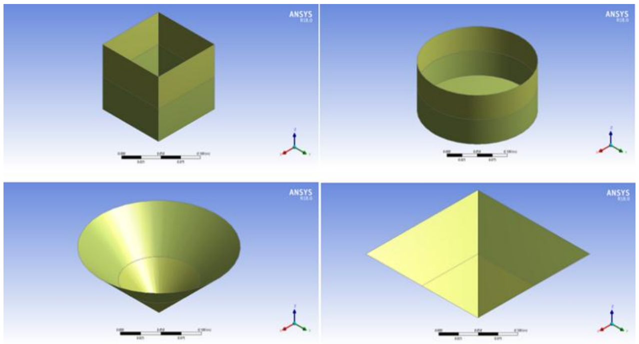

Figure 10: Proposed Buoy Geometries

The buoy shapes were meshed with a maximum element size of 0.003 m as shown in Figure 4. The number of elements is 15680, 30156, 28375, and 17936 for cubic, cylindrical, conic, and pyramidic buoys respectively.

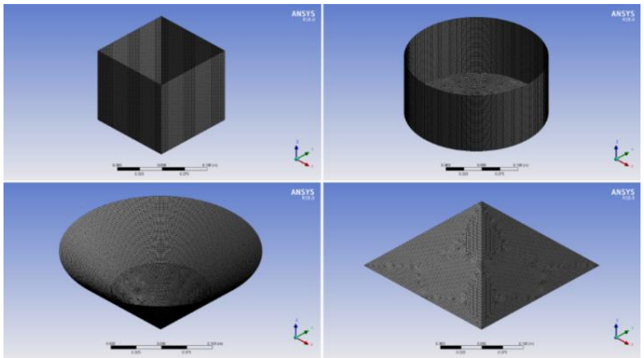

Figure 11: Meshing of the 3D Buoys' Geometries

Four mesh sizes were investigated to verify that the simulation results are independent of the mesh size, with an element size of 0.0033, 0.0031, 0.003, and 0.0029. The total number of mesh elements as well as simulation results are shown in Table 2. The maximum element size of 0.003 was used for the final results.

Table 24. Verification Results of the Simulation Model

Element Size (m)	*Number of Elements*	*Heave Z (N/m)*	*Out of Balance Forces/Weight*
0.0033	13209	98.065681	2.623168
0.0031	14580	98.067108	2.6232119
0.003	15680	98.065903	2.6231372
0.0029	16820	98.065025	2.6231592

The input wave range is -180° to 180° with an interval of 45° resulting in 7 intermediate wave directions as illustrated in Figure 5. The incident wave range has lowest frequency of 0.1 rad/sec and highest frequency of 63.47637 rad/sec and 18 intermediate frequency values.

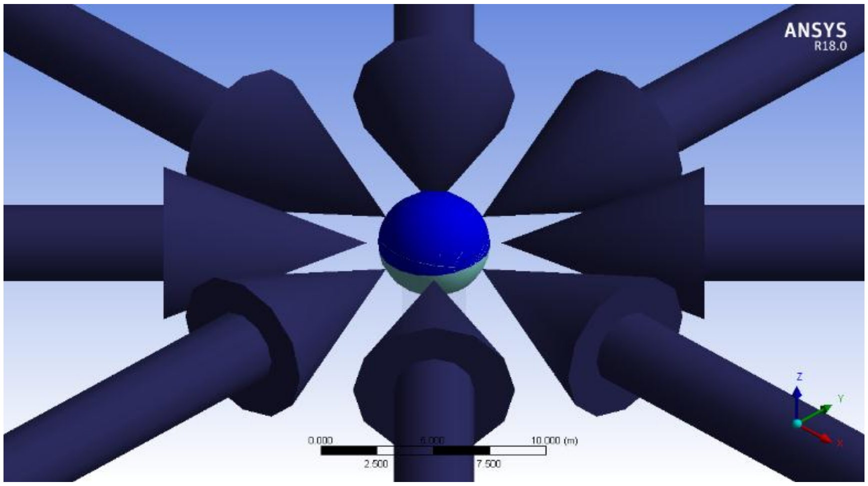

Figure 12: Wave Directions with a 45° Interval

3. RESULTS AND DISCUSSION

The results of the numerical analysis were observed, in incident wave frequency range of 0.1 – 63 rad/sec, with the geometry change of each buoy and the results of the buoy's heave, pitch and roll motions were recorded.

The heave motion of each buoy shape is observed first. Figure 6 shows the values of each buoy's heave motion in the vertical Z-direction. It is observed that the cylindrical buoy yields the highest heave motion with 308.06888 N/m, and the conical buoy yields the lowest heave motion with 77.014214 N/m.

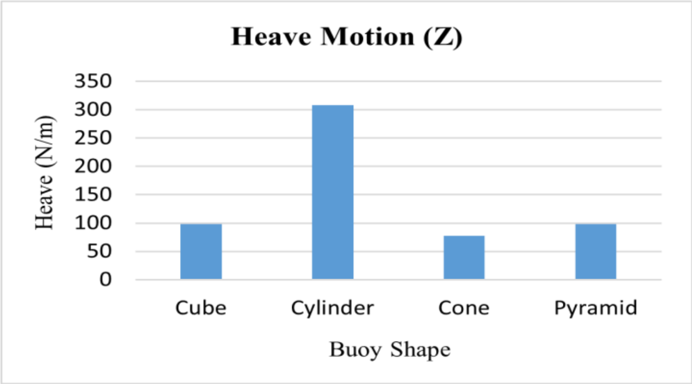

Figure 13: Heave Motion of Proposed Buoy Shapes

The buoys' roll movement in the Z-direction is observed for each shape. Figure 7 shows the values of each buoy's roll motion around the vertical Z-direction. It is observed that the cylindrical buoy yields the highest roll motion with 9.0362×10^{-7} N.m/m, while the conic buoy shape yields the least roll motion with -9.1072×10^{-8} N.m/m.

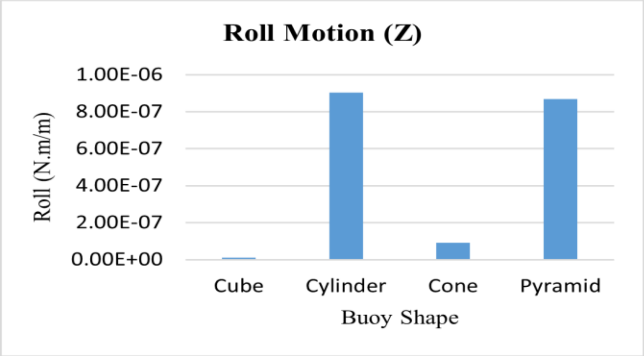

Figure 14: Roll Motion of Proposed Buoy Shapes

The pitch motion of each buoy shape is recorded. Figure 8 shows the values of the pitch motion in the vertical Z-direction for each buoy shape. It is observed that the cylindrical buoy yields the highest pitch motion with 2.2967×10^{-6} N.m/m, while the cubic buoy shape yields the least pitch motion with -9.9922×10^{-8} N.m/m.

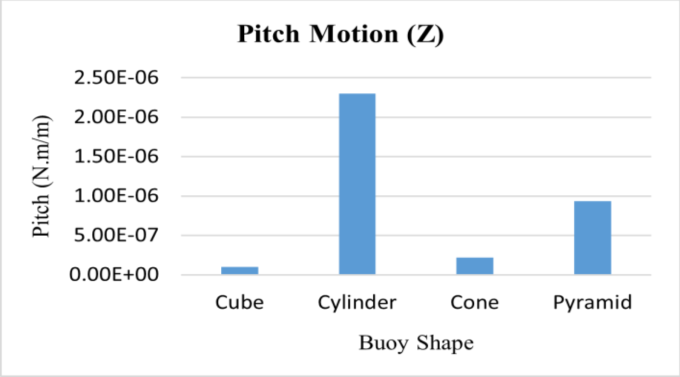

Figure 15: Pitch Motion of Proposed Buoy Shapes

Figure 9 shows the out-of-balance forces affecting the different buoy geometries in the vertical Z-direction. It is observed that a force per unit weight of 10.38197 affects the cylinder, while a minimum force per unit weight of -0.0516 affects the cone.

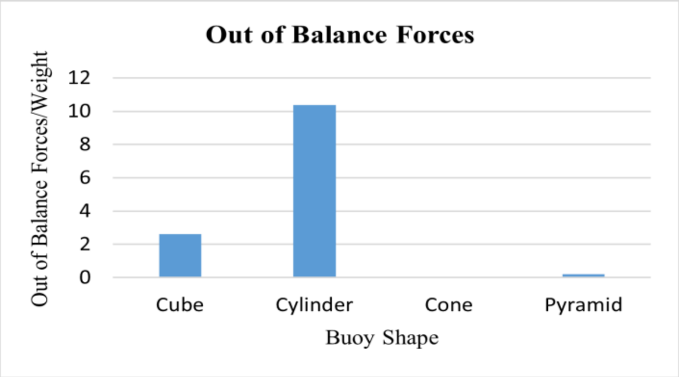

Figure 16: Out of Balance Forces/Weight of the Proposed Buoy Shapes

4. CONCLUSIONS

This study presents a method of evaluating the response of buoy wave energy absorbers based on their motion in the vertical Z direction and the forces that affect the buoys causing their heave motion given the complex interaction between waves and a moving/oscillating buoy which affects its stability as well as energy harnessing efficiency (Yu et al., 2023).

The analysis is carried out by implementing changes in the buoy's geometry and comparing the response of each shape to the out of balance forces generated by the incident waves which is evaluated through the buoys' movement in the heave, roll, and pitch motions.

The four selected geometrical shapes for the buoys are 3D modelled with a characteristic dimension/radius of 0.1 m and a fixed mass of 0.138 kg. The geometries are then meshed with a maximum element size of 0.003.

A range of incident waves from -180° to 180° with an interval of 45° are imposed on each buoy resulting in 7 intermediate wave directions with the lowest frequency of 0.1 rad/sec and highest frequency of 63.47 rad/sec.

The research results show that, for the buoys heave motion, the cylindrical buoy shape yields a heave movement in the Z-direction 52.83% higher than the average achieved motion of 145.3 N/m. The heave motion makes up the largest component of the buoys' motion in the Z-direction.

The out of balance forces are used as an indication of the response of the various buoy designs to the incident waves, which show that the cylindrical buoy is exposed to 68.3% higher value of out of balance forces in the Z-direction than the average value of 3.29 Newton per unit weight.

The results conclude that the cylindrical buoy shape achieves the highest movement values in heave, roll and pitch motions in the vertical Z-direction as well as the highest out of balance forces in the Z-direction making it the most responsive shape to the incident wave conditions analyzed.

In conclusion, the use of cylindrically shaped wave energy absorbing buoys can be efficient and cost effective when compared to other buoy geometries gives the high displacements they reach when exposed to waves. This in turn leads to the increased output of the energy absorbing system while reducing the costs by using the optimum geometry for wave energy harvesting (Zhang et al., 2023).

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Liquefied Natural and Petroleum Gas Carriers: An Analysis of the Potential Dangers, Safety Measures and Risk Factors

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المستخلص:

يستخدم الغاز الطبيعي المسال وغاز البترول المسال على نطاق واسع كمصادر طاقة صديقة للبيئة وفعالة للغاية. ومع ذلك، فإن نقل هذه المنتجات عن طريق البحار ينطوي على أخطار متأصلة على البيئة ورفاهية الإنسان. يحقق هذا البحث في المخاطر المحتملة وتدابير السلامة والمتغيرات التي تزيد من احتمالية الضرر المرتبط بتداول الناقلات للغاز الطبيعي المسال والغاز البترولي المسال، حيث تسعى هذه الدراسة أيضًا إلى التحقق من وجهات نظر وأحكام القائمين والعاملين في مجال تداول الغاز الطبيعي المسال وغاز البترول المسال حول المخاطر المحتملة وتدابير السلامة وعوامل الخطورة المرتبطة بسفن الغاز الطبيعي المسال والغاز البترول المسال. وتم إجراء استطلاع على عينة مختلفة مكونة من ١٠٠ شخص من مختلف قطاعات الصناعة. وكشفت النتائج أن غالبية المشاركين أعربوا عن قلقهم بشأن المخاطر المحتملة المرتبطة بنقل الغاز الطبيعي المسال والغاز البترول المسال. ومع ذلك، فقد حافظوا أيضًا على اقتناعهم بأن إجراءات السلامة والبروتوكولات والتدريب والتقدم التكنولوجي الحالية تعتبر فعالة في التخفيف من المخاطر. وأعرب المشاركون عن رضاهم عن مستوى الشفافية والتواصل والعمل الجماعي والمعايير المتخذة في الصناعة، فضلاً عن كفاية عمليات التأمين والضمانات. وتشير نتائج الدراسة إلى أن تصور الجموع العام لنقل الغاز الطبيعي المسال والغاز البترول المسال كان إيجابيًا في الغالب ومتوافقًا مع تدابير السلامة التي تم وضعها.

Abstract

Liquefied natural gas (LNAG) and liquefied petroleum gas (LPG) are extensively used as environmentally friendly and highly efficient energy sources. Nevertheless, the movement of goods by water has inherent risks to both the environment and human well-being. This study examines the potential hazards, safety precautions, and risk factors related with the transportation of Liquefied Natural Gas (LNG) and Liquefied Petroleum Gas (LPG) carriers. This research also aims to examine the perspectives and opinions of individuals working in the LNG and LPG business on the possible hazards, safety precautions, and risk elements related with LNG and LPG carriers. A survey was performed among a heterogeneous sample of 100 individuals from various areas of the business.The analysis reveals that a huge part of individuals expresses problem approximately ability risks associated with LNG and LPG transportation. While self belief in present day safety measures is extraordinary, there are dissenting evaluations, suggesting regions for improvement. Safety protocols, emergency reaction approaches, and the qualifications of personnel also showcase numerous perceptions. Environmental impact emerges as a chief challenge, highlighting the need for similarly research. Transparency and communique within the industry show blended responses, emphasizing potential regions for enhancement. Participants generally well known the fantastic impact of technological advancements, but neutrality suggests various views. Insurance and liability mechanisms are perceived positively, however dissenting critiques underscore areas of skepticism. International cooperation and requirements garner combined responses, indicating ability possibilities for global collaboration. The take a look at concludes by exploring the alignment between public notion and actual protection measures. While a massive component is glad, dissenting and impartial responses indicate room for development in aligning public belief with enterprise protection realities. Overall, this research contributes valuable insights for stakeholders, guiding future safety enhancements and coverage concerns in the LNG and LPG transportation area.

Keywords: LNG, LPG, transportation, safety, risk, perception, attitude, survey.

1. INTRODUCTION

Liquefied natural gas (LNG) and liquefied petroleum gas (LPG) are substantial sources of energy that are transported on a global scale using specialised carriers. The marine industry is witnessing a growing prominence of liquefied gas utilisation on account of its potential to serve as a more environmentally friendly and effective alternative to conventional fuels (Pitblado and Woodward, 2011). The transportation of these gases has inherent dangers; thus, it is critical to understand the safety standards and potential dangers associated with their transportation. Dedicated boats are utilised to transport LNG and LPG while maintaining the gases in a liquefied state at exact temperature and pressure parameters. These boats play a vital role in enabling the global transit of petroleum products and natural gas. However, there are inherent dangers associated with the shipping of LNG and LPG, including the potential for leaks, burns, and explosions. It is critical to ensure the security of these carriers to prevent accidents and preserve lives and the environment.

A number of countries, including Japan, South Korea, and some European countries, lack the capability to acquire undersea or terrestrial pipelines in order to tap the natural gas reserves of their neighbouring countries. Given the continuing Ukraine War (2022) and the situation concerning fixed gas connections and the oppressive Russian government, which has affected practically every EU member state (Khujadze and Janužytė, 2023), the crucial importance of LNG transit becomes evident. Comparable conditions pertain to the need for LPG; certain enterprises are significantly apprehensive regarding the accessibility of supplies via maritime transportation. Constantly, ensuring the safety of liquefied gas transport at sea has been of the utmost importance. Precautions are implemented to mitigate the effect of any incidents that do transpire and to increase the probability of their occurrence by decreasing their probability. By adhering to the most stringent industry standards for risk assessment and management, these safeguards supplement technological measures that are consistent with crew training requirements. Due to the Intentional Maritime Organization's (IMO) attention on it in a number of gas code issues and professional organisations, important players are quite informed (such as SIGTTO or OCIMF). The likelihood of an accident or incident is also never zero. Engineers must thus possess a comprehensive comprehension of past incidents in order to devise effective responses (Gucma & Mou, 2022).

Questionnaire about potential dangers, preventative measures, and risk factors associated with LNG and LPG transporters is the objective of this research. This study has the potential to offer valuable insights into the safety of LNG and LPG transportation for regulatory authorities and stakeholders in the energy and transportation industries by examining these facets.

2. RESEARCH OBJECTIVE

This research aims to:

1) Examine the potential hazards, precautionary measures, and factors that contribute to the risk of injury in the transportation of LNG and LPG carriers
2) Examine the perspectives and assessments of persons working in the LNG and LPG business about the possible hazards, safety precautions, and risk factors linked to LNG and LPG vessels.

3. RESEARCH QUESTIONS

1) What are the perceived risks connected with the transportation of LNG and LPG carriers, as indicated by those employed in the LNG and LPG industries?
2) What safety measures do staff often use while transporting LNG and LPG carriers to reduce possible risks and hazards?
3) Which elements have industry specialists recognized as important contributors to the risk of harm in the transportation of LNG and LPG carriers?

4. REVIEW OF LITERATURE

4.1. LNG/LPG Safety

In contrast to other industries involved in petroleum and processing, the LNG industry has an exceptional safety record. This is demonstrated by the rare mistakes and catastrophes that have transpired since the first LNG facility in West Virginia was established in 1912. Foss (2003) highlighted several aspects that contribute to the safety performance of the LNG industry in his research. An element contributing to this is the sector's dedication to ensuring secure operations, a goal that has been accomplished via technical and operational progress. There are several facets to technological and operational advancements, including the engineering discipline that supports LNG facilities, operational processes, and employee technical expertise. In addition, the technology and processes have been designed with the physical and chemical properties of LNG, along with the related risks and dangers, in mind. The stringent requirements and restrictions that are implemented within the LNG sector (Forte and Ruf, 2017).

The absence of intolerable levels of risk or severe bodily injury constitutes safety. Facilities and carriers engaged in the transportation and storage of LNG and LPG are subject to various dangers that have the capacity to impact their operations (Narayanasamy et al., 2018). A hazard is a physical situation or situation that, whether present alone or in combination, is capable of causing harm to human life, property, the environment, or property damage. Risk avoidance and mitigation strategies are implemented across the whole LNG value chain. Risk prevention techniques are used with the intention of proactively averting the occurrence of hazards and its adverse effects, whilst risk mitigation tactics are utilised to lessen the severity of hazards. Risk can be conceptualised as the product of the probability of an unfavourable incident transpiring and the gravity of its repercussions, or as the amalgamation of the probability of its transpiration and the scale of its potential affects (Wang and Trbojevic, 2007).

Despite the implementation of many safety protocols, incidents of an unanticipated nature may occur throughout the LNG/LPG value chain. An incident that transpires within a segment of the LNG/LPG value chain has the potential to impact other segments as well. For instance, an incident or mishap associated with the functioning of LNG carriers when loading or unloading LNG might potentially impact the LNG storage tanks through the pipelines (Briouig, 2014). One approach to identify operational hazards associated with LNG/LPG carriers is to employ a brainstorming process that examines the safety characteristics of the various components of the LNG/LPG value chain. Five primary operations comprise the LNG value chain: production of natural gas, transportation of LNG, liquefaction of natural gas, re-gasification, and distribution. In order to facilitate the uninterrupted flow of natural gas from the well to the liquefaction plant, a number of procedures must be executed. These encompass the activities of drilling and completion of a natural gas well, casing the well bore for reinforcement, evaluating the formation's pressure and temperature, and installing the necessary equipment (Naturalgas Online, 2010).

By transforming natural gas into a liquid state, liquefaction plants enable the transfer of LNG via LNG carriers. The liquefaction facility has a range of safety protocols, such as fire alarm systems, secondary containment of LNG storage tanks to ensure gas separation in the event of an accident, and automated shutdown mechanisms. Carriers for LNG and LPG are utilised to move fuel between several containment tanks. The safety risks linked to the transportation of LNG and LPG are escalating as a result of the expanding distribution and demand for these fuels, a development that is garnering more and more scholarly interest (Nwaoha et al., 2016).

To safeguard the LNG, LNG carriers are outfitted with double-hull systems and containment systems comprising over four layers, respectively, to limit the possibility of gas leakage. Vaporizers are utilised in the regasification process to transform LNG from its liquid state to gaseous state. For the purpose of preventing environmental contamination and safeguarding workers, rigorous compliance with occupational safety and health regulations (HSE) and standards is upheld (Varagka, 2015). Through pipelines, the natural gas generated by the re-gasification process is transported to ultimate consumers. To guarantee the integrity of natural gas transmission, regular checks are conducted on these pipes. Pipeline inspection serves to disclose the safety status of the pipelines, so enabling timely intervention or correction in the case of any complications. An assortment of internal procedures, including ultrasonic, eddy current, geometry/calliper, and magnetic flux leakage, are utilised to check the pipeline. Furthermore, diver inspection, remote-operated towing vehicles (ROTVs), and remote-operated vehicles (ROVs) are all examples of exterior inspection techniques (Nwaoha et al., 2016).

4.2. LNG & LPG Hazards

Combustibility of liquid gas vapours is the greatest danger. However, the health implications of a medicine are of equal importance. Hydrogen, biodiesel, liquefied natural gas (LNG), methanol, and ethanol are all considered viable alternatives to traditional fuels. LNG is utilised to propel LNG carrier boats; due to its higher hydrogen-to-carbon ratio compared to traditional marine fuels, this fuel type effectively mitigates NOx and CO2 emissions. LPG, an ecologically acceptable replacement for petroleum in cars, is a gasohol blend composed of butane and propane. By employing steam-methane reform and electrolysis, it is possible to extract hydrogen from various substances in order to generate an emission-free propellant. The purpose of ethanol, a gasoline alternative derived from corn and sugarcane, was to serve as a replacement for petroleum. Despite having unique physicochemical properties, these fuels emit fewer pollutants due to their simple molecular structures as compared to traditional fuels. Significantly lower particulate and hydrocarbon emissions result from the use of these fuels. The properties of diesel fuel and alternative fuels that were investigated in this study are summarised in Table 2. A comparison of LNG delivered in bulk by ship with LPG, gasoline, and VCM demonstrates if LNG is extremely hazardous cargo (Table 1). (Djermouni and Ouadha, 2021).

Table (1): Comparison of LNG with LPG, VCM and gasoline (Djermouni and Ouadha, 2021).

Characteristics	LNG	LPG
Temperature of the flame (K at 100 kPa)	2233	2243.15
Limits on flammability (vol.% air)	4–16	2.2-9.5
Evaporation heat (kJ/kg)	479	428
Molar Mass (kg/kmol)	18	51
Boiling point °C	-162	-40
The temperature of autoignition in Kelvin	810	727.6-783.15
LFL % (in air)	5	2
Flash point °C	-175	-105
UFL % (in air)	15	9
Value of net thermal (MJ/kg)	46–50.2	46.3

Liquid gas vapors' flammability is the major risk. the toxicity, carcinogenicity, oxygen shortage, and other unique characteristics of chemicals constitute health dangers. The issue with liquefied gases, specifically LNG, is the incredibly low temperature. Comparison of LNG with LPG, gasoline, and VCM, transported in bulk by ship, reveals if LNG is very dangerous cargo (Table 1) (Starosta, 2007).

4.3. 2019 Kerch Strait liquified gas tanker fire

When two ships, Kandy and Maestro, caught fire while transporting liquefied gas from one vessel to another in the Kerch Strait on January 21, 2019, it resulted in a significant crisis. During the event, six crew members—including Libyan, Turkish, and Indian sailors—went missing, and fourteen people perished. The Russian Navy was able to save twelve men who dove into the ocean. Maestro had fifteen crew members, whereas Kandy had seventeen crew members. 4,500 metric tons of gasoline were being carried by both ships at the time of the accident.

Turkish ships Maestro and Kandy, flying the Tanzanian flag, were involved in the ship-to-ship fuel transfer that culminated in the fire explosion and spread to both ships (Bosneagu, 2022). The effort to put out the fire was spearheaded by the Russian multipurpose salvage vessel Spasatel Demidov;

however, despite dousing both ships, the fire raged on for five more days. Ten ships, one of which was a Soviet rescue ship, participated in the crew rescue mission (Bosneagu, 2022).

4.4. Risk Assessment of the Gas Carriers

Accidents involving flammable goods, such as LNG, can have disastrous effects, including fire and explosions. Asset managers are obligated to design safety measures in compliance with regulatory regulations in order to mitigate such effects. Risk analysis has become a very effective tool for this purpose in safety-critical sectors to help guide choices on asset design, production, installation, operation and maintenance (O&M), and decommissioning (Animah & Shafiee, 2020).

Risk analysis is a relatively new topic, having only been studied scientifically for roughly 30 to 40 years, according to Aven (2016). Although a relatively new field of study, risk analysis has been used in a variety of fields, including medicine, engineering, transportation, security, and the military, as well as social and legal issues, to identify the best possible technological, safety, economic, and environmental solutions (Aven, 2016). Risk analysis may have its origins in the nuclear business of the past (Pasman, 2015).

The first probabilistic risk assessment (PRA) approach was created for a nuclear power plant in the 1970s, according to information from the United States Regulatory Commission, and several more techniques and tools have since been created. In order to help decision-makers continually handle operational, safety, economic, and environmental concerns in safety-critical sectors, Villa et al. (2016) highlighted that risk analysis methodologies are transitioning from conventional approaches to more dynamic ones.

4.5. Previous studies

Multiple scholars have contributed to the enhancement of safety measures for LNG/LPG carrier operations through the use of risk assessments. Significant volumes of LNG/LPG or its vapour emission are the principal safety threat for LNG/LPG carriers (Crolius et al., 2021). It is imperative to quantify and mitigate the hazards associated with LNG/LPG, including potential injury to human life, damage to carrier systems, and environmental hazards. A quantitative risk assessment approach was implemented on a generic LNG/LPG carrier using the formal safety assessment (FSA) paradigm (Vanem et al., 2008). The FSA determined the consequences of a collision, grounding, contact, fire, explosion, or loading or unloading of LNG or LPG carriers using Event Tree Analysis (ETA). The idea of As Low as Reasonably Practical (ALARP) identified the greatest potential for collisions. The dangers connected with LNG carrier systems and LNG terminals have been investigated qualitatively and quantitatively by a number of studies. Pitblado et al. (2004), Östvik et al. (2005), Kim et al. (2005), Bubbico et al. (2009), Moon et al. (2009), and Nwaoha et al. (2009) have all contributed to these investigations (2011a, 2012b, 2013). In their study, Bublico et al. conducted a preliminary risk assessment of LNG/LPG vessels approaching the Panigaglia maritime port (2009).

Intentional damage to the containment systems of the LNG tankers due to terrorism caused pool fires. The analysis of the results indicated that harmful thermal consequences were anticipated within a 700–1500 m radius in the region under examination. The impacts of both the residential population and the anchoring were negligible. In a similar vein, Pitblado et al. (2004) examined the potential hazards and repercussions associated with inadvertent malfunctions, such as terrorist assaults, that may occur on LNG vessels at an ordinary LNG terminal in the United States. The research undertaken by Kim et al. (2005) involved the application of fault tree analysis (FTA) to evaluate the quantitative risk associated with the onshore LNG storage tank in Korea. The study determined that loading and unloading LNG carriers constituted one of the six potential disaster scenarios that may lead to an LNG spill from the onshore LNG storage tank in Korea. A number of FTA diagrams were generated for the six accident categories that were identified, and the failure probability of each were evaluated. Additionally, a study conducted by Stvik et al. (2005) elaborated on the utilisation of a qualitative risk assessment methodology to compute the potential dangers linked to the 138,000 m3 membrane-type LNG carriers presently under construction by Navantia. During the process of risk identification and estimation, many operating stages of LNG tankers were considered.

Moon et al. (2009) conducted research that underscored the significance of risk assessment in evaluating various gas turbine propulsion system designs for LNG carriers. The primary objective was to identify potential hazards associated with each design and ascertain the primary contributors to these hazards. Further investigation was conducted into the origins of gas discharge, with a particular focus on the novel attributes of gas turbine propulsion systems, in order to identify potential remedies for mitigating the hazards and causes of gas emissions. Nwaoha et al. (2011a) conducted a probabilistic risk assessment (PRA) on LNG carrier systems utilising an FTA. Utilizing the FSA methodology, the research presents a novel fuzzy evidential reasoning (FER) model to handle the failure mode uncertainty of the LNG containment system and transfer arm. Suggested in the work by Nwaoha et al. (2013) are sophisticated computational techniques for dealing with unpredictable conditions. A risk-based evaluation of LNG carrier hazards was conducted in this study utilising a combination of FER and a risk matrix.

5. METHODOLOGY

A mixed-methods approach was utilized in this study to obtain a comprehensive understanding of the potential hazards, safety measures, and risk factors associated with the transportation of these gases. This approach incorporated both quantitative and qualitative methods.

5.1. Data Collection

The data collection procedure proceeded with the distribution of a **Likert scale questionnaire** to a sample of **100 individuals** who were employed in the transportation and energy sectors (Appendix 1). The questionnaire was created to evaluate the participants' perspectives of the possible hazards, safety precautions, and risk factors linked to LNG and LPG transporters. The participants were chosen based on their proficiency and background in the industry, guaranteeing a thorough comprehension of the topic. In addition, a thorough examination of relevant literature and case studies was conducted to get qualitative perspectives on the safety of LNG and LPG transporters.

5.2. Sample Size

The survey sample comprises 100 individuals who are employed in the transportation and energy sectors. The current sample size is deemed sufficient for capturing a wide array of viewpoints and experiences pertaining to the transportation of LNG and LPG. The participants include of experts engaged in the operation and regulation of LNG and LPG carriers, together with those with knowledge in the safety and risk management of these specialized vessels.

5.3. Data Analysis

A statistical analysis was conducted on the data acquired from the Likert scale questionnaire with the purpose of identifying trends and patterns in the viewpoints of the participants. Software applications, including SPSS (Statistical Package for the Social Sciences), were utilised to process the quantitative data in order to provide descriptive statistics and inferential analyses. Thematic analysis was used to the qualitative data obtained from the literature review and case studies with the purpose of identifying recurrent patterns and obtaining significant insights into the safety of LNG and LPG carriers.

5.4. Ethical Consideration

The participants were provided with informed consent documents that detailed the aims of the study, the intended use of their responses, and their rights as subjects of research. Thorough precautions were used to ensure the preservation of confidentiality and anonymity. The collected data will be utilised solely for the intended purposes of this research. In addition, to protect the rights and welfare of the participants, the research adheres rigorously to ethical guidelines and standards set out by regulatory bodies and pertinent institutional review boards. Furthermore, the study focuses increased importance on guaranteeing the ethical management of any confidential data obtained throughout the inquiry. Every potential conflict of interest has been duly disclosed, and the research has been conducted in an entirely transparent and truthful manner.

6. RESULTS AND DISCUSSION

6.1 An Examination of the Questionnaire

A) Age

Table 2. Age of participants.

Age	Frequency	Percent (%)
Less than 25 years old	5	5
25-35 years old	35	35
36-45 years old	40	40
Above 45 years old	20	20
Total	100	100

The age distribution mentioned inside the furnished information offers treasured insights into the demographic composition of the surveyed members, shedding light on the generational perspectives contributing to the observe on LNG and LPG transportation.

The largest cohort within the sample is individuals aged between 36 and 45 years, constituting forty% of the members. This age organization possibly represents specialists with a massive amount of revel in and know-how, doubtlessly presenting a pro and nicely-knowledgeable attitude on the situation depend. Their insights can be shaped through a aggregate of early-career experiences and a extra mature information of enterprise dynamics.

The 25-35 age organization accommodates 35% of the sample, representing a large part of mid-profession professionals. This demographic can also bring a stability of contemporary insights, having skilled the evolution of enterprise practices and technology at some stage in their careers.

Participants above 45 years vintage make up 20% of the pattern, representing a set with significant revel in and doubtlessly imparting historic context and insights into the long-time period adjustments in the enterprise.

The age organization much less than 25 years old, constituting five%, represents the perspectives of early-career experts. While a smaller cohort, their inclusion is essential for capturing sparkling viewpoints and expertise the concerns and expectancies of the rising group of workers within the subject.

In conclusion, the age distribution inside the take a look at reflects a numerous representation of experts across exceptional levels in their careers. This range in age companies enriches the study by way of incorporating numerous perspectives shaped by way of unique profession ranges, reports, and ancient contexts. It highlights the want for a comprehensive information of generational dynamics within the enterprise, spotting that each age institution can also make contributions precise insights to discussions surrounding LNG and LPG transportation.

B) Gender

Table 3. Gender of participants.

Gender	Frequency	Percent (%)
Male	80	80
Female	20	20
Total	100	100

The gender distribution presented in the provided data indicates the representation of male and female participants within the surveyed population. This categorization is essential for understanding the diversity of perspectives and experiences brought to the study on LNG and LPG transportation.

The majority of participants, 80%, identify as male. This imbalance in gender representation is a notable aspect of the sample and raises considerations about the potential impact on the study's findings. It underscores the importance of promoting greater gender diversity and inclusivity in future research endeavors within the energy and transportation sectors.

The female representation at 20% highlights the presence of women in the field, albeit in a minority. Recognizing and amplifying the voices of women in industries traditionally dominated by men is crucial for fostering diversity of thought and experience. The perspectives of female professionals may bring unique insights and considerations to the forefront, enhancing the overall richness of the study.

In conclusion, while the gender distribution in this study may reflect existing gender imbalances within certain industries, it also emphasizes the need for concerted efforts to promote inclusivity and diversity in research samples. Future studies should strive for more balanced gender representation to ensure a more comprehensive understanding of perspectives and challenges within the context of LNG and LPG transportation.

C) Level of Education

Table 4. Level of Education.

Level of Education	Frequency	Percent (%)
High school or equivalent	6	6
Bachelor's degree	24	24
Master's degree	40	40
Doctorate's degree	20	20
Total	100	100

The breakdown of individuals' stage of education within the provided records elucidates the academic qualifications of the surveyed populace. This categorization is instrumental in comprehending how people with varying instructional backgrounds understand and have interaction with the difficulty matter related to LNG and LPG transportation.

The largest organization in the pattern accommodates people with a Master's diploma, representing forty% of the individuals. This indicates a sizable proportion of individuals who have pursued superior schooling, potentially bringing a deeper expertise of the technical, environmental, and safety elements associated with LNG and LPG transportation. Their perspectives may be knowledgeable by way of specialized know-how received through postgraduate research.

Bachelor's diploma holders constitute 24% of the sample, presenting a good sized representation of specialists with foundational academic qualifications. This group in all likelihood brings a diverse set of abilties and understanding, contributing to a well-rounded view of the challenge depend. The inclusion of participants with a excessive school or equal education (6%) acknowledges those with sensible industry revel in who may also offer particular insights based on their fingers-on involvement.

Participants with Doctorate's ranges make up 20% of the pattern, reflecting a great presence of people with the best level of academic achievement. This subgroup can also contribute a specialized and research-oriented attitude, including depth to the overall analysis of LNG and LPG transportation-associated problems.

In summary, the educational distribution amongst participants famous a diverse and well-balanced illustration of professionals with varying levels of instructional attainment. This variety complements the breadth of perspectives in the study, encompassing insights from people with specific educational backgrounds and areas of understanding. Understanding this range is crucial for interpreting the nuanced responses to the survey questions, because it permits for a extra comprehensive knowledge of the way schooling impacts perceptions in the context of LNG and LPG transportation.

D) Current occupation

Table 5. Current occupation.

Occupation	Frequency	Percent (%)
Energy industry professional	45	45
Transportation industry professional	30	30
Regulatory authority representative	15	15
Other	10	10
Total	100	100

The breakdown of player occupations within the provided records furnishes a complete know-how of the various professional backgrounds contributing to the survey. This categorization enables a nuanced analysis of the way people from diverse sectors and roles in the industry perceive and respond to the have a look at's attention on LNG and LPG transportation.

The preeminent class is Energy Industry Professionals, representing 45% of the surveyed populace. This widespread representation underscores the significance of perspectives from the ones directly engaged inside the electricity region. Their insights, fashioned by means of arms-on enjoy and enterprise-unique expertise, possibly preserve large weight in evaluating the protection measures, dangers, and precautionary components related to LNG and LPG transportation.

The Transportation Industry Professionals class, comprising 30% of the sample, brings a crucial angle to the take a look at. These people, with their direct involvement within the transportation region, contribute treasured insights into the operational intricacies and challenges faced within the real motion of LNG and LPG.

The inclusion of Regulatory Authority Representatives at 15% guarantees a regulatory perspective within the study. Their presence is critical for knowledge how industry regulations, requirements, and compliance elements have an effect on perceptions of safety and hazard control in LNG and LPG transportation

The "Other" category, representing 10%, provides a layer of variety, acknowledging experts with roles outside the explicitly referred to sectors. This inclusivity broadens the scope of the have a look at, shooting insights from a variety of roles that may have indirect but sizeable connections to the challenge count number.

In summary, the occupational distribution reflects a properly-balanced and diverse illustration of specialists with varied understanding and duties in the electricity and transportation industries. This variety enhances the richness of the records, imparting a holistic view of perceptions and attitudes toward LNG and LPG transportation from multiple vantage points. Understanding these professional backgrounds is pivotal for interpreting and making use of the have a look at's findings correctly across one of a kind aspects of the industry.

E) Years of experience

Table 6. Years of experience.

Years of experience	Frequency	Percent (%)
Less than 6 years	14	14
6-10	26	26
11-20	45	45
More than 20	15	15
Total	100	100.0

The provided records on years of revel in within a positive domain presents a clear distribution of the surveyed population, providing insights into the professional tenure of the members. The frequency distribution illustrates the variety of enjoy stages within the pattern, offering a precious context for deciphering different survey responses.

Notably, the majority of members fall in the mid-variety of expert enjoy, with 45% reporting 11 to twenty years of revel in. This suggests a substantial portion of the pattern with a large amount of time spent in their respective fields. It shows that a full-size variety of respondents own a wealth of knowledge and information, potentially influencing their perspectives and responses to questions related to the difficulty be counted.

The distribution additionally highlights a balanced representation across distinct revel in brackets, which includes those with much less than 6 years (14%) and those with 6 to 10 years (26%). This blend guarantees a diverse variety of insights, incorporating the views of each early-career experts and those who have had a more considerable exposure to the sphere.

The inclusion of a class for individuals with extra than two decades of enjoy (15%) recognizes the precious contributions of seasoned professionals who carry a wealth of enterprise know-how and ancient context to the observe. Their perspectives can offer unique insights into the evolution of practices and modifications in the industry over an prolonged duration**.**

6.2. Questionnaire Questions

Table 7. Results of questionnaire questions.

	Questions	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1	**I am concerned about the potential dangers associated with the transportation of LNG and LPG.**	20%	40%	16.7%	13.3%	10%
2	**I believe that current safety measures for LNG and LPG carriers are effective in mitigating potential risks.**	30%	40%	13.3%	10%	6.7%
3	**Safety protocols and emergency response procedures for LNG and LPG carriers are adequate.**	20%	43.3%	20%	3.3%	13.3%
4	**I believe that the training and qualifications of personnel involved in the operation of LNG and LPG carriers are sufficient to ensure safety.**	13.3%	50%	26.7%	6.7%	3.3%
5	**The potential environmental impact of LNG and LPG transportation is a major concern.**	13.3%	46.7%	30%	6.7%	3.3%
6	**I am satisfied with the level of transparency and communication regarding the safety of LNG and LPG carriers within the industry.**	23.3%	43.3%	3.3%	16.7%	13.3%
7	**I believe that technological advancements have significantly improved the safety of LNG and LPG carriers.**	16.7%	40%	20%	10%	13.3%
8	**I feel that the potential risks associated with LNG and LPG carriers are adequately covered by insurance and liability mechanisms.**	16.7%	36.7%	23.3%	13.3%	10%
9	**I am satisfied with the level of international cooperation and standards in place for the safety of LNG and LPG carriers.**	10%	46.7%	13.3%	16.7%	13.3%
10	**I believe that the public perception of LNG and LPG transportation accurately reflects the actual safety measures in place.**	13.3%	33.3%	23.3%	16.7%	13.3%

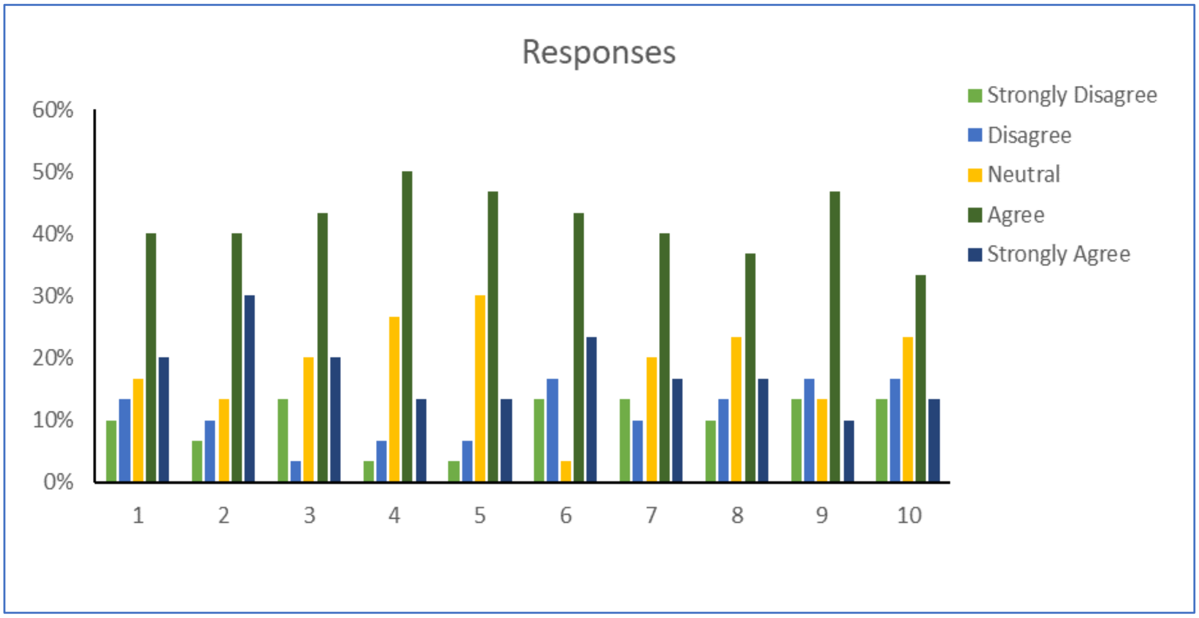

Figure 1. Participants Responses

The aim of this study is to investigate the capability hazards, precautionary measures, and danger factors related to the transportation of LNG and LPG. The individuals had been supplied with a series of statements, and their responses had been categorised into five stages: Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree. Each class's percentage become calculated primarily based at the responses to provide an insightful analysis of the perceptions inside the sample.

The first query examined the members' concerns about the ability risks of LNG and LPG transportation. Notably, forty% of respondents agreed, indicating a giant level of challenge, at the same time as 20% strongly agreed. This suggests a heightened awareness and acknowledgment of the capability risks associated with the shipping of these gases.

Moving on to the effectiveness of contemporary protection measures, 70% (30% Strongly Agree + 40% Agree) of contributors expressed confidence in the present protection protocols for LNG and LPG providers. However, it's far noteworthy that 16.7% disagreed or strongly disagreed, highlighting a portion of the sample which could understand inadequacies inside the present day safety measures.

Concerning protection protocols and emergency response tactics, 63.3% of individuals (20% Strongly Agree + forty three.3% Agree) taken into consideration them adequate. The presence of a neutral response at 20% suggests a part of the pattern remains not sure or neutral in this matter.

The qualifications of personnel worried within the operation of LNG and LPG carriers had been typically perceived definitely, with 50% agreeing that the training and qualifications are sufficient for making sure safety. However, it's miles critical to word the ten% who strongly disagreed or disagreed, indicating some skepticism inside the sample.

The potential environmental effect of LNG and LPG transportation emerged as a major concern for forty six.7% of members, signaling a considerable stage of apprehension in the pattern. Moreover, 30% expressed neutrality, suggesting a need for in addition investigation into public sentiment in this element.

Transparency and communication in the enterprise acquired combined responses. While 43.Three% agreed and 23.3% were impartial, 30% expressed dissatisfaction. This indicates a capacity place for development in terms of information dissemination and communication techniques.

Technological advancements were generally perceived undoubtedly, with 56.7% (16.7% Strongly Agree + forty% Agree) expressing notion in their advantageous effect on protection. However, it's far vital to address the 23.Three% who have been neutral, likely indicating a lack of consensus or data in this subject matter.

Regarding insurance and liability mechanisms, fifty three.Four% (sixteen.7% Strongly Agree + 36.7% Agree) believed that capacity risks are competently blanketed. However, the 23.Three% who disagreed or strongly disagreed imply a subset of individuals with reservations about the present day coverage and liability measures in place.

International cooperation and standards for protection garnered a effective reaction from 46.7% of individuals. However, the 16.7% who disagreed and 13.3% who had been neutral highlight potential areas in which international collaboration and standardization can be more desirable.

Finally, the look at explored the alignment between public belief and actual protection measures. Notably, forty six.6% expressed pleasure or settlement, but the 30% who disagreed or had been impartial suggest room for improvement in aligning public belief with the industry's safety reality.

In end, this analysis gives a complete evaluate of the participants' perceptions on diverse aspects of LNG and LPG transportation protection. The findings highlight areas of consensus, as well as points of competition and uncertainty, imparting precious insights for stakeholders in the enterprise to address worries and give a boost to protection measures.
The desk supplied herein encapsulates the responses accumulated via a meticulous survey designed to attain a profound understanding of perceptions surrounding the transportation of Liquified Natural Gas (LNG) and Liquified Petroleum Gas (LPG). The overarching goal of this examine is to delve into the potential dangers, precautionary measures, and danger elements related to the shipping of those critical electricity resources. By scrutinizing participants' attitudes and evaluations, we aim to get to the bottom of the intricacies of their worries, ideals, and checks touching on the protection protocols, environmental influences, and average safety landscape related to LNG and LPG carriers.

In pursuit of this objective, the survey administered a sequence of ten questions, each addressing awesome aspects of the transportation technique. The responses have been meticulously categorized into 5 tiers, starting from Strongly Agree to Strongly Disagree, presenting a nuanced and unique exploration of members' views. Through this systematic approach, our have a look at endeavors to make a contribution valuable insights that can tell stakeholders within the LNG and LPG transportation enterprise, fostering a much better and responsive protection framework.

The principal recognition of the studies lies in unraveling the nuanced tapestry of perceptions in the surveyed cohort, losing mild on regions of consensus, divergence, and capacity areas for development. As we navigate thru the tabulated facts, we purpose to determine patterns, identify key tendencies, and offer a complete understanding of the triumphing sentiments surrounding protection measures, environmental issues, technological advancements, and global cooperation within the realm of LNG and LPG transportation.

By aligning player responses with the wider goal of scrutinizing dangers, precautionary measures, and risk elements, this table serves as a crucial device in unlocking insights that may guide destiny safety improvements and policy considerations. The observe aspires to make contributions no longer only to the instructional discourse but also to the sensible evolution of protection practices within the LNG and LPG transportation industry, ultimately promoting a safer and greater sustainable destiny for the worldwide energy landscape.

7. CONCLUSION

In conclusion, the complete evaluation of player responses inside the presented table gives precious insights into the perceptions surrounding the transportation of Liquified Natural Gas (LNG) and Liquified Petroleum Gas (LPG). The overarching purpose of this look at become to examine ability risks, precautionary measures, and danger factors related to those vital energy sources' transport.

The findings screen a nuanced panorama of views inside the surveyed cohort. While a vast portion of participants expresses concerns approximately ability dangers related to LNG and LPG transportation, there is a widespread level of self-belief in contemporary safety measures. However, it's miles noteworthy that positive respondents harbor reservations and uncertainties, especially concerning the adequacy of protection protocols, personnel qualifications, and the capability environmental impact.

Environmental concerns come to be a distinguished subject, with a enormous percentage of participants highlighting the need for in addition scrutiny and mitigation techniques. Transparency and communication in the industry additionally warrant interest, as a noteworthy percent of respondents express dissatisfaction with the current ranges.

The wonderful perceptions regarding technological advancements and insurance mechanisms imply a foundation for boosting protection practices, whilst the regions of problem offer clean signposts for targeted upgrades. The examine underscores the importance of worldwide cooperation and requirements, suggesting ability avenues for collaborative efforts to reinforce the protection framework on a global scale.

In mild of these observations, stakeholders within the LNG and LPG transportation enterprise are encouraged to remember the numerous views uncovered on this look at as they work towards refining protection measures. By addressing issues, fostering transparency, and leveraging technological improvements, the enterprise can similarly enhance its dedication to safety and environmental stewardship.

This look at serves now not simplest as an educational exploration but additionally as a practical manual for industry experts, policymakers, and applicable stakeholders. As we flow forward, non-stop engagement with these insights can be instrumental in shaping a safer, greater sustainable, and resilient destiny for the worldwide LNG and LPG transportation landscape.

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Appendix 1
Questionnaire

A) Demographic Questions

1. What is your age?
- Under 25
- 25-35
- 36-45
- Over 45

2. What is your gender?
- Male
- Female

3. What is your highest level of education?
- High school or equivalent
- Bachelor's degree
- Master's degree
- Doctoral degree

4. What is your current occupation?
- Energy industry professional
- Transportation industry professional
- Regulatory authority representative
- Other (please specify)

5. How many years of experience do you have in the energy or transportation industry?
- Less than 6 years
- 6-10 years
- 11-20 years
- Over 20 years

B) Likert Scale Questions

6. I am concerned about the potential dangers associated with the transportation of LNG and LPG.
- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

7. I believe that current safety measures for LNG and LPG carriers are effective in mitigating potential risks.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

8. Safety protocols and emergency response procedures for LNG and LPG carriers are adequate.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

9. I believe that the training and qualifications of personnel involved in the operation of LNG and LPG carriers are sufficient to ensure safety.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

10. The potential environmental impact of LNG and LPG transportation is a major concern.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

11. I am satisfied with the level of transparency and communication regarding the safety of LNG and LPG carriers within the industry.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

12. I believe that technological advancements have significantly improved the safety of LNG and LPG carriers.

- Strongly Agree
- Agree

- Neutral
- Disagree
- Strongly Disagree

13. I feel that the potential risks associated with LNG and LPG carriers are adequately covered by insurance and liability mechanisms.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

14. I am satisfied with the level of international cooperation and standards in place for the safety of LNG and LPG carriers.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

15. I believe that the public perception of LNG and LPG transportation accurately reflects the actual safety measures in place.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree