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Blue economy

The blue economy, characterized by the sustainable utilization of ocean resources for economic advancement while preserving the integrity of marine ecosystems, encompasses environmental, economic, and social dimensions. This multifaceted approach emphasizes the interdependence of ecological health, economic prosperity, and societal well-being. Core to the blue economy paradigm are oceanic assets such as coral reefs, mangroves, seagrass meadows, and wetlands, which not only yield tangible goods and services but also provide critical ecosystem functions such as coastal protection and carbon sequestration. Consequently, the preservation and resilience of marine and coastal ecosystems are imperative for fostering sustainable development, particularly in regions where millions are engaged in fisheries, fish farming, and coastal tourism, with significant contributions to global GDP and essential protein intake for billions, notably in developing countries.

The evolving conceptualization of the blue economy underscores the need to align economic growth with environmental stewardship. This entails embracing regenerative practices that foster human health, food security, and sustainable livelihoods while mitigating environmental degradation. Projections indicate substantial economic potential within the ocean economy, with estimated annual contributions reaching $1.5 trillion, expected to rise to nearly $3 trillion by 2030. Achieving these projections necessitates targeted interventions across key sectors including fisheries, aquaculture, tourism, energy, shipping, port activities, and seabed mining, as well as fostering innovation in renewable energy and marine biotechnology. Investment in a sustainable ocean economy transcends mere financial returns, emphasizing the preservation and restoration of intangible blue resources essential for planetary health.

Strategic Blue Growth initiatives, as advocated by the European Union, advocate for the adoption of environmentally sensitive technologies and practices while acknowledging the imperative of social considerations in fostering sustainable development. The EU Blue Growth Agenda prioritizes the provision of marine environmental services, notably in aquaculture, blue biotechnology, blue energy, marine mineral extraction, and tourism. However, the viability of these sectors hinges upon the maintenance of healthy marine and coastal ecosystems, underscoring the critical importance of regulatory frameworks and environmental stewardship.

In the African context, where a significant proportion of nations are coastal or island states, the ocean assumes paramount economic significance, facilitating over 90% of the continent's imports and exports. United Nations Sustainable Development Goal 14 underscores the imperative of ocean conservation and sustainable resource utilization, with programs addressing this goal concurrently addressing poverty alleviation, food security, energy access, infrastructure development, reduced inequality, urban development, sustainable production and consumption, climate action, biodiversity conservation, and institutional capacity building. The second African Blue Economy Model underscores the challenges and opportunities inherent in Africa's burgeoning ocean economy, advocating for the promotion of sustainability through the adoption of circular economy principles. Nonetheless, a persistent challenge lies in securing adequate funding to expand these industries and realize their developmental potential fully.

Collision between supply vessels and offshore installations case cargo handling and personal transferring operation

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المستخلص

هذا البحث يقدم منظومة تهدف إلى تحليل المخاطر المرتبطة بالأخطاء البشرية والعوامل المرتبطة بها، والتى ينجم عنها تصادم بين سفن الإمداد والتموين والمنشآت البحرية مع التركيز على ثلاث فئات من المخاطر الرئيسية هى عملية نقل البضائع والأفراد،وعدم الحفاظ على موقع السفينة،ومناورات السفينة.لإنجاز هذه المهمة تم تنظيم هذا البحث إلى ثلاث مراحل منفصلة وتطبيقها كدراسة حالة على عملية نقل البضائع والافراد.

تم استخدام نموذج حالة الانهيار والتأثيرات، والحرجية (FMECA) لتحديد المخاطر. كما تم استخدام النموذج التفسيري الهيكلي (ISM) متعدد المعايير لتصنيف سيناريوهات المخاطر بطريقة أكثر تفصيلاً مما يسهل عملية اتخاذ القرار (MCDM). بالإضافة إلى ذلك، تم إجراء تحليل لعواقب سيناريوهات الحوادث لسفن الإمداد والتموين باستخدام تحليل شجرة الأخطاء (FTA) لتقييم الأسباب الجذرية للحوادث الذي هو منهج شامل لتقييم وإدارة المخاطر فى إطار منهجية تقييم السلامة الرسمية (FSA) للمنظمة البحرية الدولية (IMO).

Abstract

This paper presents a systematic methodology aiming at investigating human-error induced collisions between attendant vessels and offshore installations, with focus on three key risk categories: Cargo handling and personnel transferring (CH), loss of station keeping (SK) and ship handling and maneuvers (SH). Because of space limitation, the methodology will be applied here to the first category (CH) only.

The Failure Mode, Effects and Criticality Analysis (FMECA) method was used to identify the hazards. Moreover, the Interpretive Structural Modeling (ISM) of Multi Criteria Decision Making (MCDM) was used for the same purpose and results of both methods were favorably compared. Moreover, the Fault Tree Analysis (FTA) was used to evaluate the root causes of accidents down to the Underling Factors (UFs) benefiting from the revised guidelines for the IMO Formal Safety Assessment (FSA).

Background

It is unanimously agreed upon that the majority of collision incidents between Offshore Supply Vessels OSVs and offshore installations are caused by human errors (Sánchez-Beaskoetxeaa, 2021).

The analysis of collision between attendant vessels and offshore installations, specifically focusing on human error, within the framework of risk management, presents inherent challenges due to numerous factors and causes that significantly influence this type of operation. This subject is a topic of considerable concern and exploration in numerous scholarly articles and research papers. Therefore, many researchers have attempted to come up with a methodology that would respond to the magnitude of the risks involved; however, reviewing the literature reveals that there has not been a one methodology that is considered the standard of the industry. Rather, some research endeavors have been attempted.

For instance, Tvedt (2014) considered collisions between attendant vessel and offshore installations and proposed a framework for risk modeling. The model provided no quantifications however, it a good foundation for future work. The generic collision scenarios involved have been analyzed using FTA to identify and break down the operational barrier functions available to reduce collisions. It tackled only three scenarios of attendant vessel- installations collisions while on voyage and did not consider attendant vessel operations within the 500m- zone.

Also, Azad (2014) employed the FMECA tool to assess risks related to attendant vessel, but again did not consider collision incidents between attendant vessel and offshore installations. In their research, Yasa and Akylidiz (2018) suggested a framework for applying FSA on attendant vessel aiming to improve safety. Their work has been based on expert judgments and historical data. They also recommended using FTA, ETA and Failure Mode and Effect Analysis (FMEA) as assessment tools. The study provided general and basic guiding for future research, but was not specific to the case of collision. Moreover, Zhu et al. (2022) were pioneers in employing ISM in their work in the offshore industry risk assessment; however, their work was current with storm risk and was not specific to attendant vessel.

This research attempts to fill this gap by proposing such a methodology and this is presented in the following three sections. The first section reviews the current risk management frameworks in the offshore maritime industry. The second section proposes the methodology for identifying, analyzing and evaluating the risks of human errors caused attendant vessel offshore installations collisions. Finally, the implementation of the methodology is detailed. considering one risk category only, i.e. cargo handling and personnel transferring.

Review of the current risk management frameworks in the offshore maritime industry

The risk management process for collisions involves a series of sequential steps that are placed within a framework. One of the most commonly used frameworks for risk management in the offshore industry is the Formal Safety Assessment (FSA) process used by the International Maritime Organization [IMO], (2019)

The FSA process steps are visually depicted in the flowchart of Figure (1) .Five distinct steps, commencing with system definition and concluding with cost-benefit assessment, constitute the process.

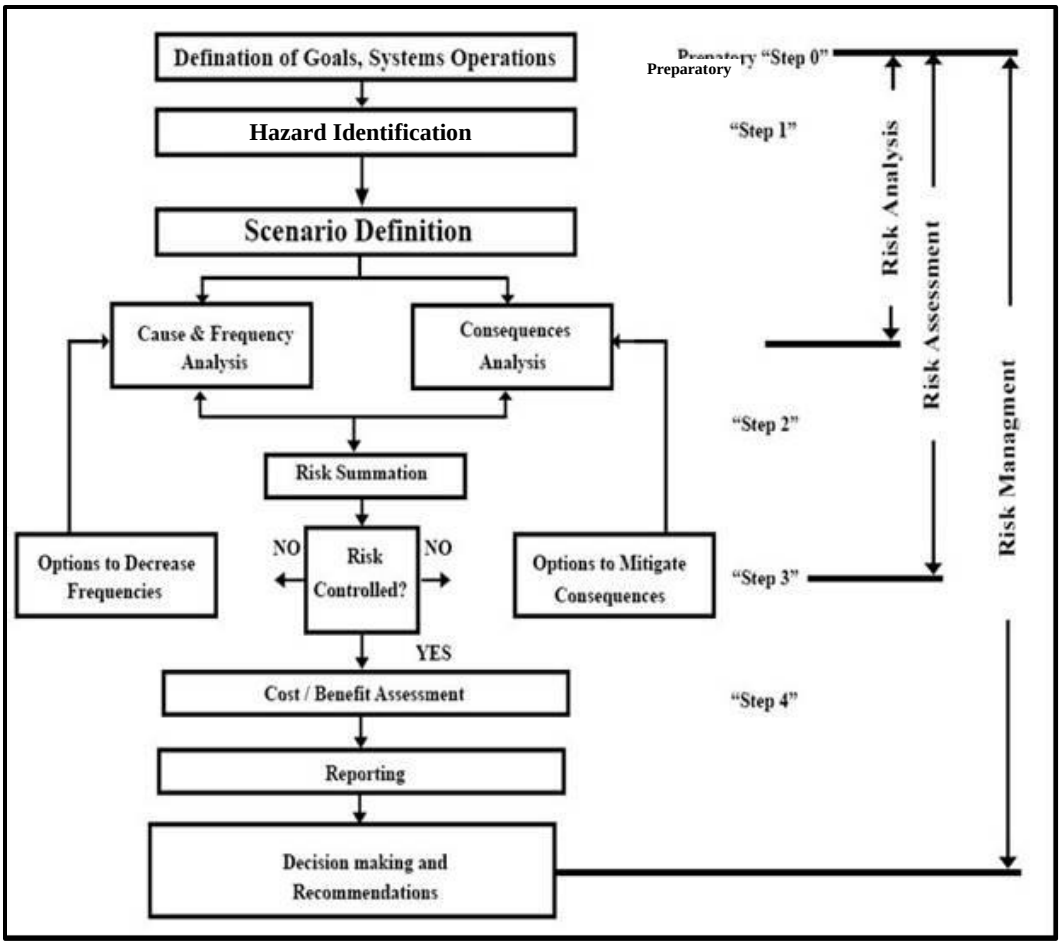


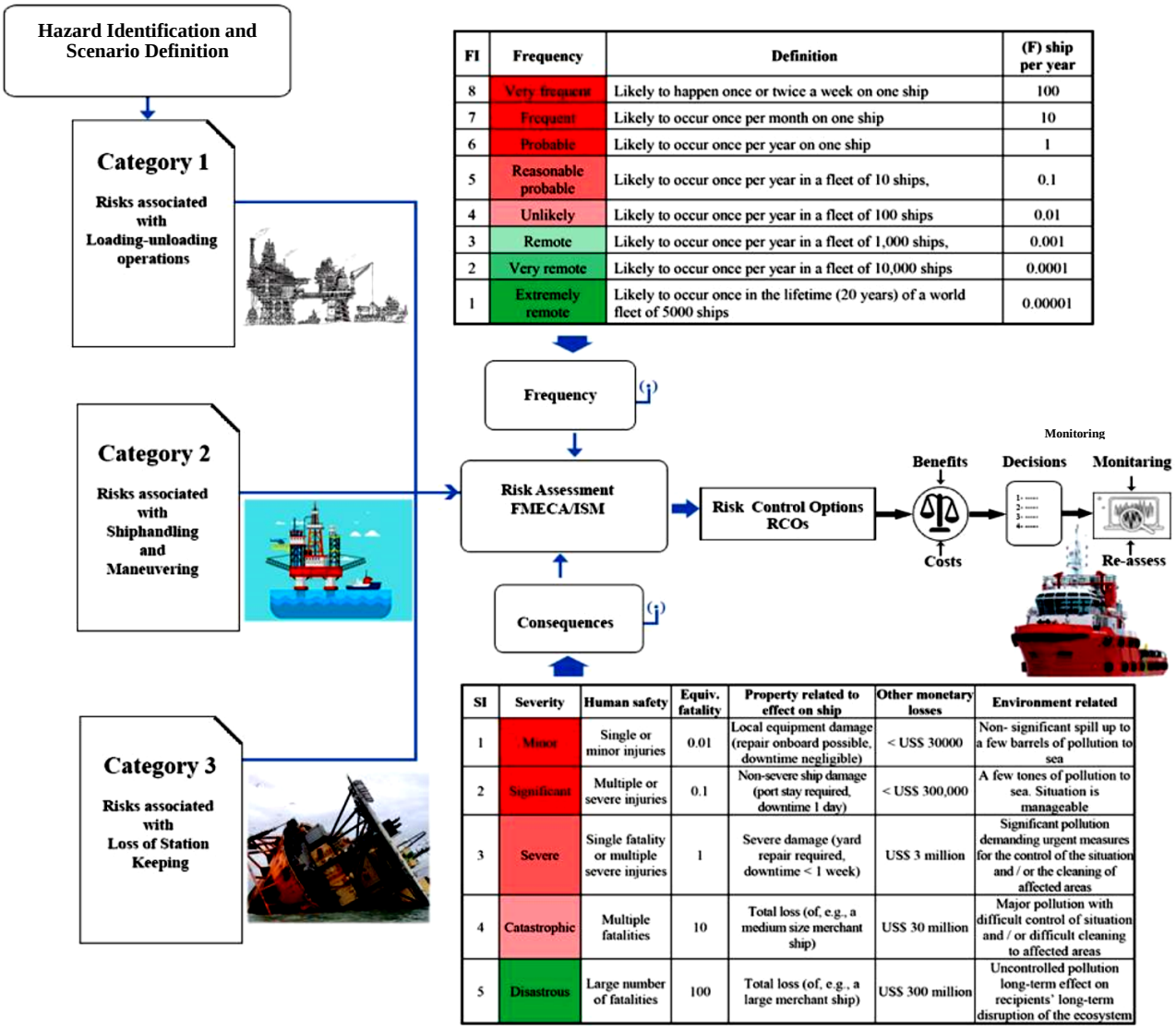
Figure (1): Flow chart of the formal safety assessment process (IMO, 2019)

There are other frameworks and methodologies, such as Hazard and Operability Studies (HAZOP), Failure Mode and Effects Analysis (FMEA), and Layers of Protection Analysis (LOPA), that are used in the offshore industry to assess and manage risks (Health and Safety Executive [HSE], 2015). Nonetheless, this research adopts the FSA methodology, which Where the FSA represents a baseline for the proposed methodology because of its comprehensiveness, support in early identification of potential failures and compliance with regulations.

Methodology for identifying, analyzing and evaluating the risks of human error caused OSV-offshore installation collisions

Figure (2) presents the organizational framework for risk management in attendant vessel operations within the 500m zone. Thus, the first steps included hazard identification and scenario definition. The following categories of risk scenarios were taken into consideration: (1) cargo handling and personnel transferring (CH), (2) ship handling and maneuvering (SH) and (3) loss of position keeping (SK).

The methodology proposed analyzes and evaluates these risks using a combination of quantitative and qualitative methods. It takes into account quantification of the frequency of occurrence of an event and its associated consequences (Brannen, 2017).



FI	Frequency	Definition	(F) ship per year
8	Very frequent	Likely to happen once or twice a week on one ship	100
7	Frequent	Likely to occur once per month on one ship	10
6	Probable	Likely to occur once per year on one ship	1
5	Reasonable probable	Likely to occur once per year in a fleet of 10 ships,	0.1
4	Unlikely	Likely to occur once per year in a fleet of 100 ships	0.01
3	Remote	Likely to occur once per year in a fleet of 1,000 ships,	0.001
2	Very remote	Likely to occur once per year in a fleet of 10,000 ships	0.0001
1	Extremely remote	Likely to occur once in the lifetime (20 years) of a world fleet of 5000 ships	0.00001

SI	Severity	Human safety	Equiv. fatality	Property related to effect on ship	Other monetary losses	Environment related
1	Minor	Single or minor injuries	0.01	Local equipment damage (repair onboard possible, downtime negligible)	< US$ 30000	Non- significant spill up to a few barrels of pollution to sea
2	Significant	Multiple or severe injuries	0.1	Non-severe ship damage (port stay required, downtime 1 day)	< US$ 300,000	A few tones of pollution to sea. Situation is manageable
3	Severe	Single fatality or multiple severe injuries	1	Severe damage (yard repair required, downtime < 1 week)	US$ 3 million	Significant pollution demanding urgent measures for the control of the situation and / or the cleaning of affected areas
4	Catastrophic	Multiple fatalities	10	Total loss (of, e.g., a medium size merchant ship)	US$ 30 million	Major pollution with difficult control of situation and / or difficult cleaning to affected areas
5	Disastrous	Large number of fatalities	100	Total loss (of, e.g., a large merchant ship)	US$ 300 million	Uncontrolled pollution long-term effect on recipients' long-term disruption of the ecosystem

Figure (2): The organizational framework of risk management; OSV-offshore installation collision

The aforementioned quantification of frequency of occurrence of an event and its consequences is transformed into frequency indices and severity indices, which serve as the basis for determining the risk indices. Subsequently, these indices are utilized to assess the risk to human life, to the environment, to the cargo and to the ship.

Then, risk analysis stage follows, which aims to develop an understanding of the vessel's risks and provide input data for the evaluation stage. Risk analysis involves assessing the two key components: probability/frequency and severity. Additionally, other relevant attributes are considered. This comprehensive risk analysis process incorporates both qualitative and quantitative impact assessment for each risk scenario category associated with attendant vessel-offshore

installation collisions, considering human errors and their underlying factors. Once the risk analysis stage is completed, it is straight forward to evaluate the risk index using the equation:

$$R = F \times C \quad (1)$$

where **R** is the risk, **F** the frequency, and **C** the consequence(s). Alternatively, the logarithmic form can also be used:

$$\text{Log } (R) = \log (F) + \log (C), \quad (2)$$

or simply

$$\mathfrak{R} = \mathfrak{F} + \mathfrak{C}, \quad (3)$$

where $\mathfrak{R}$ is the risk index, $\mathfrak{F}$ the frequency index, and $\mathfrak{C}$ the consequence index (Skjong, 2002). Then, the hazard and scenarios are ranked accordingly, the process of proposing RCMs for mitigating the impact after most hazardous scenarios practiced. This process is complemented by a cost-benefit analysis, which aids in establishing a set of useful criteria for decision-making. Decisions are made with consideration for the broader context of risks, risk barriers and the risk tolerance of stakeholders, thereby complementing the overall risk management process.

Details of the Implementation of the FSA Methodology

Expert opinion demonstrates that risk management is an ongoing and iterative process that occurs throughout the entire duration of an activity. This process follows a cyclical nature and consists of five essential stages: establishing the organizational context and planning for risk, identifying hazards, conducting risk analysis (including quantitative, semi-quantitative, and qualitative approaches), establishing risk management strategies, and implementing monitoring and control measures (Goerlandt & Montewka, 2015). The proposed methodology in this study incorporated multiple approaches for risk planning, identification and ranking of hazard scenarios. First, experts identify the most significant operation scenarios, specifically focusing on collisions between attendant vessel and platforms caused by human errors and related factors. Historical events serve as primary data, combined with experts' judgment to assess risks.

To rank the contributing factors, the methodology recommends utilizing FMECA, an analytical method employed in the evaluation of mechanical and electrical systems to assess the potential consequences and probability of failure (Stavrou & Ventikos, 2015). Primarily, FMECA serves as a quantitative and qualitative tool for expert judgment during workshop-based sessions, which encompasses the following steps:

(i) Process identification, (ii) Listing operation function, (iii) Describing failure mode, (iv) Describing failure effect, (v) Describing failure causes, (vi) Describing failure probability, (vii) Describing failure severity, and (viii) Assigning risk priority number. to identify, evaluate, and prioritize pertinent hazards.

In this context, a group of experts is presented with specific questions pertaining to the object or system being analyzed, such as identifying potential failures, estimating their frequency, and

evaluating their severity. FMECA primarily focuses on conducting thorough analyses to assess system reliability and inform decision-making processes.

On the other hand, ISM is a widely recognized methodology used to establish relationships among specific components that address problems or raise concerns. Complex situations often involve interconnected aspects and considering each element in isolation may not accurately capture the overall situation. ISM helps provide a clearer understanding of the relationships between different components, both direct and indirect, which contributes to a more comprehensive depiction of the situation. By employing ISM, it is possible to gain insights into how individuals perceive these linkages in a general sense (Attri et al., 2013). Implementation of ISM involves the following steps (Vinodh, 2021): (i) Identifying structural self-interaction matrix, (ii) Developing initial reachability matrix, (iii) Establishing final reachability matrix, (iv) Levelling partition, (v) Developing a digraph, and (vi) modifying the ISM model.

In the current methodology, therefore, both FMECA and ISM tools are used for ranking the contributing factors and the results obtained are compared. This comparison is meant to aid in decision making regarding the ranking of operation types concerning human error and their underling factors.

The next stage of the methodology includes risk assessment. For such an objective, the framework recommends utilizing the widely adopted Fault Tree Analysis (FTA) tool to evaluate the root causes of accidents down to the UFs. Hence, FTA helps recommend Risk Control Measures (RCMs) that would subsequently reduce/mitigate risk of collision with emphasis on the most recurring causes of hazards associated with human error and UFs.

As per the International Association of Oil and Gas Producers (IOGP, 2010) provided by the Bureau of Safety and Environmental Enforcement [BSEE], (2023). Fault Tree Analysis (FTA) is a logical framework that defines the sequence of events required for an undesirable improper event to occur. In FTA, the undesirable event threat is usually placed at the top of the diagram. The analysis involves the use of gates to represent the relationship between events at different levels (IOGP, 2010).

There are two common types of gates in FTA: (a) OR gate (the event above this gate occurs if any one of the events connected below it occurs), and (b) AND gate (the event above this gate occurs only if all of the events connected below it occur simultaneously).

By implementing all the previous steps using the recommended methods and tools, the framework becomes complete. Hence, the proposed methodology is comprehensive in the sense that it embeds a mixture of both inductive and deductive approaches, and also uses qualitative and quantitative designs, which matches with the realism philosophy and the mixed approach that was selected to support decision making to improve safety (Smart, 2014).

Results and Discussion

The primary data required for FMECA analysis was collected via brain storming and in-person discussion sessions from a group of experts who were selected based on their experience in the offshore industry to identify the different operation hazard scenarios and later to conduct FMECA;

the group consisted of five attendant vessel captains. The years of experience for the individual experts ranged from 15 to 25 years. Since those experts came from different time zones and remote locations, zoom internet video sessions were carried out according to time suitability for the experts.

On the other hand, the secondary data was collected from IOGP reports. This data was in the form of historical attendant vessel -platforms collision accidents and incidents and was used to identify three different groups of hazard scenarios (G_1, G_2 and G_3). Group G_1 summarizes Loss of Station Keeping (SK) (8 scenarios), group G_2 Cargo Handling (CH) and personnel transferring (8 scenarios), and group G_3 Ship Handling (SH) and maneuvering (16 scenarios). The current paper is concerned with group G_2 only, consisting of eight scenarios, as shown in Table (1). These were further compressed to three scenarios only, namely CH-1, CH-2 and CH-3, as shown in Table (2), to reduce the effort provided by the experts and the time they spend to structure the FMECA and FTA analyses. Furthermore, the data used did not have accident reports including details about all the CH scenarios. In addition, the process of compression was essentially proposed by three experts. Moreover, Table (3) lists twenty eight underling factors of human errors, together with their individual definitions.

Table (4) illustrates the details of the FMECA session based on three accidents in the Gulf of Mexico (GOM). The table lists the risk index in each case, based on frequency and severity indices in terms of Health and Safety (H&S) and Environment (E),each corresponding to one CH scenario, in accordance with Loer et al., (2007). It also lists the failure causes (underling factors) associated with each accident based on Table 3. As may be seen from the RI values, the second scenarios CH-2 is the most risky scenario, followed by CH-3 and CH-1.

Table (1): Cargo handling (CH) and personnel transferring scenarios

N0.	Scenario
1	Bulk hoses of the wrong length
2	Crane limited to one side
3	Change in work scope (i.e., extended duration, hose work, etc.)
4	Unjustifiable prolonged periods near risers or other sensitive area
5	Idle time alongside installation “non-productive time”
6	Inadequate carne outreach
7	Unjustifiable prolonged periods of hose connections
8	Excessive stand-by time for the next lift or remaining connected to bulk hose

Table (2): Comprressed cargo handling (CH) and personnel transferring scenarios

Code	Scenario	Explanation
CH-1	**During cargo handling, the crane is Limited to the weather side (upwind) or the bulk hoses are of the wrong length or crane is limited outreach (poorly sited)**	The vessel is forced to work on the weather side (upwind) side in marginal weather due to the crane on the lee wind side being occupied with another operation or malfunctioning. In addition, the inadequate length of the bulk hose or the crane being poorly sited or the vessel has to handle too heavy lifts forces vessels to work too close to the installation to compensate for length and allow flexibility of hose or reach of crane increasing the risk of collision especially under the sudden changes of current, swell and wind.
CH-2	**The vessel spends excessive Non-Productive time alongside installation/ standby time for the next lift or remaining connected to bulk hose, or there is change in work scope during cargo handling with the rig (i.e., extended duration, hose work)**	The extra time spent by the vessel near the installation being on the DP System poses increased risk as any malfunction may occur at any moment. Moreover, the unplanned change in cargo handling plan by adding tasks that overload the vessel's captain/ chief officer in duty, and therefore could result in multiplied risk of error leaving vessel under collision risk due to weather and other failure factors.
CH-3	**There is poor communication between vessel and installation during cargo handling.**	Poor communication fails to prompt good planning for back cargo manifest problems such as dangerous cargo handling. This adds to the spent time to re-arrange cargo plan, and thus the collision risk.

Table (3): Definitions of UFs of human errors

No.	Underlying factor	Definition
1	**Bad visibility**	During an approach to the platform in dense fog or other weather conditions that reduce the visibility, the vessel cannot rely on visual lookout. Operating the radar and AIS equipment will then be amore important task and should have dedicated personnel. Bad visibility is a constant variable that cannot be improved or avoided.
2	**Blackout**	A complete loss of power resulting from damage or equipment failure in a power station, power lines or other parts of the power system (Babicz, 2015)
3	**DP incident**	A major system failure, environmental or human factor which has resulted in loss of DP capability. (International Marine Contractors Association [IMCA], (2013).

No.	Underlying factor	Definition
4	**DP undesired event**	A system failure, environmental or human factor which has caused a loss of redundancy and/or compromised DP capability (International Marine Contractors Association [IMCA], (2013).
5	**Drifting collision (Drift On)**	A collision of a vessel drifting towards the installation as it has lost its propulsion or steerage or has experienced a progressive failure of anchor lines or towline and its drifting only under the influence of environmental forces (Drift On) (Oltedal, 2012).
6	**Fatigue**	A reduction in physical and/or mental capability as the result of physical, mental or emotional exertion, which may impair nearly all physical abilities including: strength; speed; reaction time; co-ordination; decision making, or balance (IMO, 2000).
7	**Handling error in collision avoidance**	A process in which one ship (manned or unmanned) departs from its planned trajectory to avoid potential undesired physical contact at certain time at future (Huang et al., 2020).
8	**High workload**	Both high physical workload and high mental workload (such as tasks with excessive demands on attention) may lead to fatigue (IMO, 2019).
9	**Human control failure**	An inappropriate or undesirable human decision or behavior that leads to unwanted outcomes or has significant potential for such an outcome (Grech et al, 2008).
10	**Inadequate familiarization period**	The new crew not taking enough time to be familiarized with their duties and important information about the ship
11	**Inadequate knowledge of regulations/standards**	Lack of knowledge or understanding of required regulations due to inadequate regulations/ standards: experience and/ or training. Examples of possible regulations; company policies and standards, national and international regulations, maritime regulations of other port States, local jurisdiction regulations, shipboard regulations, cautionary notices, chart notations, or labeling (IMO, 2000).
12	**Inadequate knowledge of ship operations**	Lack of knowledge resulting from inadequate experience, ignorance of regulations, inadequate knowledge of procedures, inadequate training, and/or unawareness of role/task/responsibility. Examples of areas where an individual might lack knowledge: navigation, seamanship, propulsion systems, cargo handling, communications, and weather (IMO, 2000).

No.	Underlying factor	Definition
13	**Inadequate situational awareness**	Not knowing, due to inadequate experience, lack of communication, co-ordination and/or training, the current status of the ship, its systems, or its environment. Examples include lack of knowledge of location, heading or speed and lack of knowledge of status of ongoing maintenance onboard (IMO, 2000).
14	**Inadequate technical knowledge**	Not having, due to inadequate experience and/or training, the general knowledge which is required for the individual's job onboard. Examples include navigation, seamanship, propulsion systems, cargo handling, communications, and weather (IMO, 2000).

Table (3): Definitions of UFs of human errors (Cont'd)

No.	Underlying factor	Definition
15	**Inappropriate transfer of command**	Formal change of command on the bridge is a way to remove confusion as to who is in charge, and inappropriate transfer of command causes unclear roles and responsibilities which in turn can lead to important tasks (e.g. monitoring, steering) being left unattended. Related RIFs can be "adherence to procedures" and "organizational safety culture".(Oltedal, 2012)
16	**Lack of awareness**	Described as when the officer on the bridge for some reason is not aware of the offshore installation, the collision course or the position of the ship itself. This means that no actions to avoid a collision are undertaken on the ship (Geijerstam, and Svensson, 2008).
17	**Lack of communication or co-ordination**	Not making use of all available information sources to determine current status. This may be the result of a lack of initiative on the part of the individual or a lack of initiative and/or co -operation on the part of others. Examples of poor communication/co-ordination include: poor communication between bridge officers, poor communication with pilots, and poor deck-to-engine-room co-ordination (IMO, 2000).
18	**Lack of maintenance**	"Failure to maintain a ship and its equipment in a safe and efficient condition can have serious consequences, including loss of life, injury, pollution and damage to the marine environment, as well as financial losses for ship owners and operators (IMO, 2020).

19	**Lack of system understanding**	Lack of system understanding is listed as an underlying factor related to the detection of the autopilot status, but this can also be a factor for the watchkeeper when using the radar or AIS. Lack of system understanding can point to organizational deficiencies, in the same way as lack of familiarity with emergency steering. Related RIFs can be "competence", "familiarity" and “competence management".
20	**Layout and Design of the Bridge**	The bridge of a ship is intended to be the heart of the vessel and must provide a clear and unobstructed view of the surrounding area. the primary purpose must be fulfilled (Menon, 2020).
21	**Marginal Weather**	(Described by the significant wave height and wind force), up to which the ship can fulfill the criterion. For manoeuvrability in adverse conditions, a convenient and frequently used measure is the marginal (i.e., maximum) weather severity (Shigunov, 2018).
22	**Non-compliance with safety procedures**	Following the procedures is important for the safety, but this failure is very wide and basically not telling us anything of what went wrong. If a vessel is colliding with a platform, there will always be a breach of the procedures at some level. Addresses this as an underlying factor in all the major supply vessel collision accidents. Related RIFs can be "adherence to procedures" and "organizational safety culture". (Oltedal, 2012)
23	**Operator error**	An action which is not in accordance with planned procedures (Taylor, 2005).
24	**Poor visibility combined with undetected radar fault**	Any condition in which visibility is restricted by fog, mist, falling snow, heavy rainstorms, sandstorms or any other similar causes (Lloyd’s Register Rulefinder, 2005).
25	**Powered collision (drive on)**	Collision between a vessel moving under power and an installation (Drive On) (Oltedal, 2012).
26	**Technical failure**	A failure that is not affected directly by humans in the specific situation. This can for example be a production failure that arises during the usage of equipment but not related to the user (Geijerstam, and Svensson, 2008).
27	**Weather pattern**	Weather patterns risk refers to the likelihood of a vessel encountering adverse weather conditions that may pose a danger to the safety of the vessel, its crew, and the environment. These adverse weather conditions may include storms, hurricanes, heavy seas, high winds, and other weather-related phenomena that can impact the safe operation of a vessel. (IMO, 2017)
28	**Weather side**	the side (as of a ship) to windward **:** the side exposed to weather (https://www.merriam-webster.com)

Table (4): FMECA session and classification of hazards related to cargo handling and Personnel Transferring (CH) Category

Title:	Attendant vessel HAZID	Project :	RCMs to Reduce Risk of Collision Between Attendant Vessels and Offshore Installations	Legend: 1- (SK). 2- (CH) 3- (SH)
Date:	25.09.2023	Process :	**Cargo Handling (CH) And Personal Transferring Category**	

Description of Function		Failure Effect			Failure Cause	Scenarios		Frequency index, (FI)		Consequence index, (SI)		Risk index, (RI)		Remarks
Accident (Scenarios)	Failure Mode Description	Immediate		Ultimate		Sc.	Category	H&S	E	H&S	E	H&S	E	
		To vessel	To Platform											
Crew boat 05/06/2013 GOM (CH-1)	Collision	Bent the back of the boat where it was under the platform.	This bent the piping, grating, and braced on the platform upwards several inches.	As a result, the back of the boat bent while being under the boat landing. The platform braced several inches upwards where piping, gratings suffered significant bent.	7- Handling error in collision avoidance 13- Inadequate situational awareness. 14- Inadequate technical knowledge. 19- Lack of system understanding 28- Weather side	2 3	G_2 G_3	3	2	4	2	7	4	1- Asset /Business Impact 2- Damage to both Vessel/Platform 3- No injuries or fatalities 4- No spill
M/V Warren G 06/06/2013 GOM (CH-2)	Collision	Damage to the vessel	The boat landing was damaged and appears to have moved to the north by as much as three feet. has a three-foot dent on Port Stern side	As a result, one individual was pushed against a handrail by the wave, the boat landing noticed to be moved three feet to the north and the attendant vessel has a three-foot dent on Port Stern side.	7- Handling error in collision avoidance 13- Inadequate situational awareness. 14- Inadequate technical knowledge. 19- Lack of system understanding 28- Weather side	2 3	G_2-G_3	5	3	3	3	8	6	1- Asset /Business Impact 2- Damage to both Vessel/Platform 3- Single injury 4- No spill
M/V Danielle Callais 05/12/2010 GOM (CH-3)	Collision and hit	A swell hit the Danielle pushing the vessel into the rig's port leg		Both rig and vessel suffered physical damage as a result.	7- Handling error in collision avoidance 13- Inadequate situational awareness. 14- Inadequate technical knowledge. 19- Lack of system understanding 28- Weather side	2 1	G_2 G_3	3	3	4	2	7	5	1- Asset /Business Impact 2- Damage to both Vessel/Platform 3- No injuries or fatalities 4- No spill

Although the three scenarios have been ranked using the FMECA, the process falls short of providing the influence of the scenarios on each other. Therefore, ISM model was used for two reasons: (I) to further confirm the results obtained from the FMECA and (ii to measure the mutual influences of the scenarios on each other. The ISM **re**sulted in the digraph shown in Figure (3), which illustrates the sub-dimensions of CH category. It is observed that CH-2 is considered as an influencing sub-dimension on the other sub-dimensions. On the other hand, the sub-dimensions, CH-1 and CH-3 are of equal ranks.

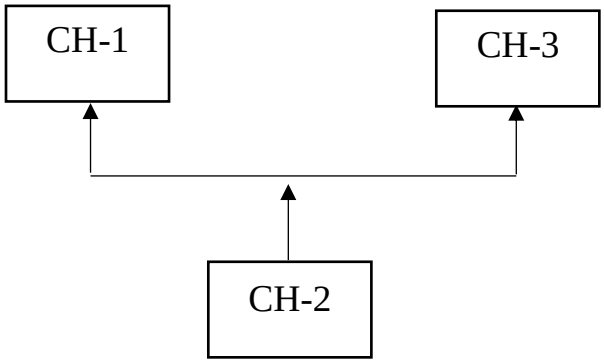


Figure (3): Digraph for cargo handling category sub-dimensions

Contrasting these results to those of FMECA, it becomes clear that both models have provided similar ranking, although RI values related to environment ranked CH-3 above CH-1. The experts, however, tended to be more in favor of the ISM results, because they show the mutual influences, as has been explained above. To summarize, both FMECA and ISM have shown the CH-2 is the most hazardous scenario, followed by CH-3 and CH-1. It remains to further investigate these accidents more deeply to single out the route cause (underlying factors) behind them; this was attempted implementing the FTA. It was felt, however, that using the scenarios of Table (1) would provide more accurate results compared to using the compressed scenarios of Table (2).

Figure (4) demonstrates the FTA for improper cargo handling and personnel transferring as the second threat (T2) that leads to the top event of collision between attendant vessel and offshore installation. The sequence of analysis proceeds from the bottom level of UFs to the next level up using the ‘AND’/‘OR’ gates. The figure shows that the top hazardous scenario is spending idle time alongside installation. The idle time is exemplified by time spent waiting for next lift, personnel transfer or to disconnect cargo hose. It may also be because of change in work scope, for instance by adding tasks. The previous probable reasons may be also combined with any malfunction in the DP system or weather factor that can cause the vessel to collide with the offshore installation closest to the vessel.

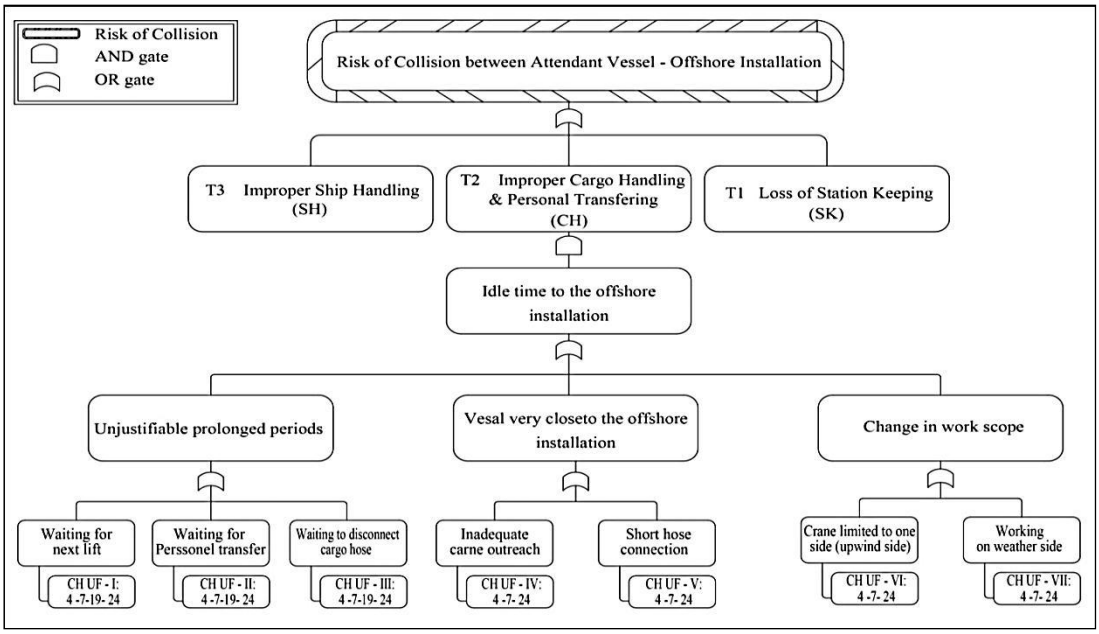


Figure (4): FTA analysis for CH scenarios

Generally, the current endeavor has shown that the causes of marine accidents primarily depend on more than one category of human factors. Additionally, it has confirmed that by addressing and influencing those human factor categories, the frequency of marine accidents can be reduced, leading to an overall improvement in shipping safety. Thus, after identifying the top UFs contributing to attendant vessel -installation collisions, future work would recommend a set of control measures to reduce the risk level.

Comparison of FMECA and FTA results show that 'Inadequate knowledge of ship operations' and 'Handling error in collision avoidance' came on top of the causing UFs in both analyses. It also identified many similarities in the top five causing UFs. This was important to validate the results, identify the critical UFs, and propose appropriate RCMs accordingly.

Furthermore, the researcher sought to validate the above results of other researchers; however, there is much rarity in available data that are related to quantifying UFs of HEs as contributing causes to maritime accidents. This rarity is even greater when it is specified to attendant vessel-installation collisions.

Conclusion

Collisions between attendant vessels and offshore installations during cargo handling and personnel transferring pose a substantial risk within the oil and gas industry. Human factors significantly contribute to these incidents. While several methodologies and tools have been created to evaluate and mitigate these risks, there are still shortcomings and constraints in the existing frameworks. To mitigate these risks effectively, it is crucial to address the human factors involved, establish comprehensive guidelines for risk assessment and management, and continuously explore new technologies through ongoing research. By taking these important steps

and implementing the proposed framework, the aim to minimize the likelihood and severity of collisions between attendant vessel and offshore installations can be achieved. It is also worth mentioning that the proposed methodology and framework can be employed by other researchers in different applications to enhance safety in the maritime industry, or elsewhere.

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The Future of Coastal Navigation Safety in Egypt: Improving the Reliability of Electronic Charts

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المستخلص

تبحث هذه الورقة في درجة الثقة والأعتمادية للخرائط الإلكترونية (ENC) المستخدمة للملاحة البحرية بالساحل المصري. تم إجراء تقييمات شاملة مع التركيز على المناطق ذات الأهمية الخاصة مثل قناة السويس ومضيق جوبال ومدخل خليج العقبة و ميناء الغردقة. تكشف النتائج بعد أستخدام خاصية (CATZOC) إلى وجود خطأ بالموقع بهذة الخرائط يتجاوز الخمسمائة مترويؤدي ذلك إلى التأثير المباشر على سلامة الملاحة والبيئة البحرية بهذة المناطق ذات الكثافة العالية لحركة مرور السفن. وفي الوقت نفسه، فإن قرب الممرات الملاحية من الأماكن السياحية و الشعب المرجانية يؤثر على سلامة الملاحة والبيئة البحرية بهذة المناطق. واستجابة لهذه التهديدات الملحة، يجري بالفعل تنفيذ مبادرات واعدة بين الهيئات المصرية لسلامة الملاحة البحرية ووكيل IHO بجمهورية مصر العربية لمعالجة أوجه القصور في الخرائط الإلكترونية باستخدام أساليب علمية متطورة . كما ستؤدي عمليات التحقق الإلزامية من الوظائف وتدريب الطاقم وإنفاذ الامتثال إلى تحسين استخدام منظومة ECDIS الحالية. ستساعد الاستثمارات المستدامة لتحديث هذه البنية التحتية المعلوماتية الأساسية في مواءمة الإطار الملاحي لمصر مع أفضل الممارسات لحماية الأرواح والممتلكات والبيئة. تعد الاستراتيجية متعددة الأوجه التي تعالج الأبعاد البشرية والتقنية عبر السفن والموانئ ضرورية للقضاء على المخاطر التي لا داعي لها. سيوفر تعزيز سلامة خرائط ENC للسفن التي ترفع العلم المصري والسفن الزائرة ضمانًا أكبر للوضع عند عبور الممرات المائية الضيقة، مع منع الحوادث المدمرة التي تؤثر على سلامة الملاحة والبيئة البحرية بهذة المناطق.

Abstract

This paper investigates the integrity and reliability of electronic navigation charts (ENCs) used for maritime navigation along the Egyptian coast. Comprehensive assessments were conducted, focusing on critical stretches including the Suez Canal, Strait of Jubal, Aqaba Gulf entrance, and Hurghada Port access channels. The findings expose alarming accuracy gaps in these vital yet confined transit zones, with Category of Zone of Confidence (CATZOC) classification results indicating positional uncertainties exceeding five hundred meters. Such imprecision severely erodes navigational safety buffers for ships amidst intense traffic volumes. Meanwhile, proximity to delicate coral ecosystems and coastal communities raises the stakes for averting accidents. Responding to these urgent threats, promising initiatives are already underway between Egyptian agencies and international hydrographic bodies to systematically address ENC deficiencies

through new surveys and data enhancements. Mandatory functionality checks, crew training, and compliance enforcement will also optimize the utilization of existing ECDIS installations. Sustained investments to upgrade this core informational infrastructure will help align the country's navigational framework with best practices for protecting life, property, and the environment. A multifaceted strategy tackling both human and technical dimensions across ships, ports, and shoreside administrators is essential for eliminating needless risk. Strengthening ENC integrity will provide Egyptian-flagged and visiting vessels with greater situational assurance when transiting confined waterways, while preventing devastating shipping accidents that could damage fragile marine ecosystems.

1- Introduction

Historically, mariners relied on paper nautical charts for navigation. However, the shipping industry is rapidly adopting electronic alternatives, which offer enhance functionality. ENCs that comply with International Hydrographic Organization (IHO) standards display vessels' real-time position integrated with geospatial data on depths, terrain, obstructions, and other hazards to facilitate route planning (Zissis et al., 2021). However, the transition brings risks. Unlike seasoned paper charts refined over decades, ENCs rely on digital hydrographic survey data, which can suffer from inaccuracies and gaps in coverage (Huang et al., 2021). Such deficiencies erode ENC reliability. Without augmenting strategies, navigating solely with error prone ENCs has already resulted in multiple ship groundings and collisions (Witkowska & Śmierzchalski, 2020).

The issue has magnified its urgency in Egypt. Traffic in the narrow confines of the Suez Canal and busy shipping lanes of the Red Sea renders margins for navigational errors non-existent (Wang et al., 2021). Meanwhile, ENC adoption is accelerating across vessels frequenting Egyptian ports. This paper presents findings from extensive ENC reliability tests in Egypt's coastal zones using the globally recognized CATZOC standard. The results reveal alarming deficiencies. Concrete initiatives to enrich Egypt's ENC portfolio through updates are then outlined to proactively enhance safety.

2- Ensuring Navigational Safety: The Concerns with Transitioning to ECDIS

The rapid transition from traditional paper navigational charts to Electronic Chart Display and Information Systems (ECDIS) has raised some concerns regarding deficiencies that can undermine safety. In a study on Australian-registered ships, Costa et al. (2021) found that 59% of ECDIS units had not completed vital benchmarking checks to identify potential system errors. Recognizing growing reliance on digital charts, the IHO thoroughly evaluated various ECDIS platforms to identify critical flaws per established specifications (IHO, 2012). Nineteen vulnerabilities were detected that could significantly impair navigational safety. These encompassed failures to display key maritime zones, incomplete symbology for hazards, and route planning deficiencies (Svilicic et al., 2019). Responding to these findings, the IHO disseminated advisories urging shipping companies and vessels worldwide to urgently evaluate their respective ECDIS systems and report any anomalies detected so that solutions could be devised (IHO, 2012). Egypt also has a substantial stake and has implemented evaluations, given that Egypt's Suez Canal

is a vital global waterway, handling approximately 12% of global trade and 30% of global container traffic. In 2020, the Suez Canal Authority recorded that nearly 19,000 ships utilized the route, making it the world's busiest waterway. This amounts to an average of 51.5 ships per day, with a net tonnage of 1.17 billion tones, carrying over $1 trillion worth of goods annually (New Zealand Ministry of Foreign Affairs and Trade, 2021; Egypt Today, 2022).

A set of IHO-prescribed ECDIS reliability tests were conducted aboard the Egyptian training vessel Aida IV, traversing between Alexandria and the Red Sea. The assessment utilized the vessel's Transas NAVI-SAILOR 4000 system, certified by maritime inspection authority Nippon Kaiji Kyokai (Class NK) as fully IMO compliant (Transas, 2013). Across nineteen checkpoint parameters, no errors or malfunctions were exhibited, confirming reliability per standard. Coupled with further enhancement initiatives for coastal ENC data quality, maritime navigation safety in Egypt can be preserved.

3- Assessing ECDIS Functionality for Key Safety Parameters Along the Egyptian Coast

To complement the analysis of geospatial ENC data reliability, physical on-board testing of the core ECDIS functionality is also vital, as navigation depends on an accurate rendition of hazards. A rigorous protocol of checks prescribed by the IHO ensures that systems meet essential baseline requirements for contemporary vessels (IHO, 2012). A set of evaluations was conducted aboard the ship Aida IV, traversing between Alexandria and the Red Sea, to verify four key aspects:

3.1 Test No. 1: Display of Critical Maritime Zones

The first test validated that the on-board Transas ECDIS correctly depicted navigationally significant special areas recently defined by the IMO including archipelagic sea lanes, environmentally sensitive zones, and Particularly Sensitive Sea Areas (PSSAs) (Transas, 2018). These had previously been prone to software omissions, but were now correctly shown, indicating compliance.

3.2 Test No. 2: Visualization of Navigational Light Signals

Proper differentiation of navigation aid light characteristics is imperative for nighttime transit or reduced visibility. Checks confirmed the ECDIS properly encoded sectors, ranges, and signaling types for five sample beacons along the Egyptian coast without gaps.

3.3 Test No. 3: Hazards and Obstruction Symbology

The system's chart presentation fully populates the requisite hazard icons for shallows, wrecks, and outcrops in test locations, including the Strait of Jubal, based on reference paper charts.

3.4 Test No. 4: Route Planning Hazard Detection Verification

One of the most vital ECDIS functionality checks is whether the on-board route planning tools can accurately detect charted hazards and alert users to risks from navigational dangers or obstructions along pre-programmed voyage paths (Zaman et al., 2021). Failure here negates a key benefit of ECDIS in enabling initiative-taking re-routing.

The IHO-prescribed protocol was applied to the Transas ECDIS system, evaluating route options from Port Said transiting through the Strait of Gubal towards Aqaba. Reference paper charts indicated five flagged wrecks, several rock outcrops, and an area of dangerous shallows intersecting with the plotted courses.

Gratifyingly, upon initiating the route planning tool's safety cross-check calculations, the ECDIS precisely triggered violation warnings for the routes concerned and highlighted the corresponding hazard symbols, including shallow patches coded red. This verification of the effectiveness of the core system upholds navigational safety. It also assured reliability prerequisites were met prior to Aida IV conducting subsequent live ENC evaluation surveys of Egyptian coastal zones, relying extensively on ECDIS guidance.

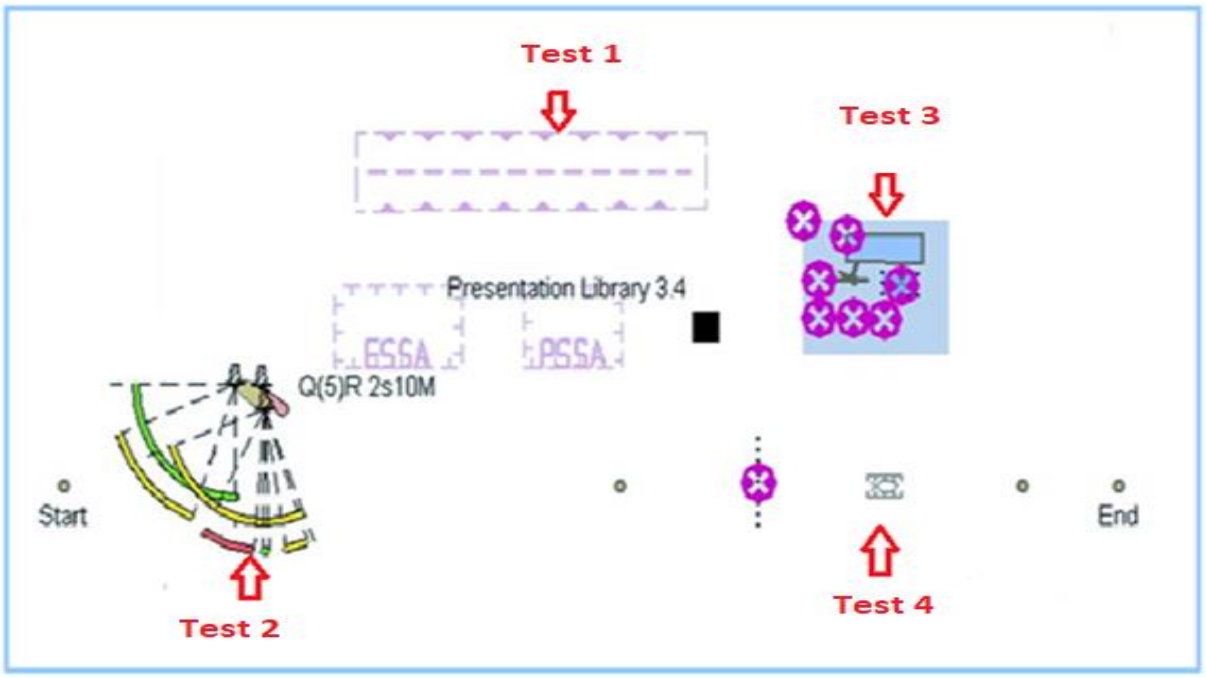


Figure (1): Tests for Detecting Deficiencies in the Electronic Chart Display and Information System (ECDIS). Source: IHO, 2012.

4- Navigating Egypt's Coast: Evaluating the Integrity of ENC Data for Safer Maritime Routes

With digital navigational charts replacing paper ones as ships' primary route planning reference, the integrity of the underlying ENC data defines safety margins. However, previous studies have exposed deficiencies in some editions lacking updated surveys (Witkowska & Śmierzchalski, 2020). Hence, a thorough evaluation of ENC integrity for Egypt's coast was undertaken, given the intense traffic and proximity hazards.

Following initial ECDIS functionality validation, targeted ENC reliability checks were conducted during an Alexandria-to-Aqaba transit by the Aida IV. Focus areas included the Suez Canal approaches, the Strait of Jubal, and the Northern Red Sea, based on the intensity of navigation and complex shoals. The IHO's CATZOC classification system gauged survey accuracy and confidence, with A1 denoting full recent coverage and D for uncharted areas (Costa et al., 2021).

Worryingly, findings revealed CATZOC C ratings, indicating position uncertainty exceeding 500 m for multiple ENC cells, including Jubal Strait and the main Suez Canal shipping lane. With most turns barely one nautical mile wide, such potential inaccuracy severely erodes buffer margins (Admiralty, 2010). Indeed, analysis by Zaman et al. (2021) indicates over 24% of Egyptian coastal ENCs fall below minimum safety CATZOC thresholds.

The results underline the imperative for Egyptian authorities to commit resources towards improving hydrographic surveys and ENC integrity. Targeting areas with chronic problems will boost navigation safety. Selected areas of high significance for this test include:

4.1 Strait of Jubal

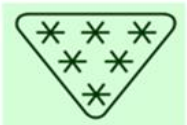
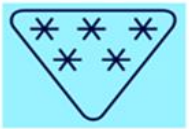
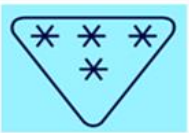
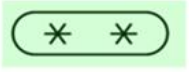
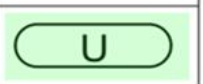
The narrow Strait of Jubal presents uniquely intense navigation challenges. This route connection between the Gulf of Suez and Red Sea handles dense traffic to/from the Suez Canal yet has documented hazards like Little Ganef Reef along the eastern lane edge (NHHO, 2022). Unfortunately, ENC analysis here also exposed worrying data gaps.

The CATZOC rating for the Jubal area is just three stars – the same low confidence score afflicting the entire Gulf of Suez region. This equates to over five hundred meters of potential lateral position error for charted soundings and hazards (Admiralty, 2017). With the main safe passage often less than 0.5 nautical miles wide, such inaccuracy leaves minimal margin for navigational corrections. Indeed, (Nossir, 2021) had marked Little Ganef Reef with a buoy since danger was beyond ENC reliability.

The findings reinforce calls by shipping industry groups for countries having intense coastal traffic like Egypt to prioritize key zones for systematic hydrographic resurveys (IMCA, 2022). This will enhance ENCs to boost safety, while also saving lives and preventing environmental disasters., as shown in Figure 2.

Figure 2: Navigational Danger and Confidence Level of the Electronic Chart in the Gubal Area in the Gulf of Suez Source: Captured from the Transas ECDIS system on the ship "Aida IV"(10/2023)

Table (1): Category of Zone of Confidence

1	2	3		4	5	6
ZOC 1	Position Accuracy	Depth Accuracy		Seafloor Coverage	Typical Survey Characteristics	CATZOC Symbol
A1	± 5 m + 5% depth	= 0.50 + 1%d		Full area search undertaken. Significant seafloor features detected and depths measured.	Controlled, systematic survey high position and depth accuracy achieved using DGPS or a minimum three high quality lines of position (LOP) and a multibeam, channel or mechanical sweep system.	
		Depth (m)	Accuracy (m)			
		10	± 0.6			
		30	± 0.8			
		100	± 1.5			
		1000	± 10.5			
A2	± 20 m	= 1.00 + 2%d		Full area search undertaken. Significant seafloor features detected and depths measured.	Controlled, systematic survey achieving position and depth accuracy less than ZOC A1 and using a modern survey echosounder and a sonar or mechanical sweep system.	
		Depth (m)	Accuracy (m)			
		10	± 1.2			
		30	± 1.6			
		100	± 3.0			
		1000	± 21.0			
B	± 50 m	= 1.00 + 2%d		Full area search not achieved; uncharted features, hazardous to surface navigation are not expected but may exist.	Controlled, systematic survey achieving similar depth but lesser position accuracies than ZOC A2, using a modern survey echosounder, but no sonar or mechanical sweep system.	
		Depth (m)	Accuracy (m)			
		10	± 1.2			
		30	± 1.6			
		100	± 3.0			
		1000	± 21.0			
C	± 500 m	= 2.00 + 5%d		Full area search not achieved, depth anomalies may be expected.	Low accuracy survey or data collected on an opportunity basis such as soundings on passage.	
		Depth (m)	Accuracy (m)			
		10	± 2.5			
		30	± 3.5			
		100	± 7.0			
		1000	± 52.0			
D	Worse Than ZOC C	Worse Than ZOC C		Full area search not achieved, large depth anomalies may be expected.	Poor quality data or data that cannot be quality assessed due to lack of information.	
U	Unassessed – The quality of the bathymetric data has yet to be assessed					

Source: Admiralty Guide to ENC Symbols used in ECDIS

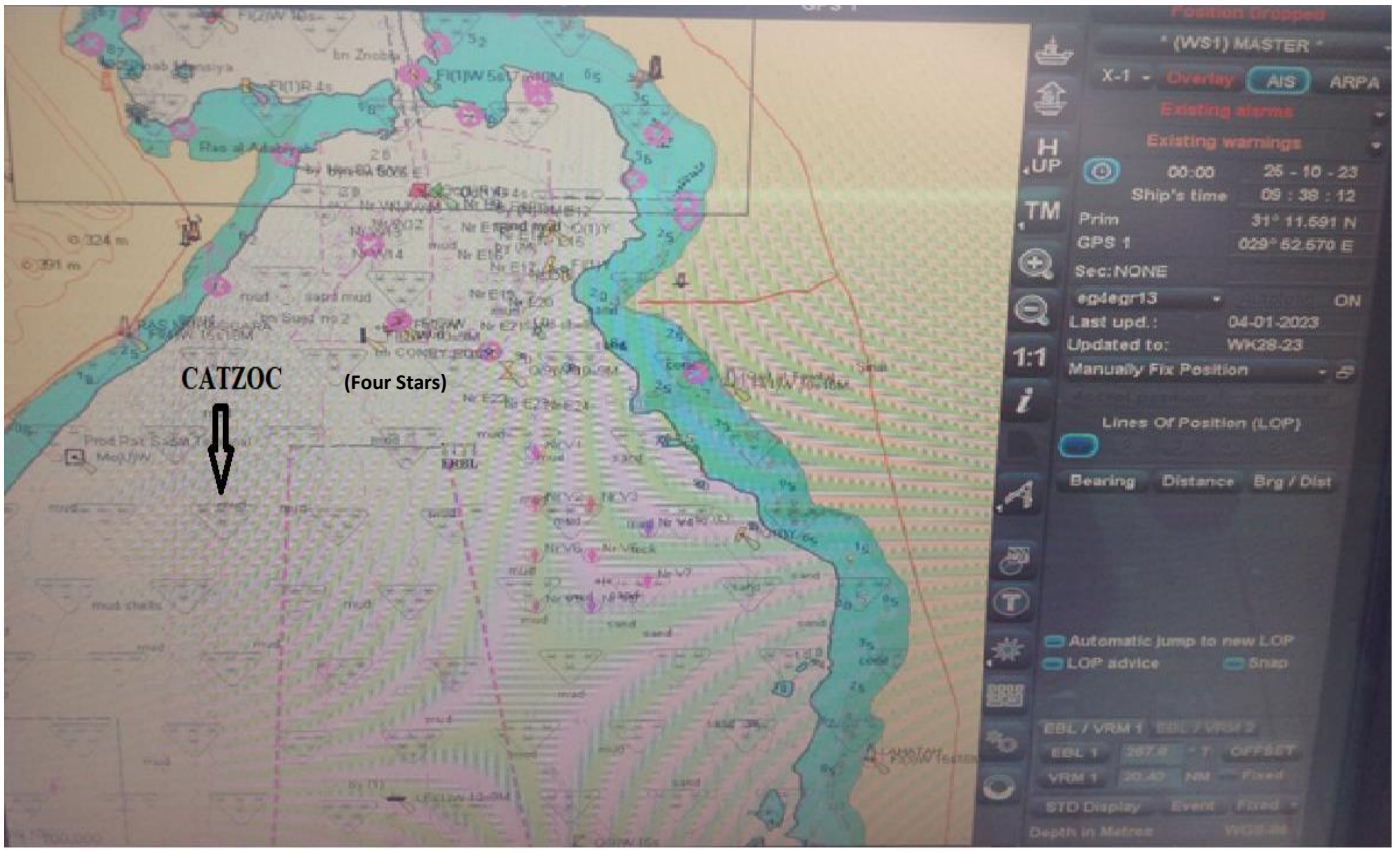


Figure 3: CATZOC for the North of the Suez Gulf Area.
Source: Captured from the Transas ECDIS device of the ship Aida IV. (10/2023)

4.2 North of the Gulf of Suez

The southern entrance of the Suez Canal in the Gulf of Suez is an area of high vessel traffic density. This includes ships entering or leaving the Suez Canal as well as those anchored in internal or external anchoring areas (IMO, 2021). The reliability of the survey in this region is considered low, with a 3-star confidence rating indicating very weak reliability (Smith et al., 2019). The low accuracy of the survey suggests significant positional errors exist on nautical charts of this vital area (Wang et al., 2020).

In response, the IMO (2021) has issued notifications advising all ship operators and vessels to promptly conduct ECDIS verification tests. Failure to address these chart precision issues presents risks to navigation safety and environmental protection in the heavily trafficked Gulf of Suez region (Wang et al., 2020). Further hydrographic surveys have been proposed to improve nautical chart reliability and uphold maritime safety standards in the area (Smith et al., 2019).

4.3 Entrance of the Gulf of Aqaba

The entrance of the Gulf of Aqaba is a critical navigation area for ships entering or departing the Gulf, in addition to being located by environmentally sensitive coral reef regions and tourism destinations (Smith, J., Hassan, A., & Rahman Z., 2021). The navigable channel spanning the

separation zone here is just eight hundred meters wide (Wang, L., Lee, J., & Kim, N. 2019). However, reliability testing suggests significant positional errors exceeding five hundred meters on the electronic nautical charts of this area (IMO, 2022: Circular MSC.1/Circ.1512/Rev.1).

The IMO (2022) has issued notifications requiring verification of ship ECDIS to address these concerns. With chart errors of this magnitude, safe navigation relies completely on ECDIS for avoiding environmental hazards in the area (Wang, Lee, & Kim, 2019). Further hydrographic surveys could improve chart accuracy to meet modern safety standards for this narrow corridor (Smith, Hassan, & Rahman, 2021). Updating the charts is vital for preventing shipping accidents near coral ecosystems and tourism centers around the entrance to the Gulf of Aqaba (IMO, 2022).

Figure 4: CATZOC of the entrance of the Gulf of Aqaba.
Source: Captured from the Transas ECDIS device of the ship Aida IV. (10/2023)

4.4 Entrance of Hurghada port

The entrance of Hurghada Port is vital for ships accessing the port and is proximate to coral reef ecosystems and tourism destinations that attract many visitors (Hassan, 2022). The navigable channel through the harbor entrance is relatively narrow (Wang et al., 2020). Reliability assessments reveal a 4-star chart confidence rating at this location, indicating marginal reliability (IMO, 2021).

Significant positional discrepancies have been identified on the electronic nautical charts of the Hurghada entrance area (Hassan, 2022; IMO, 2021). In response, the IMO (2021) has advised ships to verify electronic chart systems to support safe passage. Further hydrographic surveys could improve chart accuracy around sensitive coastal environments in this major tourist city (Wang et al., 2020). Updating nautical charts is important for safeguarding maritime navigation and preventing ecological impacts near the entrance to Hurghada Port, where chart reliability is currently inadequate.

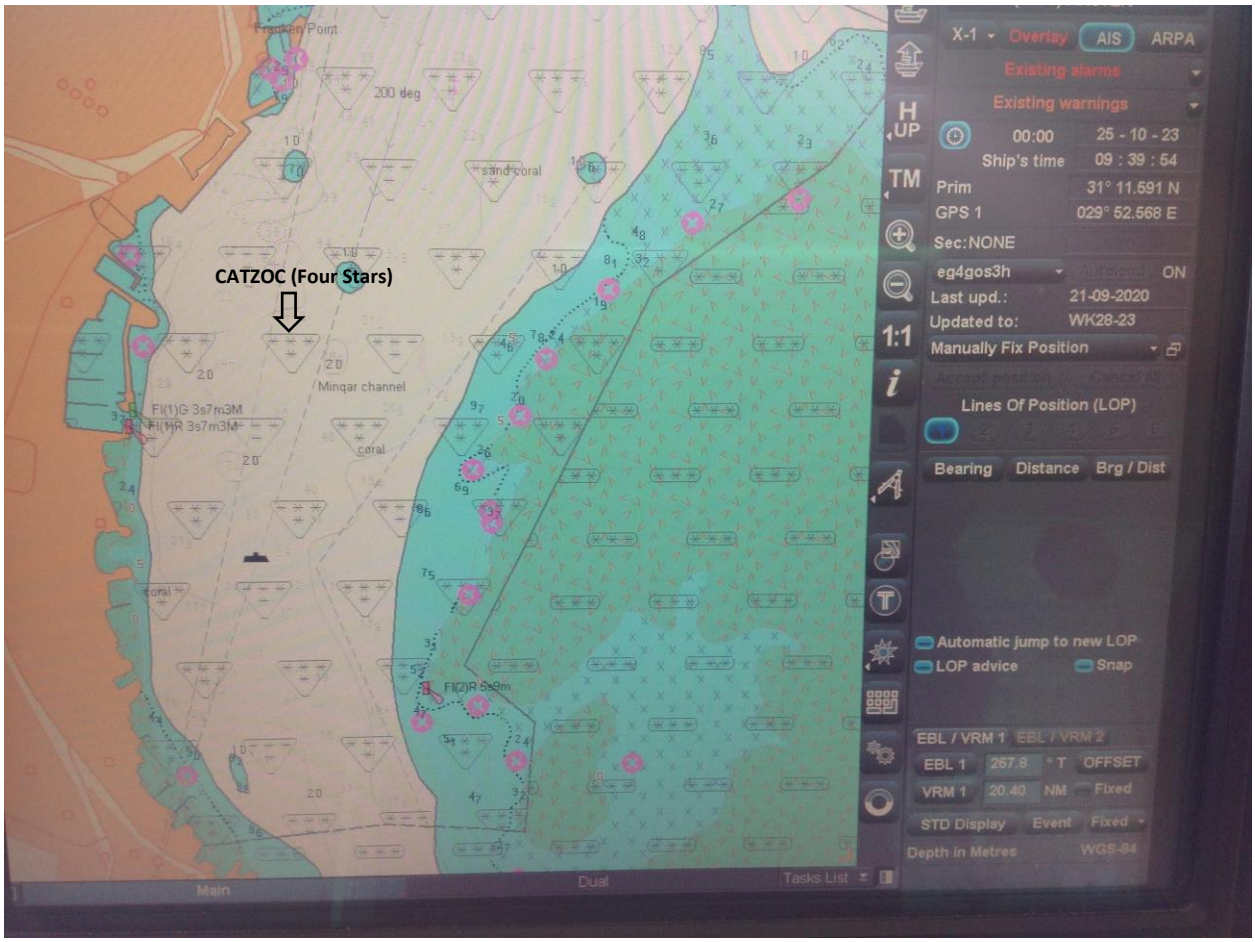


Figure 5: CATZOC of Hurghada port.
Source: Captured from the Transas ECDIS device of the ship Aida IV. (10/2023)

Reliability assessments reveal multiple regions along Egypt's coastline with inadequate nautical chart positional accuracy, including parts of the Suez Gulf, the Aqaba Gulf entrance, and the entrance to Hurghada Port. These areas correspond with heavy ship traffic, proximity to sensitive marine ecosystems, and tourism destinations. The findings demonstrate the need for urgent actions to uphold maritime safety standards in Egypt's waters (Wang et al., 2020; Hassan, 2022).

In response to these issues, Egypt’s maritime administration has advised ships traversing their waters to promptly cross-check electronic chart information through supplementary onboard position verification methods (Nossir, 2021). Additionally, plans are underway between the

Egyptian Navy Hydrographic Department (ENHD) and the IHO to perform new hydrographic surveys of the country's most frequented and environmentally vulnerable regions (Nossir, 2021).

Upgrading nautical charts through additional field surveys and integrating the latest data into electronic navigational charts will help align the reliability of Egypt's coastal navigation system with internationally recognized best practices for marine preservation and the safety of life at sea (IMO, 2021).

5- Navigational Safety in Egyptian Waters: Implementing ECDIS Guidelines

To Enhance navigational safety, Egypt is implementing guidelines for ships utilizing ECDIS when entering ports or sailing through Egyptian waters (Nossir, 2021). These comprehensive best-practice recommendations are modelled after the Australian Maritime Safety Authority's guidance (AMSA, 2012) and involve:

A) Adherence to International Standards: Vessels must conform to IMO criteria such as those in Resolution MSC.232(82) stipulating use of current IHO-approved ENC, an independent paper or electronic backup system, and extensive system functionality testing (IMO, 2018).

B) Proper ECDIS Equipment: Raster Chart Display Systems alone cannot serve as primary navigation aids per IMO SN.1/Circ.207/Rev.1. Hardware must be certified by accredited classification organizations (IHO, 2020).

C) Crew Training Requirements: Officers should complete generic and type specific ECDIS training with certification indicating proficiency (IMO, 2018).

D) Port State Inspections: Egyptian Port State Control officers will evaluate on-board ECDIS installation, operation, and document compliance following International Association of Marine Aids to Navigation and Lighthouse Authorities guidance (IALA, 2021). Deficiencies must be addressed before port entry is granted.

Strict adherence to these guidelines ensures ECDIS reliability for optimizing navigational safety within Egypt's waters.

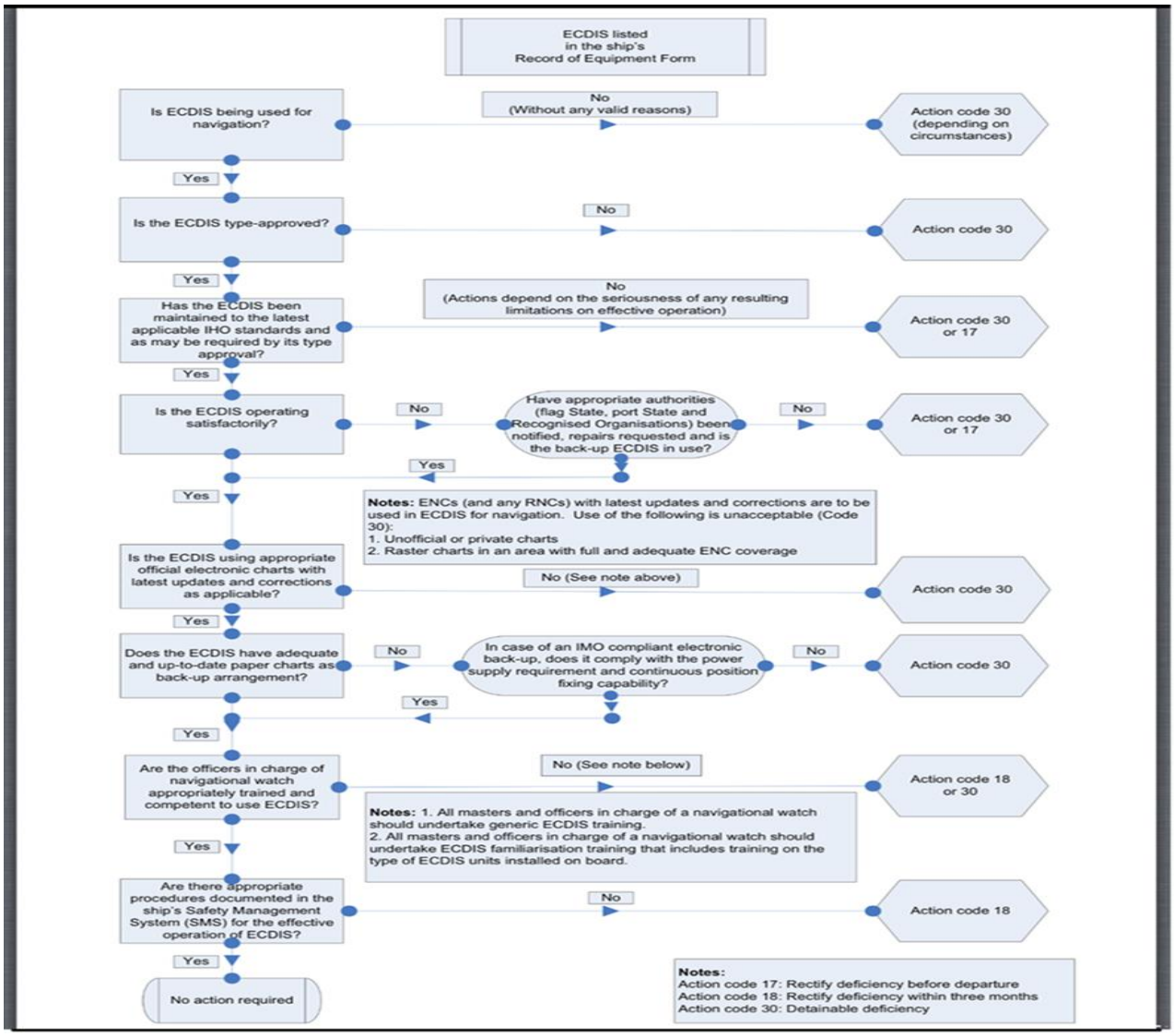


Figure 7: Proposed Flowchart for ECDIS Inspection on Ships by Egyptian Port State Control Officers (PSCO)

Source: (Australian Maritime Safety Authority, 2012)

6- Results (Closing the Reliability Gaps: Enhancing Safety in ECDIS)

The widespread adoption of ECDIS has brought advances in maritime navigation, yet reliability gaps exist that potentially jeopardize safety and environmental protection (Hassan, 2022; IMO 2021). Recognizing these issues, the IHO has instituted ECDIS functionality checks for identifying and resolving deficiencies in partnership with industry manufacturers (IHO, 2020).

Recent successful conformance tests of the TRANSAS NAVI-SAILOR 4000 aboard the Aida IV following IHO specifications confirm the capabilities of some equipment for meeting international ECDIS standards when properly implemented (Vlassis, 2022). However, a subsequent electronic chart survey from Alexandria Port to the Red Sea on this verified ECDIS platform revealed

inadequate reliability levels, particularly in critical waterways like the Suez Canal, Suez Gulf entrance, Gubal Strait, Aqaba Gulf access, and southern Red Sea (Hassan, 2022).

Given the risks these findings pose to navigation and ecologically sensitive regions, Egyptian Authority for Maritime Safety (EAMS) is prioritizing actions to improve safety assurances. These include enacting ECDIS testing regulations for all vessels by the EAMS, with Central Maritime Inspection Authority oversight (Nossir, 2021). Additionally, plans are progressing to upgrade unreliable electronic charts via new hydrographic surveys by the IHO-approved Egyptian Navy Hydrographic Department (Nossir, 2021).

Implementing mandatory checks on ship ECDIS installations while replacing deficient charts will help Egypt align its coastal navigation framework with best practices for protecting life, property, and the environment.

7- Recommendations

To address identified gaps in electronic chart reliability and uphold navigational safety standards, the following actions are advised:

- Implement mandatory verification procedures for ship ECDIS installations overseen by the EAMS (Nossir, 2021).
- Prioritize new hydrographic surveys by the IHO-accredited Egyptian Hydrographic Division to improve ENC navigational data quality along the country's coast (Nossir, 2021).
- Expedite the release of ECDIS guidelines detailing Egyptian PSCO inspection protocols to assist visiting vessels in achieving compliance (Rambabu et al., 2021).
- Leverage satellite communication resources to disseminate ECDIS advisories ensuring maritime domain awareness for ships transiting regional waters (IALA, 2020).
- Encourage frequent ENC updates from the ENHD to incorporate the latest chart notifications (Smith et al., 2021).
- Urge mariners to cross-check ECDIS information against multiple navigational data sources for critical safety redundancies (Wang et al., 2019).
- Reinforce best practices in ECDIS operation through enhanced international coordination and training programmes (IMO, 2021).

These recommendations can assist in optimizing Egypt's coastal navigation framework to protect life, property, and delicate marine ecosystems.

8- Conclusion

This research analyzed major deficiencies afflicting the reliability of ENCs along critical stretches of the Egyptian coast. Targeted assessments exposed alarming accuracy gaps in vital maritime transit zones, including the Suez Canal, Strait of Jubal, Aqaba Gulf entrance, and Hurghada Port access channels.

With vessel traffic intensity escalating, the implications of these findings are severe. Relying on imprecise charts erodes safe navigation buffers in restricted corridors, threatening collisions, or

groundings. The consequences could prove catastrophic given their proximity to delicate coral reef systems, beaches, and coastal communities. Decisive action is imperative.

Promising initiatives are already underway between EAMS and international hydrographic bodies to systematically address the ENC integrity crisis through new surveys and data Enhancements. Sustained investments to upgrade core informational infrastructure will help align the country's navigational framework with best safety practices.

Meanwhile, mandatory functionality checks, crew training, and compliance enforcement will optimize the utilization of existing ECDIS equipment. A multifaceted strategy tackling both human and technical dimensions across ships, ports, and shoreside administrators is essential for eliminating needless risk.

The rewards of these collaborative endeavors will be substantial. Strengthening ENC integrity will provide Egyptian-flagged vessels and visiting ships with greater situational assurance when transiting narrow passages. In parallel, averting shipping mishaps preserves fragile marine ecosystems.

Through continued hydrographic and technological progress, Egypt is charting a course towards a more secure and sustainable maritime future—one that simultaneously upholds efficiency for coastal shipping while preventing devastating accidents. The nation's seafaring prosperity depends on it.

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Implications of the Offshore Oil & Gas Working Environment on Mental Health and Performance of Workers

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المستخلص
تهدف هذه الدراسة إلى بحث الآثار المحتملة لموقع العمل على العلاقة بين المخاطر النفسية الاجتماعية في بيئة عمل صناعة البترول والغاز واضطرابات الصحة النفسية والأداء للعاملين. تم استخدام الأساليب الكمية والأساليب الاستنتاجية، و شمل مجتمع الدراسة العاملين المصريين في قطاع البترول والغاز، حيث تضمنت عينة الدراسة (409) مشارك. تم تحليل البيانات باستخدام التحليل الوصفي، وتحليل الارتباط، واختبار "t" للعينات المستقلة، ونمذجة المعادلات الهيكلية (SEM). أشارت النتائج إلى وجود مستويات عالية من المخاطر النفسية والاجتماعية في بيئة عمل البترول والغاز، حيث كانت للعزلة والبعد والظروف المعيشية السيئة أعلى المستويات بشكل ملحوظ. كذلك أظهرت ادوات فحص الاكتئاب والتوتر والقلق لدى عينة الدراسة وجود مستويات متوسطة من اضطرابات الصحة النفسية وأشارت أغلب الاجابات إلى صعوبات في التغلب على تلك الاضطرابات. كما أظهرت النتائج مستوى متوسط للأداء مع انخفاض ملحوظ في جوانب الأداء السياقي لعينة الدراسة. خلصت الدراسة إلى أن الأداء في صناعة البترول والغاز البحرية ليس نمطًا وظيفيًا بالكامل بل يمكن أن يتأثر ببيئة العمل، حيث يوجد تأثيرا معدلا لمكان الموقع على مستويات اضطرابات الصحة النفسية لدى العاملين و ينتج عنه الإضرار بمستويات أدائهم، مما قد يؤدي في النهاية إلى الإضرار بمصالح واستدامة هذا القطاع الحيوي.

Abstract
This study aimed to investigate the potential effect of the site location on the relationship between the Oil and Gas working environment's psychosocial hazards, mental health disorders and workers' Performance. Quantitative methods and deductive approaches have been used. The study's population was Egyptian Oil & Gas workers, and the study sample included 409 participants. The collected data were statistically analyzed using descriptive analysis, correlation analysis, independent samples t-test, and Structural Equation Modelling (SEM). The results indicated a high levels of psychosocial hazards in the Oil & Gas working environment, where isolation, remoteness and adverse living conditions significantly depicted the highest levels. The presence of mental health disorders was confirmed by screening Depression, Stress and Anxiety among the study sample, where most responses indicated difficulties in their abilities to overcome. Further, the results showed an average level of performance with a noticeably low levels in contextual performance aspects. The study concluded that performance in the offshore Oil & Gas industry is not entirely a functional pattern but can also be influenced by the working environment,

where the moderating effect of the site location of the Oil & Gas working environment on workers' mental health disorders could eventually compromise their performance levels, ultimately harming the interest and sustainability of this vital sector.

Key Words: Offshore, Industry, Working Environment, Moderating, Performance, Workers

1- Introduction

The Oil & Gas industry is currently one of the most contributing sectors to the sustainability of the global economy since oil and gas have become primary energy sources for the development of almost all industries, communities, and transportation means across the world, as per the International Labour Organization (ILO, 2022a).

In Egypt, the Oil & Gas sector has grown to be one of the most vital sectors contributing to the Egyptian economy. Currently, the sector's operations are deflecting deep waters in the Mediterranean to explore new areas to increase the gas production rate needed to boost the country's economy and satisfy the world's energy demand (EgyPS, 2022). However, research revealed that the unique working environment conditions associated with overseas offshore Oil & Gas operations could bring up additional stressors on workers (Okoro & Godwin, 2019).

Given the fact that performance in the Oil & Gas industry is considered imperative value, especially for a sector that significantly involves multiple essential and vital aspects for the sustainability of world economies (Thorbecke, 2019), there would be serious concerns knowing that the characteristics and nature of work may contribute to the prevalence of mental health issues among the workforce according to the World Health Organization (WHO, 2005). In this regard, 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. 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 (ILO, 2022b).

These concerns are agreed upon by the US National Offshore Petroleum Environmental Management Authority (NOPSEMA), referring to the Oil & Gas environment as hazardous, isolated, labour-intensive, and stressfully demanding, where workers confront a unique combination of stressors besides their challenging routine work activities (NOPSEMA, 2021). As per the WHO, 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 (WHO, 2022a).

2- Literature Review

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). 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 working environments.

2.1 Psychosocial Hazards of the Oil & Gas Working Environment

Psychosocial hazards are work-related factors that can cause harm to people psychologically, socially, and physically; they can 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). 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).

2.2 Mental Health Components in the Working Environment.

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 et al. (2013), who further explained that personal factors involve the distinctive characteristics of each person, such as age, gender, health condition, 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. Nevertheless, organizational factors could positively or negatively impact employees' mental health. While motivation and appreciation might be favourable, a worker's mental health may deteriorate if he lacks the desire or passion for his job. One of the most significant factors is enforcing policies that maintain the workers' perception of administrative fairness and the equitable distribution of work based on each worker's skills and capabilities (Ouellet et al., 2013).

2.2.1 Work-related Mental Health Disorders

Research has indicated the presence of mental health disorders among workers in specific harsh working environments as a consequence of interactions with particular psychosocial hazards in their workplaces. Reddy et al. (2020), Dodia & Parashar (2020), and Dohrmann et al. (2020) provided evidence to support this claim on the negative effect of intense work schedules on individuals' mental health. However, according to the World Health Organization (WHO), mental health has been one of the most neglected aspects of public health worldwide. As a result of being underestimated or misunderstood, sustaining mental health becomes challenging for many people (WHO, 2022b). In its comprehensive report on transforming mental health for all, the WHO, (2022a) raised serious concerns regarding the existence of around one in eight persons worldwide experiencing a mental illness silently. Although this is a significant number of individuals all over, the majority of social and health systems in most world societies have ignored mental health and

thus failed to provide individuals in these societies with the sufficient attention and adequate assistance they need.

The Chartered Institute for Personnel and Development (CIPD) revealed that this is a hidden risk since most workers would not report nor admit their mental health problems as a matter of concern for losing their jobs (CIPD, 2018). According to the World Health Organization (WHO), Stress, Anxiety, and Depression are currently the most prevalent mental health disorders globally (WHO, 2022a). However, operators of the Oil & Gas industry still do not pay adequate attention to such significant risk-contributing factors Beck & Lenhardt (2019).

2.3 Impact of Mental Health Disorders on Economies

Research has demonstrated that mental health is a crucial factor for the sustainability of the global economy. This finding was supported by Palumbo et al. (2020), who explained that psychosocial factors related to the working environment could harm the workers' mental well-being and lead to increased absenteeism to the degree that induces a considerable adverse effect on the operational costs, which according to the EU-OSHA, (2014), entails high expenses for both companies and society. This claim was backed up by the WHO, which stated that the implications of work-related Anxiety and Depression are thought to cause the global economy an annual cost of 1 trillion dollars due to decreased productivity (WHO, 2022c). It can be observed that the negative impact of mental health disorders on the global economy comes from the consequence of work-loss time; according to WHO (2022d), 12 billion workdays are lost every year because of Stress, Anxiety and Depression, which constitutes an economic problem that imposes a significant need for improving the current global policies measures to address the potential work-related causes of mental health disorders.

In the USA, for example, the prevalence of depression as a mental health problem among employees and workers costs the US economy around $51 billion yearly due to reduced productivity and absence from work. This, in addition to another $26 billion, results from the cost of clinical treatment to an enormous number of diagnosed cases (MHA, 2022).

The UK-HSE analysis estimated a work-loss time of up to 32.5 million working days might have been lost in the financial year 2019/20 due to work-related illness. Among those days lost, an approximated 17.9 million working days specifically resulted from work-related Stress, Anxiety and Depression (HSE, 2020). In 2020/21, Figure (1) demonstrates that Stress, Depression, or Anxiety mainly accounted for 50% of all lost work days in the UK due to chronic cases of work-related illness.

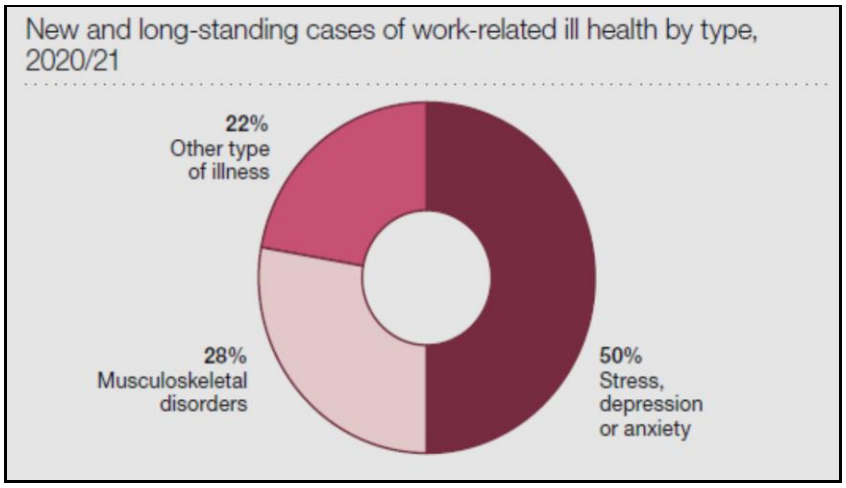

Figure (1): Causes of Lost Days of Work
Source: HSE, (2021)

2.4 Workers' Performance

Previous studies have shown that an organization's success depends on employee performance. According to Behn (2003), it is impossible to characterize or measure performance consistently because various classifications have different definitions. According to the researchers' interpretations, many factors affect an employee's performance. Abun (2021) asserted that one might draw connections between people's emotions and behaviour, implying an association between work performance and the working environment.

Although it is confirmed that different cultures might respond variably to the same working environment conditions due to several factors, it is indicated that the workplace environment generally impacts how adequately workers perform their work-related tasks. Leadership, commitment, and knowledge sharing are critical components when evaluating employees' performance levels and directly and indirectly link to their productivity (Gadot, 2007). In addition, competition and production, efficiency and effectiveness are other components of performance, and training is a means to improve an individual's performance.

Griffin et al. (2000), indicated two distinct forms of behaviour directly that play significant roles in the entire evaluation of individual work-related Performance, viewed as the "Task performance" and the "Contextual performance". The workers' behaviour is more likely to predict their contextual Performance, which is more consistently similar and comparable across different disciplines and jobs. On the other hand, their cognitive abilities are more likely to be a predecessor to task performance, which is very specific and more likely to be evaluated under a pre-determined job role that differs across professions and job prospects (Borman & Motowidlo,1997).

2.4.1 Dimensions of the Contextual Performance

According to the performance theory revealed by Griffin et al. (2000), two distinct forms of behaviour directly play a role in the entire evaluation of an individual's work-related Performance; "Task performance" and "Contextual performance". Task performance is intimately linked to the

professional core of the company, whether through the execution of its technical processes or the upkeep of its functionality. Contextual Performance shapes the organizational, social, and psychological environment that drives task-related activities or processes, thus contributing to performance. According to Borman and Motowidlo (1997), critical distinctions exist between task and contextual performance. Task performance practices and activities often differ across professions and job prospects since they are considerably specific and more prone to be measured according to a prescribed job role where the cognitive capacity of each worker is more likely to be a precursor of task performance.

In contrast, contextual performance is similar and comparable across different disciplines where workers' behaviour is more prone to be a precursor of their contextual Performance. As a result, contextual performance explains a form of employee behaviour that is primarily impacted by the degree of motivational control of employees, which is significantly related to a combination of prosocial and citizenship organizational behaviour (Griffin et al., 2000). Those are regarded as positive social behaviours carried out to preserve the integrity of work and the welfare of others. As per Carlos & Rodrigues (2015), contextual performance has five main dimensions that are more widely addressed by research when assessing the contextual performance of workers as follows;

- The persistent effort to accomplish the work tasks effectively, discipline, perseverance, and giving extra effort at work when needed;
- Volunteer to undertake work tasks even when not formally associated with the job, giving constructive suggestions, and maintain personal development and growth;
- Assistance and collaboration with others, which included supporting co-workers, using corporate tolerance, being a positive person and being socially responsible;
- Adherence to workplace policies, rules and values; working as a part of a team; being attentive to meet deadlines and expressing moral responsibility;
- Actively promoting, supporting, and upholding organizational objectives combines worker's loyalty to the company and firm concern regarding the organization's goals.

2.5 Effect of Mental Health Disorders on Worker's Performance

According to Alomari & Okasheh (2017), every organization's main objective is to boost workers' performance to increase productivity, which results in higher profits. The working environment is a critical element that affects how motivated people are and how well they perform.

Bhawsar et al. (2014), and Ouellet & Gratton (2013) revealed that Mental health problems in the workplace might adversely impact everyone, not just the individual but also the sustainability of the organizations for which he works due to the subsequent effect of decreased performance and productivity. This is in context with the study of Proper et al. (2019), who ascertained evidence confirming mental health wellness is profound to performance outcomes since the connection between employees' mental health and their work outcomes has been substantially demonstrated. In this manner, to ensure that workers' performance complies with the desired results, employers are supposed to provide an appropriate working environment for their workers.

3- Methodology

A descriptive, correlational, and comparative approach was employed for this study since it facilitates the development of the investigation sequentially, from recognizing a problem to developing aims and objectives (Azungah, 2018). The study depended on collecting primary and secondary data to achieve the study purpose. Secondary data was collected from the literature, while primary data was retrieved from a survey involving 409 oil and gas workers.

The targeted population was Egyptian workers who directly interacted with the psychosocial hazards of the Oil & Gas working environment during their assignment to multiple oil and gas-related operational, managerial and service activities.

3.1 Proposed Model for the Framework of the Interrelations between Variables

The study proposed a theoretical framework Model, as shown in Figure (2), based on submitting both direct relationships (represented by straight arrows) and indirect relationships (represented by dashed arrows) between the psychosocial hazards of the Oil & Gas working environment and workers' performance. In the Model, psychosocial hazards of the Oil & Gas working environment, presented in remoteness, isolation, stressful work schedules, high workload, and adverse living conditions, are independent variables that directly and indirectly (through mental health disorders correlate to workers' performance being a dependent variable. Further, the site location of the working environment, offshore or land, represents a moderating effect in the indirect relationship between the working environment's psychosocial hazards and workers' performance.

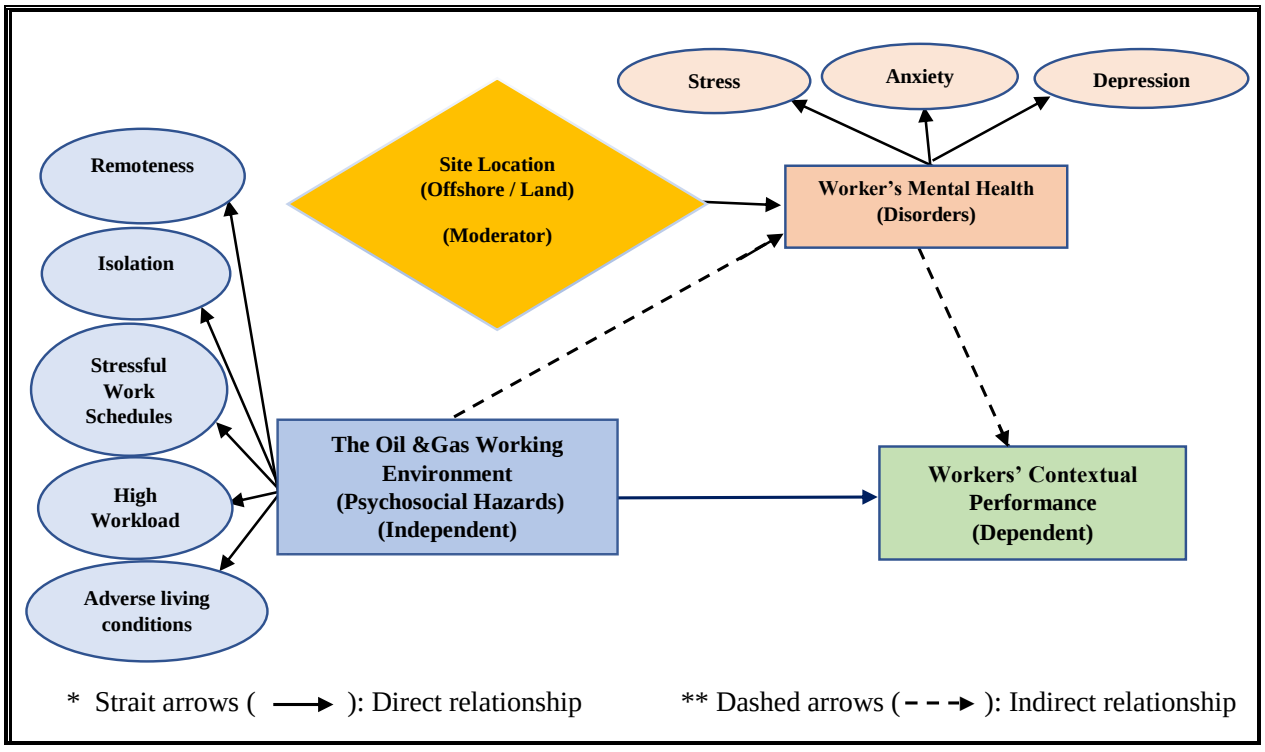

Figure (2): Proposed Model for the Interrelations between Variables

3.2 Developing the Questionnaire

The questionnaire was presented in both hard and soft copies; the soft copy was created using "Google Forms", and its link was forwarded through e-mails or messages to those in offshore and land-based work sites or on leave. The questionnaire was constructed in five sections as follows:

1- The first section involved participants' demographic data.
2- The second section involved a screening tool for measuring the working environment's psychosocial hazards in the Oil & Gas sector, including "Remoteness", "Isolation", "Stressful Work schedules", "High Workload", and "Adverse living conditions".
3- The third section included validated versions of three screening tools: the "Perceived Stress Scale" (PSS-10), the "Generalized Anxiety Disorder (GAD-7)", and the "Patient Health Questionnaire (PHQ-9)" respectively. These tools have been chosen for being reliable short-screening tools and widely utilized in either medical or community settings for assessing the prevalence of Stress, Anxiety, and Depression (Spitzer et al., 2006).
4- The fourth included statements assessing dimensions of workers' contextual performance.

The questionnaire was addressed for authenticity, privacy, and validity. Some questionnaire statements were reformulated to achieve the intended outcome and suit the work's nature, the terminology used in the oil and gas industry, and the workers' cultures. Nevertheless, no modifications were made to the sections screening mental health disorders (Stress, Anxiety and Depression) since being adopted from previous research that examined the validity of Arabic and English versions.

Reliability for the instrument was calculated using Cronbach's Alpha method after the questionnaire was applied in the field to a survey sample that included (82) participants. Table (1) shows that the reliability coefficients for the questionnaire which were higher than the minimum acceptable stability coefficient (0.70), confirming its reliability.

Table (1) Reliability Coefficients for the Questionnaire

Variable		No of Items	Cronbach's Alpha
Working Environment (Psychosocial Hazards)	Remoteness	**3**	**0.77**
	Isolation	**3**	**0.67**
	Stressful Work Schedules	**3**	**0.82**
	High Work Load	**3**	**0.89**
	Adverse Living Conditions	**3**	**0.74**
	Psychosocial Hazards	**15**	**0.92**
Worker's Mental Health (Disorders)	Depression	**9**	**0.93**
	Anxiety	**7**	**0.96**
	Stress	**10**	**0.94**
Worker's Performance		**15**	**0.97**

4- Data Analysis

Data analysis was carried out upon collecting the filled-in questionnaire forms when the researcher eventually obtained a total of (409) complete responses. In comparison (91) responses were excluded either due to uncompleted questionnaires with items not answered or those filled by participants with no previous interactions with the Oil & Gas working environment. All reverted questionnaires were checked for stray marks and other defects. The response file was generated by entering data into the Statistical Package for the Social Sciences (SPSS) version (27), and SPSS AMOS version (26), using four techniques to analyze the data; Descriptive Analysis; Correlation Analysis; Independent samples T-test; and the Structural Equation Modelling (SEM).

5- Results and Discussion

The results of the descriptive analysis showed "High" levels of psychosocial hazards in the Oil & Gas working environment from the perspective of the study sample, with a mean of (2.50) for the total score. Regarding mental health disorders, the results indicated a "moderate" level of Depression, with a mean of (10.19), a "mild" level of Anxiety, with a mean of (8.79), and a "moderate" level of Stress, with a mean of (23.49). Furthermore, the results showed a "moderate" total performance score, with a mean (2.01). This performance level can be explained by the workers' high levels of items related to task performance such as official duties and responsibilities, which can be observed in their answers to the statements, showing that they fulfil their responsibilities specified in their jobs' descriptions and accomplish their assigned duties optimally on time as targeted. In contrast, the participants' answers indicated a low level of volunteer participation in activities that help their companies' success and a humble desire to take on additional responsibilities to serve the interest of their work. Also, the answers indicated an induced desire to participate in teamwork to achieve work goals.

These findings might refer to a critical issue, which is that despite the workers' high level of commitment towards their duties and responsibilities, they significantly showed low levels in their ability to adapt, the capability of career development, the desire to participate and take on additional responsibilities, work in new projects, and increase productivity to serve the interest of their work. Those are considered vital and core components of the contextual Performance that seem to be significantly breached.

The results of utilizing the Pearson correlation coefficient showed a positive and statistically significant correlation between the working environment psychosocial hazards and mental health disorders and a negative statistically significant correlation between psychosocial hazards and workers' performance. Also, a negative and statistically significant correlation existed between workers' mental health disorders and performance.

The independent samples t-test results showed that offshore workers experience higher levels of psychosocial hazards and mental health disorders but lower levels in contextual performance than land-based workers. The results of utilizing the Pairwise parameter comparisons indicated a moderating effect of the site location (offshore / land-based) on the effect between the

psychosocial hazards, mental health disorders, and workers' performance, where the highest effect was for the offshore workers.

5.1 Differences in Psychosocial Hazards According to the Site Location (offshore / land)

Table (2) shows significant differences at the level of significance (0.01) in the psychosocial hazards of the Oil & Gas working environment among the study sample, according to the site location. The value of "t "was (12.71), and the highest mean was for offshore workers (2.71), while the mean for land-based workers was (2.04).

Table (2): Differences in the levels of the Psychosocial Hazards according to the Site location (n=409)

Variable	Worksite Location	N	Mean	Std. Deviation	t	P-value / Sig.
Remoteness	Offshore	284	2.95	0.56	7.91	0.00
	Land	125	2.46	0.61		
Isolation	Offshore	284	2.97	0.49	9.62	0.00
	Land	125	2.45	0.54		
Stressful Work Schedules	Offshore	284	2.37	0.80	7.62	0.00
	Land	125	1.73	0.76		
High Work Load	Offshore	284	2.43	0.76	10.89	0.00
	Land	125	1.59	0.63		
Adverse Living Conditions	Offshore	284	2.80	0.58	13.42	0.00
	Land	125	1.97	0.58		
Psychosocial Hazards	Offshore	284	2.71	0.49	12.71	0.00
	Land	125	2.04	0.47		

These results indicate that offshore workers face higher levels in all studied dimensions of the psychosocial hazards in the Oil & Gas working environment. This can be explained by the unique nature of the offshore working environment, where workers have periods of total isolation and separation from family with no social support networks due to being at sea without network coverage. This unique combination of factors can contribute to higher psychosocial hazards for offshore workers than land-based sites.

5.2 Differences in Mental Health Disorders According to Site Location (offshore / land)

Table (3) demonstrates the difference in the levels of Depression, Anxiety, and Stress among the study sample according to their Site location. It can be observed that there was a significant difference in the Depression levels among the study sample according to the Site location at the

level of significance (0.01), as the value of "t "was (9.10). The highest mean was for offshore workers (11.61), while the mean for land-based workers was (6.97).

Table (3): Differences in the Levels of Mental Health Disorders according to the Site Location (n=409)

Variable	Worksite Location	N	Mean	Std. Deviation	t	P-value / Sig.
Depression	Offshore	284	11.61	5.09	9.10	0.00
	Land	125	6.97	3.88		
Anxiety	Offshore	284	9.80	4.79	6.84	0.00
	Land	125	6.51	3.68		
Stress	Offshore	284	24.85	5.89	7.26	0.00
	Land	125	20.42	5.16		

Furtherly, there was a significant difference at the level of significance (0.01) in the Anxiety levels as the value of t was (6.84), and the highest mean was for offshore workers (9.80), while the mean for land workers was (6.51). Also, there was a significant difference at the level of significance (0.01) in the Stress levels according to the site location, as the value of t was (7.26). The highest mean was for offshore workers (24.85), while the mean for land-based workers was (20.42).

The differences in the levels of Depression, Anxiety, and Stress among the study sample clearly showed that offshore workers are experiencing higher levels of mental health disorders, which can be explained by the unique challenges that face offshore workers contributing to higher levels of mental health disorders compared to their land-based counterparts such as the unique combination of isolation, demanding work conditions, lack of recreation and leisure facilities, safety concerns, rotational schedules, and strained personal relationships due to isolation.

5.3 Difference in Worker's Performance According to Site Location (offshore / land)

Table (4) shows a significant difference in performance levels among the study sample, according to the site location at the level of significance (0.01). The value of "t "was (-9.60), and the highest mean was for land-based workers (2.43), while the mean for offshore workers was (1.82).

Table (4): Difference in the Level of Worker's Performance according to the site location (n=409)

Variable	Worksite Location	N	Mean	Std. Deviation	t	Sig.
Performance	Offshore	284	1.82	0.65	-9.60	0.00
	Land	125	2.43	0.45		

These findings confirmed that offshore workers' lower levels of performance compared to workers in land-based sites, which could be seen as logical since they face higher levels of psychosocial hazards and experience higher levels of mental health disorders.

The results of utilizing the structural equation modelling (SEM) indicated a moderating effect of the Site location (offshore /land) on the relationship between the psychosocial hazards, mental health disorders and workers' performance.

The Model for the offshore group demonstrated in Figure (3) indicates that the standardized coefficient for the direct effect of psychosocial hazards on workers' performance is (-0.09), the coefficient for the effect of psychosocial hazards on mental health disorders is (0.85), and the coefficient for the effect of mental health disorders on workers' performance (-0.39).

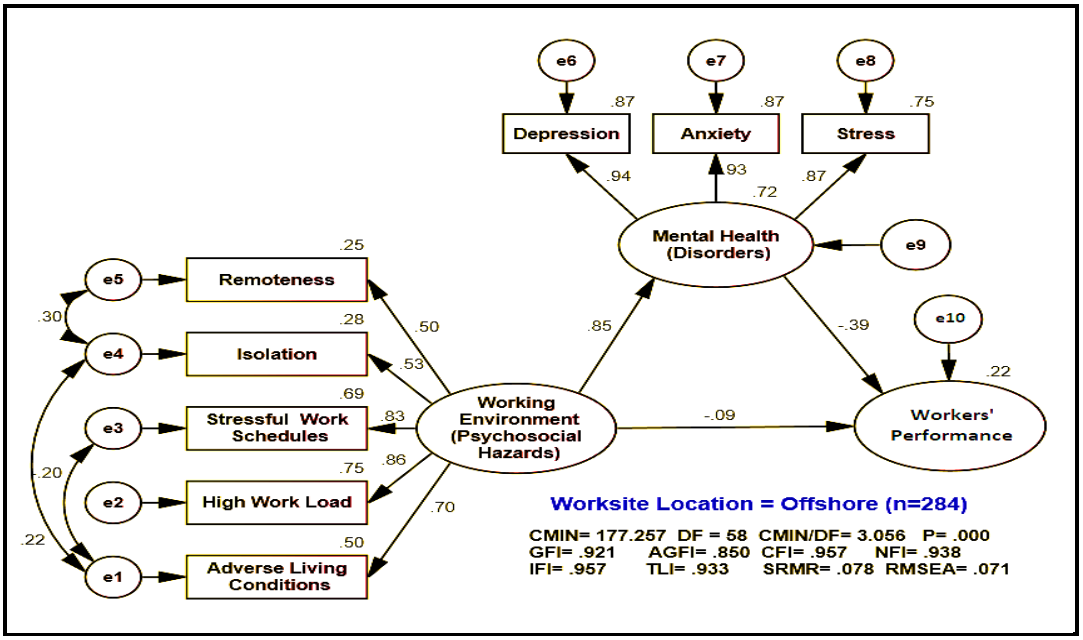

Figure (3): Model of the Relationship between Psychosocial Hazards, Mental Health Disorders and Workers' Performance for the Offshore group

The Model for the land group is shown in Figure (4). It is clear that the standardized coefficient for the direct effect of psychosocial hazards on workers' performance is (0.07), the coefficient for the effect of psychosocial hazards on mental health disorders is (0.77), and the coefficient for the effect of mental health disorders on workers' performance (-0.81).

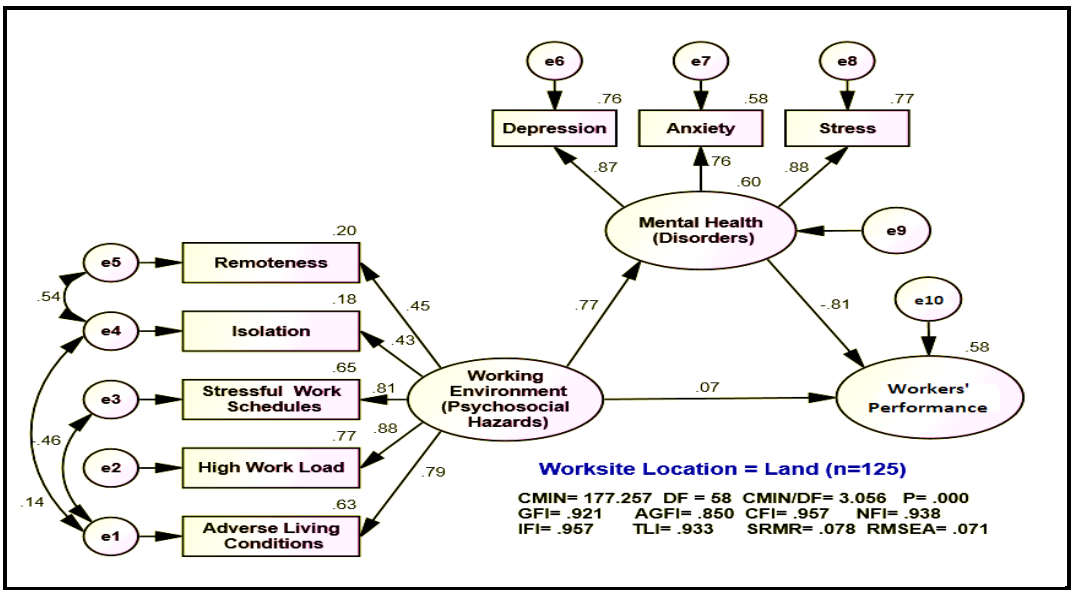

Figure (4): Model of the Relationship between Psychosocial Hazards, Mental Health disorders and Workers' Performance for the Land-based group

The Pairwise parameter comparison was used to test the moderating effect of the site location (offshore / land) on coefficient values for the relationship between the psychosocial hazards, mental health disorders and workers' Performance.

Table (5): The Moderating Effect of the Site Location (offshore / land) on the Relationship between Psychosocial Hazards, Mental Health Disorders and Worker's Performance (n=409)

Paths			Worksite Location	Standardized Coefficients	CR.	Sig.	CR for Differences
Working Environment (Psychosocial Hazards)	--->	Worker's Mental Health (Disorders)	Offshore	0.85	12.09	0.00	3.87
			Land	0.77	7.73	0.00	
Working Environment (Psychosocial Hazards)	--->	Worker's Performance	Offshore	-0.09	-0.72	0.47	-0.85
			Land	0.07	0.47	0.64	
Worker's Mental	--->	Worker's Performance	Offshore	-0.39	-3.12	0.00	1.25

Paths			Worksite Location	Standardized Coefficients	CR.	Sig.	CR for Differences
Health (Disorders)			**Land**	**-0.81**	**-5.03**	**0.00**	

Table (5) shows that there were significant differences between standardized coefficient values for the direct effect of psychosocial hazards on mental health disorders, according to the site location (offshore / land), as the value of the critical ratio was (3.87). The highest effect was for the offshore workers (0.85), while the effect coefficient for the land-based workers was (0.77). The significant differences between the standardized coefficient values for the direct effect of psychosocial hazards on mental health disorders, according to the site location (offshore / land), as the highest effect was for the offshore group, can be explained by the fact that Offshore sites are significantly isolated and remote, leading to a distinct set of psychosocial hazards related to limited social interaction, and reduced access to support networks typically available in land-based settings.

Conclusion

These site location of the Oil & Gas working environment can contribute to differing patterns of workers' mental health disorders and subsequently impact their performance in a manner distinct from land-based settings. The differences in the levels of each dimension of the psychosocial hazards clearly showed that offshore workers experience higher levels in all studied dimensions than other workers in land-based sites leading to experiencing higher levels of stress, anxiety and depression. These findings indicate that the offshore working environment can exacerbate mental health disorders and impact workers' performance differently when compared to land-based sites due to the unique challenges and stressors present in this unique working environment. This means that the "site location" of an Oil & Gas working environment has a moderating effect in determining the levels of the workplace psychosocial hazards, thus presenting a moderating impact on the prevalence of mental health disorders and subsequently the workers' performance. Workers, decision-makers and operators of the Oil & Gas industry should recognize the significance of mental health in the workplace and mitigate the psychosocial hazards which workers could encounter in an offshore working environment.

Recommendations

1- Increasing the number of workers and incorporating further automation in operation activities for tackling high workloads.
2- Providing adequate means of communication, like high-speed internet, to decrease workers' perceptions of isolation and remoteness, especially for offshore workers.
3- Ensuring workers' privacy in accommodation offshore and providing recreational and entertainment facilities to mitigate the perception of adverse living conditions.

Suggestions for Future 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 Oil & Gas Industry.

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Examining the influence of global terminal operators on the performance of container terminals via privatization strategies in the maritime sector

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المستخلص

يستعرض هذا البحث تطور التجارة العالمية من خلال استكشاف التطور الاستراتيجي لمحطات الحاويات، مع التركيز بشكل خاص على الدور المتكامل الذي يلعبه مشغلو المحطات العالمية (GTOs) وسط اتجاهات الخصخصة السائدة. إدراكًا لمحطات الحاويات باعتبارها عقدًا مهمة ضمن سلسلة التوريد البحرية، تستخدم الدراسة نهجًا شاملاً يرتكز على تحليل SWOT للكشف عن العواقب الدقيقة للخصخصة، وإبراز التأثير التعاوني الذي تمارسه GTOs البحث مخصص لكشف الديناميكيات المعقدة التي تشكل أداء محطات الحاويات، مع التركيز بشكل خاص على الكفاءة التشغيلية، والاستدامة المالية، والعمليات الإدارية، وتطوير البنية التحتية. وفي عصر الترابط الاقتصادي العالمي المتزايد، تؤكد الدراسة على الأهمية القصوى لفهم الآثار المترتبة على استراتيجيات الخصخصة. من خلال تقديم رؤى دقيقة حول الدور الاستراتيجي لـGTOs، يتجاوز هذا البحث حدود المحطات الفردية، ويقدم وجهات نظر قيمة لواضعي السياسات وأصحاب المصلحة في الصناعة والأكاديميين الذين يتصارعون مع تعقيدات تطوير البنية التحتية البحرية في هذا العصر.

Abstract

This research navigates the evolving of global trade through an exploration of the strategic evolution of container terminals, with a specific focus on the integral role played by Global Terminal Operators (GTOs) amid prevailing privatization trends. Recognizing container terminals as critical nodes within the maritime supply chain, the study employs a comprehensive approach anchored in SWOT analysis to uncover the nuanced consequences of privatization, accentuating the collaborative influence exerted by GTOs. The research is dedicated to unraveling the intricate dynamics that shape container terminal performance, with a particular emphasis on operational efficiency, financial sustainability, administrative processes, and infrastructure development. In the era of heightened global economic interconnectivity, the study underscores the paramount importance of understanding the implications of privatization strategies. By providing nuanced insights into the strategic role of GTOs, this research transcends the boundaries of individual terminals, offering valuable perspectives for policymakers, industry stakeholders, and academics grappling with the intricacies of maritime infrastructure development in this transformative era.

1- Introduction

In the ever-evolving of global trade, the strategic transformation of container terminals stands as a linchpin influencing the efficiency and effectiveness of the maritime supply chain. At the forefront

of this evolutionary shift is the accelerating trend of privatization, wherein Global Terminal Operators (GTOs) play a pivotal role in reshaping the operational dynamics of container terminals. This research embarks on a comprehensive investigation, utilizing the robust SWOT analysis framework, to unravel the intricate dynamics surrounding the impact of GTOs on container terminal performance within the context of privatization strategies in the maritime sector. The significance of this study lies in its commitment to illuminating the multifaceted consequences of privatization, particularly focusing on the collaborative engagement of GTOs in container terminal operations. As the global economy becomes increasingly interconnected, comprehending the influence of these privatization initiatives on operational efficiency, financial sustainability, administrative processes, and infrastructure development becomes imperative. By delving into the nuanced intricacies of GTO participation, this research aspires to contribute insightful perspectives that transcend the boundaries of individual terminals. The anticipated findings are poised to offer valuable insights for policymakers, industry stakeholders, and academics navigating the intricate of maritime infrastructure development during this era of transformative change. This investigation aims to bridge existing knowledge gaps by not only examining the direct operational implications of Global Terminal Operators (GTOs) in privatized container terminals but also by shedding light on the broader socio-economic ramifications. By exploring the intricate interplay between GTOs and privatization, the study endeavors to uncover innovative solutions and best practices that can enhance the resilience of maritime supply chains. Additionally, the research seeks to provide a forward-looking perspective, anticipating future challenges and opportunities that may arise as a result of the evolving shaped by GTOs and privatization, thus offering a holistic understanding crucial for steering the maritime sector towards sustainable growth.

2- Literature review

The global trend toward container terminal privatization signifies a broader transformation within the maritime industry. Traditionally, governments have held control over port operations and property, considering them strategic national assets. However, evolving dynamics in world trade and the demand for environmentally sustainable and market-responsive port management have challenged this paradigm. Publicly owned ports, shielded from market competition, often struggle with efficient resource allocation and decision-making influenced by political considerations rather than operational efficiency or commercial viability (Baird, 2002).

In contrast, private port operators face rigorous market discipline, with stakeholders closely monitoring performance. Inefficiencies can lead to immediate financial repercussions, fostering a culture of continuous improvement and innovation. Private sector ownership structures are typically more concentrated, facilitating transparent accountability and agile decision-making without bureaucratic processes that may hinder public counterparts (Heng, 2003). The shift towards container terminal privatization responds not only to financial considerations but also to the changing of global trade. As ports aim to become central nodes in global supply chains, the agility, performance, and responsiveness offered by private ownership become increasingly valuable.

2.1 Drivers and Objectives of Container terminal privatization

The drive for privatization significantly influences the evolution of the global port industry, seeking enhanced operational and commercial flexibility. As the global trade becomes more dynamic, privatization provides a pathway for ports to adapt rapidly to changing demands, technological advancements, and competitive pressures. Publicly owned ports, often entangled in bureaucratic processes, may face inefficiencies in resource allocation and operational practices (de Langen, 2023). Private entities, driven by profit motives and competition, are incentivized to optimize operations, invest in modern infrastructure, and innovate in service delivery. Container terminal privatization is further propelled by a reduction in regulations within the port sector. As regulatory barriers decrease, private sector participation in port operations increases, attracting capital investment, introducing best practices, and implementing advanced technology globally. Additionally, port users, such as shippers and logistics providers, play a more influential role in shaping port direction, advocating for practices that enhance efficiency and reduce costs. Several countries, including Argentina, Brazil, Hong Kong, Malaysia, Mexico, New Zealand, Singapore, Venezuela, and the United Kingdom, have recognized the benefits of container terminal privatization. Moves toward privatization are often driven by the dual objectives of improving operational efficiency and generating revenue for the state (Sitharamaraju, 2020).

2.2 Challenges and Risks Associated with Container terminal privatization

While container terminal privatization offers expected benefits, it brings challenges that may counteract these advantages. A primary concern is the financial constraints faced by private investors post-acquisition, requiring additional funds for facility and equipment upgrades. This limitation may impede a port's capacity to modernize and meet evolving market requirements. Evidence from the UK suggests that privatized ports may not consistently surpass the efficiency levels of their public counterparts. Despite transitioning to private ownership, substantial improvements in operational infrastructure are yet to be realized, raising questions about the effectiveness of privatization in fostering operational excellence (Monios, 2016).

The impact of privatization on port performance, especially in management and operations, is significant. However, the influence on core port operations directly affecting output and efficiency is paramount. Success in different port categories often originates from added value through transitioning from wholly state-owned entities to public/private partnerships. Such collaborations typically involve infrastructure expansion and a more commercially oriented approach to operations. Nevertheless, questions persist about the depth of privatization and its broader implications for the maritime logistics chain (Quansah, 2008).

2.3 Strategies and Policies for Managing Container terminal privatization

Diverse global strategies and policies for container terminal privatization reflect each country's unique economic, political, and social conditions. For instance, Singapore's PSA underwent conversion into an independent commercial corporation in 1997, accompanied by the establishment of the Maritime and Port Authority (MPA) to oversee and regulate PSA

Corporation, ensuring the provision of essential port and marine services and facilities (Quansah, 2008). In contrast, Korea employs a leasing model where the Ministry of Maritime Affairs and Fisheries leases terminals to the Korea Container Terminal Association (KCTA), without financial transactions. Private terminal operators are then engaged to enhance operational efficiency while the government retains ownership (Cullinane, 2017).

China's strategy emphasizes collaboration, preferring joint ventures to introduce the private sector into terminal operations. Joint ventures like the Shanghai Container Terminals (SCT) and the Yantian International Container Terminal foster a synergy between public oversight and private sector efficiency. Container terminal privatization strategies often align with a country's broader economic goals and objectives. Some nations aim to attract foreign direct investment, while others focus on enhancing competitiveness in the global maritime industry. The decision to privatize, the extent of privatization, and the choice of private partners are influenced by various factors, including economic goals, the state of the maritime industry, and geopolitical considerations (Quansah, 2008). Effective regulations play a crucial role in the success of container terminal privatization, ensuring operational autonomy while upholding safety, security, and environmental standards. Transparent and predictable regulations provide clarity to both port operators and customers. Regardless of the approach—full privatization, joint ventures, or leasing models—the overarching objective is to enhance the efficiency, competitiveness, and sustainability of the port sector (Cullinane, 2017).

2.4 Strategies of Terminal Operators

The strategies employed by container terminal operators play a crucial role in their rapid expansion, reflecting the influence of economic forces (Strategies of Container Terminal Operators). Former terminal operators entering the global system engage in horizontal integration, applying their expertise in new markets and seeking additional income sources. Shipping lines entering terminal operations represent a form of vertical integration, extending control over various links in the transport chain. A third observed strategy involves portfolio diversification, with terminal assets playing a key role. These strategies contribute to the growth and influence of global terminal operating companies, emphasizing profitability, financial assets, managerial expertise, gateway access, leverage, traffic capture, and a global perspective. The typology of global port operators and the regional distribution of terminal assets add complexity to the understanding of the strategies employed (Parola, 2013).

2.5 Private Participation in Port Terminal Operations

The historical shift from public to private participation in port terminal operations has been a crucial aspect of the evolving maritime sector. Until the 1980s, public ownership and operation predominantly shaped the of port terminals. However, operational inefficiencies of public port authorities in adapting to increasing demands led to the rise of private involvement. This shift emerged from the need to foster competition in the entire transport industry through economic liberalization policies. Developing countries were recommended by the World Bank to grant concessions to organizations capable of modernizing and efficiently managing port operations,

leading to diverse forms of public-private partnerships, commonly referred to as port devolution. The surge in demands for investment, driven by global trade growth, played a significant role in governments becoming more receptive to port governance reform. This section provides a comprehensive overview of the evolution of the port , the strategies employed by terminal operators, and the historical shift towards private participation in port terminal operations. The discussion sets the stage for the examination of the impact of Global Terminal Operators on container terminal performance in the context of privatization strategies in the maritime sector (Heejung, 2015).

3- Largest container shipping lines and terminal operators.

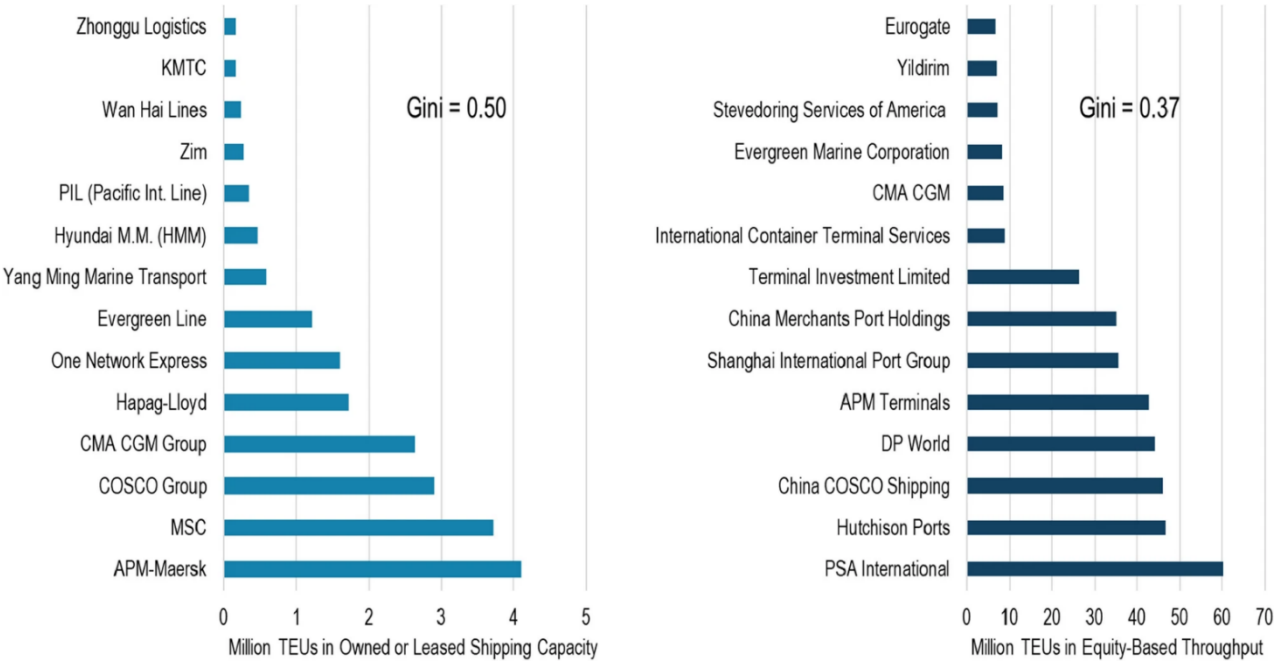

Figure (1): Largest container shipping lines and terminal operators.

Source: Notteboom, T., & Rodrigue, J. P. (2023). Maritime container terminal infrastructure, network corporatization, and global terminal operators: Implications for international business policy. Journal of International Business Policy, 6(1), 67-83.

Figure 1 presents an overview of the largest container shipping lines and terminal operators, providing a visual representation of their comparative scale and significance in the maritime industry. The size of each entity in the diagram reflects its market influence and global presence. This visual aid helps in understanding the hierarchical structure and dominance among container shipping lines and terminal operators. The figure captures the interconnectedness of shipping lines and terminal operations, emphasizing their collaborative roles in the international supply chain. Overall, this visual representation serves as a valuable snapshot of the key players shaping the container shipping and terminal.

4- Container terminal surface of the world's major terminal operators, 2019.

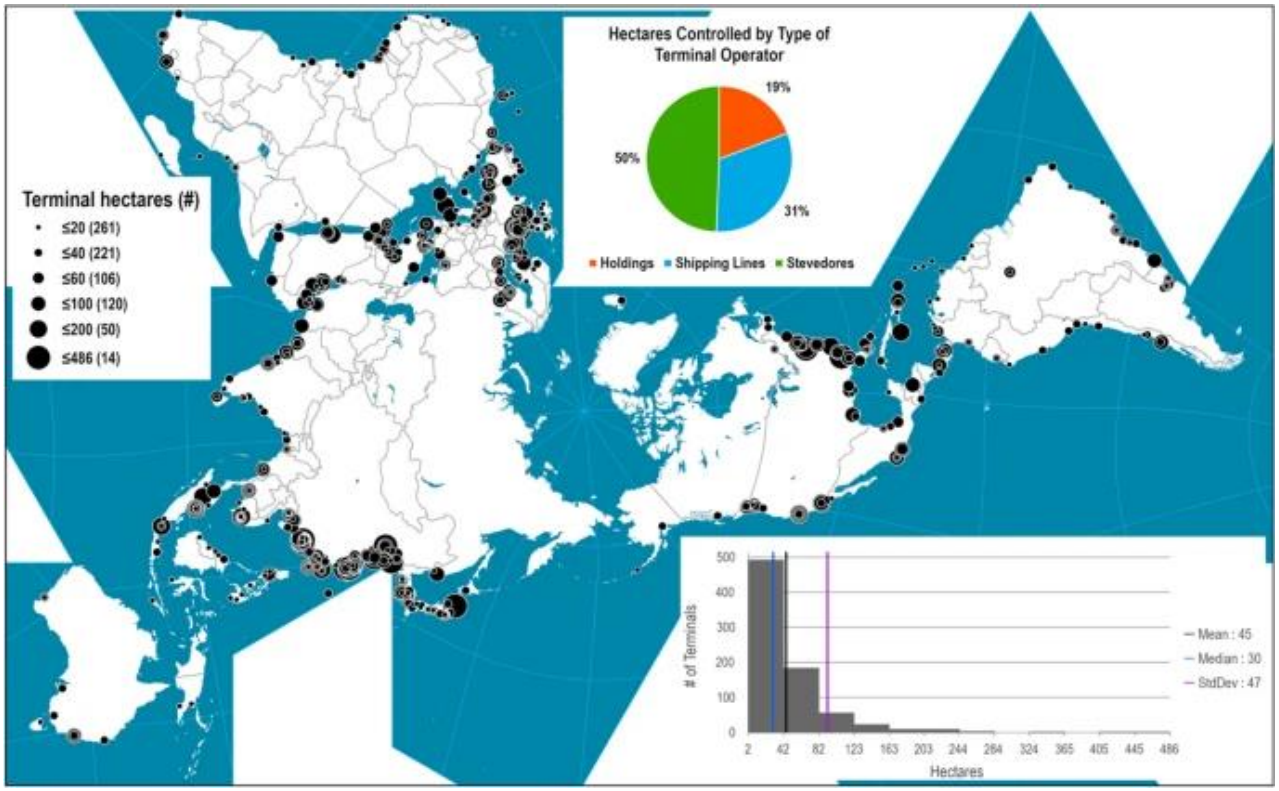

Figure (2): Container terminal surface of the world's major terminal operators, 2019.

Source: Notteboom, T., & Rodrigue, J. P. (2023). Maritime container terminal infrastructure, network corporatization, and global terminal operators: Implications for international business policy. Journal of International Business Policy, 6(1), 67-83.

The figure (Figure 2) illustrates the container terminal surface distribution of major global terminal operators in 2019. It provides a visual representation of the extensive reach and presence of these operators on a global scale. The varying sizes of the circles denote the relative surface area of container terminals operated by each major player. The data depicted in the figure reflects the competitive and market share among these terminal operators, showcasing the concentration of terminal assets and their strategic positioning. The visual representation aids in understanding the geographical distribution and significance of these major terminal operators in shaping the maritime container terminal infrastructure.

5- Research Methodology

The methodology employed in this study relies on the SWOT analysis framework to thoroughly assess the influence of Global Terminal Operators (GTOs) on container terminal performance. This approach is chosen for its efficacy in systematically exploring strengths, weaknesses, opportunities, and threats, leading to a comprehensive grasp of the dynamics at play. The structured nature of SWOT analysis is instrumental in revealing critical internal and external factors affecting container terminal performance, particularly within the context of privatization.

The decision to utilize SWOT analysis is grounded in its ability to uncover key factors that shape container terminal performance amidst privatization. The process involves a detailed examination of GTO strengths, such as operational expertise, identification of weaknesses like potential market dependence, and exploration of opportunities and threats within the broader maritime sector.

To gather a well-rounded perspective, the research employs a diverse data collection approach. This includes a quantitative analysis of operational metrics and financial reports, coupled with qualitative insights obtained through surveys and interviews conducted among terminal operators, staff, and stakeholders. The comparative analysis assesses GTO-operated terminals against publicly operated ones, evaluating aspects such as operational efficiencies, financial sustainability, administrative processes, and infrastructure development to discern patterns and variations. Ensuring the reliability of findings is paramount to the research's overall robustness. This is achieved through data triangulation, where information is cross-verified using multiple methods. Rigorous validation processes are implemented to enhance the credibility of both quantitative and qualitative data. For quantitative data, this involves comparisons with industry benchmarks and historical trends. Qualitative data undergoes scrutiny through member checking and cross-referencing with quantitative findings. Despite these measures, it is important to acknowledge potential limitations in the study. Factors such as the availability of historical data, the representativeness of the chosen sample in qualitative research, and the dynamic nature of the maritime industry may introduce constraints. These limitations are openly addressed in the study, providing transparency and context to the findings. Alternative explanations for observed patterns are also considered, contributing to a comprehensive and balanced presentation of research outcomes.

6- Research Problem

The core research problem revolves around evaluating the effectiveness and ramifications of privatization strategies within the maritime sector, particularly concerning the involvement of Global Terminal Operators (GTOs). Key inquiries aim to shed light on how GTO participation influences the efficiency and functionality of vital nodes in global trade, specifically container terminals. Essential issues to address include the extent to which GTO involvement enhances financial resources, optimizes administrative processes, and contributes to improved infrastructure development in problematic container terminals. Additionally, the research problem delves into the collaborative efforts between the public and private sectors, with a specific focus on GTOs, seeking to determine the success of these partnerships in alleviating financial burdens on governments and overcoming bureaucratic obstacles. The overarching goal is to comprehensively explore the impact of GTOs on container terminal performance, identifying challenges and opportunities associated with such collaborations and providing valuable insights for regions contemplating similar privatization strategies in their maritime operations.

7- Importance of the Research

Understanding the influence of Global Terminal Operators (GTOs) on the performance of container terminals holds significant importance for various reasons. This research seeks to uncover the impact of privatization strategies, specifically those involving GTOs, on the efficiency and effectiveness of critical global trade hubs, namely container terminals. Delving into the role of GTOs in these operations, the study aims to highlight potential advantages, including enhanced financial resources, streamlined administrative processes, and improved infrastructure development—all crucial elements for optimizing terminal performance. Moreover, the assessment of collaborative initiatives between the public and private sectors, with a focus on GTOs, is crucial in determining whether such partnerships can effectively relieve financial burdens on governments and eliminate bureaucratic obstacles.

Expanding the scope, this research aims to explore how the optimization of terminal performance through GTO involvement can translate into tangible benefits for international trade and economies. The findings may shed light on the broader economic impact, offering insights into how public-private partnerships, especially those involving GTOs, can positively influence the overall economy. This could potentially serve as a model for other regions contemplating similar privatization strategies in maritime infrastructure. This research is essential for unraveling the intricate dynamics of privatization in the maritime sector and evaluating the far-reaching implications of GTOs on container terminal performance. This encompasses not only efficiency, financial sustainability, and infrastructure development but also how these improvements can manifest as concrete advantages for international trade and economies on a global scale.

8- Research Aim and Objectives

The overarching aim of this research is pivotal in addressing pressing challenges and opportunities within the maritime sector's privatization strategies, particularly concerning the influence of Global Terminal Operators (GTOs) on container terminal performance. By systematically investigating and analyzing various facets such as operational efficiency, financial sustainability, administrative processes, and infrastructure development within privatized container terminals, this study directly addresses the broader challenges faced by regions contemplating or undergoing similar privatization strategies. Achieving the specified objectives holds paramount importance in this context. Firstly, by evaluating the influence of GTO involvement on operational efficiency, the research aims to provide insights into enhancing the overall effectiveness of container terminals, contributing directly to the optimization of global trade nodes.

Secondly, investigating the financial impact of GTO participation addresses the critical aspect of ensuring the economic viability and sustainability of privatized container terminals, thereby offering solutions to financial challenges faced by governments. Exploring the role of GTOs in streamlining administrative processes within container terminals directly contributes to addressing bureaucratic obstacles, which is a significant challenge in the privatization of maritime operations. Furthermore, assessing how GTOs promote infrastructure development within container terminals

not only contributes to the efficiency of trade operations but also addresses the broader need for robust and advanced infrastructure in maritime settings.

Finally, the research objectives aim to investigate the effectiveness of public-private collaboration, particularly involving GTOs, in managing container terminals. This directly aligns with the broader opportunities highlighted in the importance section, as successful collaborations can alleviate financial burdens on governments and pave the way for more streamlined and efficient operations. In essence, by accomplishing these objectives, the research aims to provide a comprehensive understanding of the impact of GTOs on container terminal performance. This understanding is crucial for regions considering or undergoing similar privatization strategies, offering them valuable insights into overcoming challenges and harnessing opportunities for the advancement of their maritime operations.

9- Research Questions

- How does the involvement of Global Terminal Operators (GTOs) impact operational metrics like turnaround times, vessel productivity, and container handling rates in container terminals that have undergone privatization?
- What is the quantifiable financial effect of GTO participation on revenue generation, cost reduction, and the overall financial stability within privatized container terminals, and how does this compare to terminals under public operation? Specifically, what is the assessment timeframe and the units of measurement for revenue and cost?
- What specific mechanisms underpin the observed alterations in operational efficiency, and how do the nature of partnerships and shared responsibilities contribute to the overall success of privatization initiatives?
- How do GTOs contribute to the simplification of administrative processes in container terminals, and what notable changes are evident in management practices, technological integration, and workforce efficiency?
- In what manners do GTOs contribute to infrastructure development within container terminals, and what particular investments in technology, equipment, and facilities influence the overall infrastructure of privatized terminals?

10- SWOT Analysis

The SWOT analysis highlights the positive aspects that GTOs bring to privatized container terminals, identifies potential challenges, and suggests strategic areas for further development and improvement. The results can guide decision-makers in leveraging strengths, addressing weaknesses, capitalizing on opportunities, and mitigating threats for successful privatization strategies in the maritime sector.

Strengths	Weaknesses
1.Operational Expertise: GTOs bring a wealth of operational knowledge and experience to privatized container terminals, contributing to improved	1.Market Dependency: GTOs may face challenges if they become overly dependent on specific markets, making them vulnerable to economic

efficiency in cargo handling, vessel turnaround times, and overall terminal operations. 2.Global Connectivity: GTOs often have a global network, enabling better integration of container terminals into international supply chains. This global connectivity can lead to increased market influence and diversified opportunities for trade. 3.Financial Resources: The involvement of GTOs may lead to increased financial resources for privatized container terminals through investments, technology upgrades, and business expansion, enhancing the overall financial stability of these terminals. 4.Technological Advancements: GTOs are likely to introduce and implement advanced technologies, automation, and best practices, leading to enhanced technological capabilities and modernization of infrastructure within privatized container terminals.	downturns or geopolitical shifts in those regions. 2.Regulatory Challenges: GTOs may encounter regulatory challenges in different regions, potentially impacting their ability to implement standardized operational practices across various privatized container terminals. 3.Cost Implications: Privatization strategies involving GTOs may come with increased costs, including concession fees, technology investments, and operational upgrades, which could strain the financial resources of the involved parties.
Opportunities	**Threats**
1.Technological Advancements: GTOs can capitalize on emerging technologies to further enhance operational efficiency, reduce costs, and provide innovative solutions for container terminal management. 2.Infrastructure Development: GTOs may contribute to significant infrastructure development, including the introduction of state-of-the-art equipment, facilities, and technology, thereby positively impacting the overall efficiency and competitiveness of privatized container terminals. 3.Market Expansion: GTOs, with their global reach, can facilitate market expansion for privatized container terminals by exploring new trade routes, forming strategic partnerships, and attracting a diverse range of shipping lines.	1.Geopolitical Instability: The involvement of GTOs in privatization strategies exposes container terminals to geopolitical risks, such as trade tensions, regulatory changes, or geopolitical instability in regions where GTOs operate. 2.Competitive Pressure: The competitive nature of the maritime sector may lead to increased competition between privatized container terminals operated by GTOs and other terminals, potentially putting pressure on pricing and profit margins. 3.Resistance to Change: Resistance from existing stakeholders or the workforce to changes brought about by GTOs, such as technological advancements or shifts in management practices, could pose a threat to the smooth implementation of privatization strategies.

Table (1) : SWOT analysis
Source: designed by researcher

11- Discussion

The SWOT analysis of Global Terminal Operators (GTOs) in privatized container terminals uncovers a robust set of strengths, weaknesses, opportunities, and threats. GTOs' operational expertise, global connectivity, financial resources, and commitment to technological advancements emerge as key strengths, forming a solid foundation for enhanced efficiency and competitiveness. However, challenges such as market dependency, regulatory hurdles, and potential resistance to change highlight areas for improvement. The identified opportunities, including technological advancements, infrastructure development, and market expansion, provide a strategic roadmap for GTOs to navigate the evolving of the maritime sector.

To optimize their strengths and seize opportunities, GTOs should focus on strategic areas for development and improvement. These include continuous investment in operational expertise, proactive engagement with regulatory bodies, strategic financial planning, ongoing research and development, and collaborative efforts for infrastructure development and market expansion. Recognizing consistent patterns and tailoring strategies to variations based on regional and terminal-specific factors will be crucial for sustained success. In conclusion, the SWOT analysis equips decision-makers with valuable insights to shape effective strategies, emphasizing the importance of adaptability and continuous monitoring in the dynamic environment of privatized container terminals.

12- Recommendations

• Optimization of Operational Excellence: Utilize the operational expertise of GTOs to improve efficiency, cargo handling, and vessel turnaround times by implementing industry best practices.

• Global Network Integration: Actively incorporate GTOs' global networks into strategic planning, exploring new trade routes, fostering partnerships, and diversifying trade opportunities to decrease reliance on specific markets.

• Financial Collaboration Strategy: Collaborate with GTOs to develop and execute a strategic financial plan that effectively allocates resources, taking into account concession fees, technology investments, and operational upgrades.

• Adoption of Technological Advancements: Embrace and integrate technological innovations introduced by GTOs to boost operational efficiency, cut costs, and maintain a competitive edge in managing container terminals.

• Diversification for Market Resilience: Implement strategies for diversification to minimize risks associated with market dependency, ensuring that GTO-operated terminals remain resilient and adaptable to various regions and market conditions.

These recommendations are crafted to offer decision-makers clear and practical guidance for leveraging strengths, addressing weaknesses, capitalizing on opportunities, and mitigating threats associated with privatization strategies involving Global Terminal Operators in the maritime sector.

13- Conclusion

this research delves into the transformative impact of global trade, focusing on the strategic evolution of container terminals amid the trend of privatization and emphasizing the pivotal role of Global Terminal Operators (GTOs). Through a thorough SWOT analysis, the study provides a nuanced understanding of the outcomes of privatization strategies, revealing the collaborative influence exerted by GTOs. The research sheds light on the intricate dynamics shaping container terminal performance, emphasizing aspects such as operational efficiency, financial sustainability, administrative processes, and infrastructure development. As the global economy becomes more interconnected, the study highlights the crucial importance of comprehending the implications of privatization initiatives, offering valuable insights for policymakers, industry stakeholders, and academics navigating the complexities of maritime infrastructure development.

Navigating the multifaceted realm of GTO involvement in privatized container terminals, the research identifies strengths and opportunities, providing decision-makers with a strategic roadmap for development. Despite challenges like market dependency and regulatory hurdles, the study advocates for a proactive approach, urging GTOs to leverage operational expertise, global connectivity, and financial resources. Continuous investment in technology, collaborative infrastructure development, and a keen understanding of regional variations are crucial elements for sustained success. This study contributes novel insights into the collaborative influence of GTOs in privatized container terminals, emphasizing operational efficiency, financial sustainability, and infrastructure development. The research methodology, particularly the extensive SWOT analysis, sets this study apart by offering a comprehensive exploration of the subject. Acknowledging limitations, such as case study specificity and regional variations, enhances the study's transparency and credibility, encouraging future research to build upon and refine the presented insights.

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Reviewing experimental and theoretical efforts and key findings regarding hydrodynamic journal bearing geometry

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المستخلص

تعتمد عملية المحمل العائم، خاصة فيما يتعلق بالتطبيقات البحرية، بشكل كبير على أداء أهم العوامل التشغيلية. على وجه التحديد، غالبًا ما يتعرض الزيت الزلق داخل المحمل العائم للتدهور الخطير والفشل النهائي في ظروف التشغيل الفعلية. بناءً على هذه الحقيقة، تهدف الدراسة الحالية إلى إجراء مراجعة للأدبيات حول الجهود المبذولة لتحسين أداء المحمل العائم استنادًا إلى اختيار التصميم الهندسي المناسب للمحمل العائم. تم تحليل البيانات المجمعة بدقة وتقييمها باستخدام الوسائل التجريبية والنظرية والعددية. تمثل النتائج المستخلصة من الاستعراض أساسًا متينًا لإجراء تعديلات واسعة النطاق على تصميم المحمل العائم للتطبيقات البحرية، ومن الممكن أن تُستخدم هذه البيانات في الأبحاث المستقبلية لتوسيع قدرات المحمل العائم ووظائفه لتحقيق أقصى أداء ممكن في ظروف التشغيل الفعلية.

Abstract

Journal bearing operation particularly in regard to marine applications is significantly affected by the performance of the most critical operational factors. Specifically, the lubricating oil film within journal bearing is so often than not subject to hazardous deterioration and ultimate failure in real operating conditions. Considering such fact, the current study is intended to carry out a literature survey regarding the efforts towards enhanced journal bearing performance based on proper selection of geometrical design for journal bearing. The aggregated data were thoroughly analyzed and assessed utilizing experimental, theoretical as well as numerical means. The outcomes derived from the conducted review represent firm grounds for carrying out extensive modifications into journal bearing design for marine applications. Further, such data will possibly be employed in future research investigations to extend the capability of journal bearing and its functions to attain the most possible enhanced performance in actual operating conditions. Apparently, the vast majority of both experimental and theoretical studies into journal bearing geometrical designs for enhanced performance, 66 in all, have been focused on surface texture accounting for 26.67 % (29 research studies) and 32.43 % (33 research studies) of the total investigations under study respectively. Regarding the experimental studies, realizing promoted performance of lubricating oil film by working on pressure profile has evidently obtained the largest contribution representing 35.5% of the overall bulk of the reviewed efforts, Figure 6.

Keywords: Hydrodynamic Lubrication, journal bearing geometry, operating condition.

Nomenclature		
C_0	total clearance	mm
C	radial clearance	mm
D	inner diameter for grooved bearing	mm
L	bearing length	mm
N	shaft speed	rpm
P	motor power	kW
P_{max}	maximum oil film pressure	bar
P_0	nominal bearing pressure	bar
r	Radius for Journal Shaft	mm
T	temperature	℃
W	applied load	N
Φ_s	shaft diameter	mm
CGB	circumferential grooved bearing	
CP	communication processor	
PLC	programmable logic controller	
PS	power supply	
PT	pressure transmitter	
SCADA	supervisory control and data acquisition	
TC	thermocouple	
UJBTR	universal journal bearing test rig	

1- Introduction

Safe navigation onboard ship is essentially dependent on a number of elements including Shafting Propulsion System (SPS). Such a crucial system relying chiefly on journal bearing ought to accommodate both adequately and efficiently to wide ranges of speed operating conditions. These involve slow speed, critical speed and high or rather full navigation speed. Being principally designed for operation in hydrodynamic lubrication region, journal bearing, Figure 1, ought to be maintained at the most possible optimal operating condition. The main reason for that lies in the fact that journal bearing contains the vital lubricating oil film between moving surface (journal shaft) and stationery surface (bearing). Severe operating conditions are so often than not affecting the lubricating oil film and could in certain cases incur very serious consequences such as hazardous deterioration and possibly the ultimate and disastrous failure of the whole SPS. Among the prominent serious consequences such undesirable situations could trigger is the misalignment between the main engine crankshaft, the intermediate shaft and the propeller shaft. Deterioration of journal bearing incurs increased operating and replacement costs, repetitive stop and costly downtime as well as reduced bearing life.

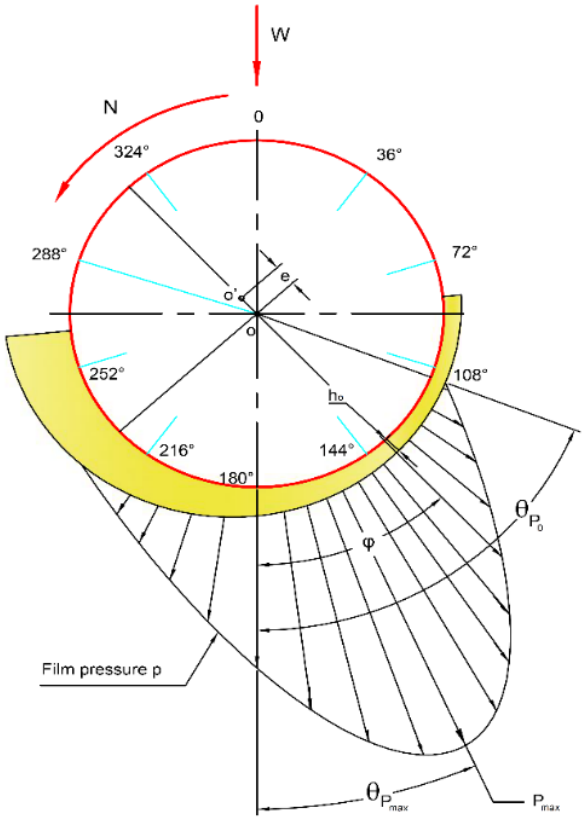

Figure 1: A schematic polar diagram of oil film pressure distribution with the minimum film thickness h_0, eccentricity e, angular location of the minimum film thickness ∅, shaft weight W, maximum film pressure P_{max}, position of maximum film pressure θp_{max} and terminating pressure of oil film θP_0.

Modification of journal bearing geometrical design, Figure 2, is definitely one of the foremost techniques to which shipyard arena manufacturers often resort for effecting tangible enhanced operational performance. Thus, the present study reviews different endeavors for enhancing performance of journal bearing based on possible geometrical designs. Additionally, it seeks to trace and highlight the most effective geometrical designs among all scanned efforts (66 research studies in all). The final objective behind the work at hand is also to identify the best contributions in this respect with view to benefiting from and building on the most significant achievements as well as attaining applicable geometrical design suitable for journal bearing even in the most severe operating conditions a ship may be face. To sum up, the present investigation is a step in a series of potential investigations for promoting journal bearing performance based on the aggregated data derived from the conducted review in regard to the most optimal geometry for enhanced performance in real operating conditions.

Figure 2: An illustration of different journal bearing geometries. (N. Marey et al., 2021)

2- The design related to the journal bearing

2.1 Research endeavors concerning journal bearing design

(Muzakkir et al., 2014), developed a test setup for tracing the possible reasons for heavy- duty, slow speed hybrid journal bearing tribological failure. Journal bearing was operated under the load of 373 N and journal speed of 27 rpm. Cylindrical magnetic bearing arrangement was confirmed to be inconsistent for heavy load and low speed operating conditions due to its very low static load-carrying capacity. To mitigate and contain the severity of the magnetic bearing failure, the study recommended the use of magnetic bearing arrangement lubricants.

(Gralde, 2014), Carried out an extensive investigation into start -stop journal bearing test rig. The study combined a manufactured test rig to the development of test rig software via MATLAB. Further, an engine lubricant was applied for the lubrication process of journal bearing. Speed variations ranged from 0 rpm up to 1000 rpm in 60 seconds duration under variable load impacts of 500 N, 1000 N, 3000 N and 5000 N. Based on the conducted study, it was possible to obtain torque amid shaft and bearing. Also, the study scope extended to trace transient states of journal bearing via a functioning test-rig.

(Chasalevris & Dohnal, 2015), investigated the possibility of minimizing vibrations in rotating shafts by introducing a variable geometry journal bearing in the final form provided by detailed design procedure. Speed limits ranged from 500 rpm up to 5000 rpm and the beams were displaced for applying the preloading for external springs. Vibration amplitude was suppressed by up to 7% compared to a conventional journal bearing. Based on the presented study, it was possible to change the effective damping and stiffness of the system through selective activation of an additional fluid film during critical operation.

(Blomstedt, 2017), introduced systems for measuring and controlling test parameters regarding tribological values and their validation. Thermocouples, displacement sensors and oil film pressure and temperature sensors were all integrated into the test rig. Also, three hydraulic cylinders were added to exert dynamic alternating loads ranging from 0 up to 100 kN. Shaft rotation speed ranged from 0 rpm up to 3000 rpm. Reducing oil pressure was found to reduce test bearing friction and vice versa. Temperature rise of oil was demonstrated to be less in bearing contact area. Also, rotational load featured higher friction than that of static load.

(Kulkarni, 2018), conducted an experimental investigation into the impact of speed and load variations on journal bearing circumferential distribution. Also, weight was added to derive the different speed variation readings. Hydrodynamic journal bearing created load supporting fluid film according to both shape and relative motion of the sliding surface. Such fluid film had the potential of preventing the metal-to-metal contact between the shafts and the bearing. Consequently, load action on journal bearing shaped the pressure profile where no friction emerged.

(Marey, 2018), designed and constructed a journal bearing test rig of multiple functions to investigate single grooved journal bearing. The selection of test rig components involving drive motor, drive shaft, bearing assembly and data acquisition system was given a special consideration. The constructed test rig unit was capable of containing wide-range test trials regarding journal bearing lubrication. Applying the different speed ranges of 50 rpm, 100 rpm, 150 rpm and 200 rpm respectively at constant load, the study assured adequate conformity between experimental test rig results and their peers derived theoretically. Such an outcome has stressed the validity of the constructed system for potential future experiments. Moreover, (N. Marey et al., 2021) carried out thorough modifications to journal bearing structure. Such modification procedures have involved adding a hydraulic loading system which facilitated even a wider range of experimental test trials. Precision of all conducted procedures and relevant outcomes were ensured via Supervisory Control and Data Acquisition (SCADA) system carried out by (Marey & Ali, 2023) . As such, the structure was transformed into a Universal Journal Bearing Test Rig (UJBTR). A system that integrated all essential monitoring devices necessary for the extensive and possibly enhancement of the foremost operational factors affecting operational conditions.

3- Experimental investigation into journal bearing geometry

3.1 Modifications of geometrical design of plain bearing

Bearing type is by all means one of the foremost factors upon which the behavior of hydrodynamic journal bearing in actual operating conditions essentially rely. Specifically, plain bearings are known to be one of one of the most effective bearing types that is commonly utilized in marine applications. Modifying plain bearing in terms of geometry can offer numerous advantages as well as tangible enhancement of journal bearing performance. Consequently, introducing innovative modifications regarding plain bearing geometrical designs for promoted operation has been the main interest of a considerable number of research investigations.

(Ahmed et al., 2013), presented a thorough evaluation regarding the individual impacts of the different variables on maximum oil film pressure. Maximum oil film pressure was evidently affected by the model terms of speed, load and oil-feed pressure. Variable speed ranges from 100:1000 rpm have been applied as well as a pressure sensor of MEAS (M5156) model, 10 MPa range and accuracy of roughly (0.001± 1% measured value) MPa. Maximum oil film pressure could accurately be estimated based on regression model and the deviation ratio was just quite negligible amounting to around 1%.

(H. C. Liu et al., 2016), examined the individual squeeze impact pertaining to the formation of hydrodynamic lubricating film in a slider on disc contact. The study involved variable modes of non-steady motions, which were analyzed on both experimental and theoretical grounds under load impact of roughly 5 N. Realizing the final steady speed at startup/shutdown process was confirmed to bring the change rate of film thickness to a maximum. Squeeze effect or rather change rate of film thickness obtained its maximum value on reaching the final steady speed.

(Mansoor & Shayler, 2018), traced the impact of oil feed pressure on friction torque factor applying light, steady loads. Shaft rotation speed ranging from 400 rpm up to 2000 rpm was controlled utilizing an electronic inverter connected to the motor. Applying a specific load SL of 4.3 bar, the study assured that the reduction of feed pressure would increase cavitation area. In such a condition, pressure gets lower in the low-pressure zone of the film. Hence, the reduction of film area incurs correspondent reductions in friction torque. As a result, eccentricity ratio and circumferential- average surface shear stress are both reduced.

(X. Zhang et al., 2019), demonstrated the significant impact of axial misalignment in regard to journal bearing seizure load. The experimental study involved a motor rated power of 5.5 kW, a rated torque amounting to 35 NM as well as a 1500 r/min rated rotational speed. The increase in clearance decreased seizure load and hence could provide a better aligned condition. Yet, regarding misaligned condition, there appeared to be an optimum radial clearance for a given misalignment angle. Consequently, seizure load was confirmed to be considerably affected by axial misalignment.

(Cui et al., 2023) traced the formation and evolution pertaining to transfer film concerning fabric composite lubricated plain bearing within cryogenic and wide temperature range. Integrating in-situ Fourier Transform Infrared (FTIR) microscopy, time evolution and time dependence of

lubricating transfer film morphology and composition concerning PTFE fabric composite through spherical plain bearing tribotester was unraveled. Also, conducting test trials at a wide range of temperature, the study pointed out the significant role of transfer and molecular reorientation of PTFE regarding PTFE fabric composite lubrication.

Notably, this group of research investigations considered promoting performance of journal bearing based on a number of crucial factors involving oil film pressure and temperature distribution, eccentricity as well as the oil film thickness. Yet, some other significant operational factors were not given due interest. These involve the oil supply pressure and temperature, the different viscosities and the vibrations.

3.2 Promoting grooved bearing performance

Another bulk of crucial research investigations focused on enhancing hydrodynamic lubrication within journal bearing via modifying groove positions, numbers or distributions.

(Ahmad et al., 2013), were concerned with promoting journal bearing lubrication performance depending on oil supply pressure at variable groove locations. Providing different measurements regarding frictional force, torque and friction coefficient, the study assured the sensitivity of torque and frictional force to variations made in groove position and oil supply pressure. The experimental test trials have been conducted at speed ranges of 500 and 800 rpm under 15 kN radial load impact.

(Adatepe et al., 2013), examined tribological tendencies related to non-grooved and micro-grooved journal bearings applying dynamic loading. Speed variations ranging from 400 up to 2000 rpm were tested to determine frictional moment variations in liquid friction zone exerting versatile suspended static loads on the bearing. Micro-grooves were concluded to have a crucial impact in the shapes of oil film thickness, friction coefficient and friction force under the operating conditions of dynamic load.

The impact of alterations in groove location on temperature and pressure profiles within journal bearing was the main focus of (Ahmad et al., 2014). Those profiles were measured at speed variations involving 300, 500 and 800 rpm under versatile radial loads of (10 and 20 kN). Locating oil groove supply in the converging section, close to the minimum oil film thickness position, was evident to reduce temperature values.

(Binu et al., 2015), have traced the nature of hydrodynamic pressure distribution related to two-axial groove journal bearings. The study introduced a novel test rig integrating a drive unit containing a 5 HP AC Motor, with a unit for controlling speed combined with a hollow shaft utilizing belt drive. Operating the structure at a speed of 1200 rpm, the study revealed the experimentally derived pressures which were less by around 20% than their peers acquired theoretically.

(Chatterton et al., 2017) investigated the twin groove cylindrical journal bearing regarding rotational speeds as well as static loads. The study involved testing the 160 mm diameter bearing under severe operating conditions at speed ranges from 66 rpm up to 1440 rpm under variable

applied loads ranging from 0 kN up to 350 kN in a vertical direction. Increased load, deformation of bearing housing as well as bending of shaft were all concluded to have significant impacts on performance. Also, increasing static load, particularly at loaded part of the bearing, was ascertained to increase bearing deformation significantly.

(Marey, 2018), carried out an experimental investigation into single grooved journal bearing. Test Rig components were carefully selected and designed. The introduced test rig unit offered a valuable chance to carry out extensive tests regarding journal bearing lubrication. Test rig was operated at the variable speeds of 50 rpm, 100 rpm, 150 rpm and 200 rpm consecutively under constant load. Conformity between experimental test trials and theoretical investigations stressed the potential of the constructed system to contain even more elaborate studies in the future.

In addition, Marey et al, conducted a series of research investigations into the most influential operational factors affecting the oil film lubrication within journal bearing utilizing the Universal Journal Bearing Test Rig (UJBTR). The behavior of journal bearing at variable speeds, loads, oil viscosities and oil supply pressure was extensively evaluated. (N. Marey, 2019), (N. Marey et al., 2022), (N. Marey, 2023) and (N. A. Marey et al., 2024).

Resuming research efforts towards optimal grooved bearing performance, (Marey et al., 2023) carried out an experimental investigation into hydro-thermal performance regarding journal bearing lubricating oil film profile within diesel engine at slow speeds. Considering the loading program of slow speed diesel engine, the study examined oil film temperature and pressure profiles utilizing variable grade fluids. With medium viscosity lubricant grades, the increase of shaft speed was demonstrated to incur reductions in the difference between optimal and heavy loads. For shaft rotational speeds of 43 rpm, 90 rpm and 104 rpm, those differences represented 22%, 9.7% and 2.1% respectively. A proper selection of a lubricant was thus concluded to provide improved operational behavior, reduced cost and extended life for journal bearings.

Based on the aforementioned group of investigations, a considerable improvement in the performance of journal bearing could be achieved depending on grooved bearing. Consequently, this type of bearing is the most practical type that is commonly utilized in marine applications currently. Notwithstanding, this bulk of research endeavors did not pay much consideration to the negative impact of vibrations on the behavior of journal bearing. Vibration impact is by all means one of the serious factors that could affect performance and operation, and is thus in need of due attention at the initial phases of journal bearing design and construction.

3.3 Experimental test trials on elliptical bearings

The ability of elliptical bearing to promote performance via enhanced dynamic characteristics and more stability gave the momentum for another group of research investigations. Such bearing type is mainly characterized by a horizontal clearance that ranges from 1.5 times to double its vertical clearance, or rather, from 33% up to 50% preload. Such an advantage means offering optimal damping as well as load capacity through re-orienting split angle between halves. Hence, from a dynamic perspective, it is a highly asymmetric bearing (Leader, 2012).

(Aher et al., 2013) worked on the lubricating oil film within elliptical journal bearing. Temperature and pressure increase in regard to the hydrodynamic journal bearing lubricating oil film under high speed rotating machinery was elaborately investigated. A noncircular elliptical bearing at constant load of 500 N and variations of speed ranges involving 1000, 1500 and 2000 rpm was employed. Results demonstrated the increase in the values of both pressure and temperature profiles under such specific operating conditions.

(Singla et al., 2014) traced the load carrying capacity of lobe bearing based on different comparisons between it and that of plain journal bearing. The variable loads of 300, 450, 600 and 750 N were applied at corresponding rotational speeds of 1000 rpm, 1500 rpm and 2000 rpm respectively. The study assured the ability of lobe manufactured bearing to yield more stability and elevated load carrying capacity at both higher and lower speeds alike than those provided by plain journal bearing.

(Zhang et al., 2019) proposed a mechanism for suppressing rotor vibration amplitude within adjustable elliptical journal bearing during normal speed operating conditions. The attempt to mitigate the impact of synchronous unbalanced load was carried out at shaft speed of 2000 rpm under constant load amounting to 200 N. A dynamic lubrication program was established where numerical simulations were conducted. Adjustable elliptical bearing suppressed forced vibrations significantly.

More important still, (Amine et al., 2023) introduced an approach combining both experimental and numerical procedures for tracing oil film thickness as well as friction regarding a wide elliptical thermoelastohydrodynamic (TEHL) considering sliding conditions extending from pure rolling to opposite sliding. The impact of varying ambient temperature, normal load and entrainment speed on film thickness and friction in a wide range of sliding conditions was verified. Also, a simple formula was created for estimating minimum film thickness depending mainly on classical dimensionless parameters and SRR and employing numerical parametric investigation as well as relevant results.

The above mentioned group of research studies are evident to lack the effect of bearing material on the performance of journal bearing. Utilizing a suitable material in the construction of journal bearing is definitely one crucial step towards achieving enhanced performance and reduced maintenance costs for journal bearing in actual operating conditions.

3.4 Enhanced performance based on tilting pad bearings

Tilting pad journal bearing was also a crucial focus of attention for a considerable number of research studies, aiming at achieving enhanced performance of operating conditions. Involving numerous bearing pads which pivot to generate a pressure field in oil film, tilting pad journal bearing could effective support the applied load. (Salazar & Santos, 2017) utilized hybrid lubrication for promoting dynamic performance of the system in regard to active tilting pad journal bearings supporting flexible rotors. The study employed a test rig involving AC motor power of 3 kW, a maximum rotor speed of 7000 rpm and a bearing load of 1440 N. Hybrid lubrication was confirmed to enhance the system dynamic performance considerably.

(Cerda & Ferreira, 2018) introduced active characteristics into standard leading edge groove (LEG) tilting pad journal bearing employing theoretical and experimental procedures. The evaluation of the feasibility of such technique was conducted at journal rotational speeds of 1000 rpm, 2000 rpm and 3000 rpm subsequently, exerting bearing mean loads of 1000 N and 5000 N respectively. The proposed design had the capability of modifying both its steady state and dynamic properties via an electrical signal fed into a servo-valve marked by a high-response.

(Ciulli et al., 2018) sought to satisfy the requirements pertaining to the next-generation high power density turbomachinery efficiency. The study involved description of a novel test rig regarding static as well as dynamic characterization in regard to high performance tilting pad journal bearings. Employing a motor of 4000 rpm maximum speed, a nominal torque of 3000 Nm, and a maximum static load of 270 kN, the study demonstrated the capability of the proposed model design to carry out the process of data acquisition effectively.

(Lou et al., 2019) considered the impact of fluid pivot journal bearing (FPJB) performance in relation to the one-sided floating state. Larger recess area ratio was concluded to incur a smaller recess pressure while bearing capacity was constant. Also, squeeze- film appeared between the pad and the bearing house. Recess pressure rose from 448 up to 1800 and remained constant from 2242 to 3300 rpm. Determination of the floating state of the pad and bearing performance calculation depended on essential data of recess pressure and floating heights of each displacement measuring point.

The possibility of utilizing alternative materials in regard to tilting pad thrust bearings working in transition to mixed friction was experimentally researched by (Wasilczuk & Wodtke, 2024). The behavior of fluid film bearings in such specific operating regimes was investigated for four tilting pad bearings of variable material compositions. The study involved stopping under load and reproduction of Stribeck curve applying reduction of rotational speed to minimized values. The involved analysis has assured the possibility of employing less popular material compositions concerning bearings utilized in specific conditions. DLC/Steel bearing demonstrated elevated and much more stable performance particularly at start-stop.

Scanning such group of investigations indicates the shortcoming in regard to the impact of critical operational factors which affect journal bearing performance in real operating conditions particularly that of overload. Also, tilting pad bearing is one of bearing types that was not practically utilized in regard to marine journal bearing as other alternative geometrical designs were concluded to yield better operational characteristics.

3.5 Applying surface texture techniques

Several research investigations have been oriented towards the influence of surface texture regarding the critical operating factors of bearing lubrication, load-carrying capacity as well as wear resistance. (Kumar Gupta et al., 2013) integrated micro-dimples into bearing surface and concluded that the increase of pressure in textured bearing exceeded that of smooth journal bearing. A commercial oil grade Hydrol 68 was utilized under variable loads from 100 N up to 800

N, for speed ranges of 1000, 2000 and 3000 rpm respectively and constant oil feed pressure of 0.05 MPa. Surface texture was found to be apparently affected by variations of speed.

(Singh & Rana 2014) were specifically focused on improving hydrodynamic and journal bearing performance relying on surface texture techniques. A novel laboratory setup involving a speed of 1500 rpm was introduced. The textured bearing included eight grooves each of which was 1 mm wide. The distance between each groove was 8 mm. Maximum pressure was evidently affected by changing certain parameters such as shaft speed, bearing context texture as well as loading conditions.

(Dadouche & Conlon, 2016) traced the impact of surface texture and contaminated fluid in regard to steady-state performance characteristics in as far as heavily-loaded journal bearings are concerned. Journal shaft was run at 16500 rpm exerting a static load of 22250 N, a dynamic load of 1335 N and a power of motor of 37 Kw. Based on the study, dimples were demonstrated to be capable of capturing contaminant particles and hence reducing the risk of bearing failure.

(Dong et al., 2017) worked on the impact of texture distribution on bearing vibration and rotor stability. Experimental test trials involved high speeds of 2800 rpm and 3600 rpm in addition to the lower speed of 1000 rpm. Acceleration amplitude of textured bearings under such specific operating conditions was apparently less than that of non-textured bearings. Also, damping effect of surface-textured bearings by far exceeded that of non-textured bearings. Increasing rotating speed would evidently maximize shaft frequency amplitude.

(Qi et al., 2019) outlined the effects of Laser Surface texturing on tribological properties of Polytetrafluoroethylene (PTFE)/ Kevlar Fabric Composite weave. Friction tests comprised variable rotation speeds of 200 r/min, 400 r/min, 600 r/min and 800 r/min under wide range load impacts of 542 N, 1084 N and 2168 N respectively. Friction and wear in a tribosystem were considerably reduced when Structural Laser Surface Texturing(LST) technology was applied. LST was thus confirmed to enhance tribological performance and reduce wear rate.

(Putignano et al., 2019) investigated the possibility of reducing friction rates by means of utilizing soft matter laser micro-texturing. Employing a Femtosecond laser manufacturing process, the study could produce a pattern of micro dimples on a Fluoro-elastomer. Soft contacts were assured to contain friction levels provided that a consistent theoretical optimization of dimple structure was carried out.

(Galda et al., 2019) introduced the characteristic parameters including sliding velocity, Hersey number and friction torque when lubrication regimes transition took place. The experimental study involved numerous journal bearing types as well as the variable speeds of 100 rpm and 500 rpm. Friction torque was considerably affected by textured sliding surfaces of journal bearings during shutdown.

(Vlădescu et al., 2019) applied laser surface texture to internal combustion engine journal bearing shells. Impacts of such a condition were experimentally tested at the variable speeds of 750 rpm up to 4000 rpm under exerted loads of 1 up to 8 kN. Laser-etched patterns were applied to surface of

shell components to discern the impact of surface texturing on crankshaft bearing. Locating textured micro-features outside load area was ascertained to reduce friction levels significantly.

(Li et al., 2023) intended to introduce the acting mechanisms related to abrasive wear comprising two-body and three-body abrasion affecting tribological systems. Utilizing bearing steel (100 Cr6) pins and discs in a flat-on-flat contact and interracial media, the study assured the significant impact of speed-induced hydrodynamic impact on frictional behavior of the system. Film thickness could be increased by 14% and friction could also be decreased by 2/3 as a result of increasing a speed-dependent hydrodynamic impact.

(Kajihara, 2024) carried out a surface treatment relying on Laser Induced Particle Impact Test (LIPIT) for enhancing tribological properties related to material surface. Considering particle mass, material surface was found to be impacted with a velocity of 400m/s to 750 m/s employing LIPIT. Results strongly referred to the capability of LIPIT to contain frictional resistance. The reason for that was attributed to the potential of dimple textured surface generated by LIPIT to promote lubricant retention.

Surface texturing is absolutely one of the promising design techniques that is likely to bring about considerable enhancement in journal bearing operation for marine applications. Hence, such field is so crucial and is still in need of thorough investigations and analysis concerning the oil film lubrication within journal bearing.

4- Theoretical Studies

In fact, a considerable improvement in the performance of hydrodynamic journal bearing can be attained via employing theoretical means. A significant bulk of research studies worked on such a crucial objective by applying theoretical approaches involving Reynold's equation, Sommerfeld number and last but not least the Navier Stoke equations. On the other hand, another group of no less importance investigations tended to realize such enhanced behavior via introducing or rather employing theoretical analyses. Those analytical studies can safely be divided into categories based on the focus point for each of them. Individual Investigations into each of FLUENT, MATLAB, GAMBIT and COMSOL were carried out and the related analyses as well as the derived outcomes have all been introduced. (Zhang et al., 2023) introduced a thorough review where beneficial guidelines regarding self-powered methods for creating smart bearings were proposed. The study involved the underlying theory, modelling techniques, methodologies as well as technologies. Further, topology, mechanisms and advantages of wireless power transfer related to a self-powered smart bearing were all illustrated. Useful tips for performance development and for promoting the applicability of self-powered smart bearings at working conditions were suggested. Those mainly involved design methodologies and technologies concerning a wide range of transducers. Also, potential research orientations and opportunities for self-powered smart bearing systems were extensively investigated.

4.1 Theoretical efforts regarding journal bearing geometry

4.1.1 Plain bearing

(K¨alvelid, 2016) constructed a numerical modelling related to plain journal bearings within oil system pertaining to a heavily-loaded engine applying the system analysis software of GT-S. Lower engine speeds involving 600 rpm and 950 rpm were applied for calculating bearing loads utilizing GT-SUITE. Considering the split lines for main bearing in the models, the study concluded the increase of oil volume flow rate by 13-16%. Based on the study, geometric irregularities could accurately be identified utilizing the Reynold's equation.

(N. Marey et al., 2018) provided a computational investigation into oil film pressure distribution of plain journal bearing utilizing CFD package ANSYS. ver.15.0. Also, an experimental journal bearing test rig was constructed for simulating journal bearing performance within the shafting system of the ship at variable speeds of 50 rpm up to 400 rpm at constant load. The introduced discipline could facilitate investigating oil film pressure behavior extensively. The most critical operational factors involving oil properties and design schemes could all thus be elaborately studied and enhanced.

(S. Cui, Gu, Wang, et al., 2018) examined hydrodynamic journal bearing behavior at startup. The rotor speed increased linearly from 0 up to 1000 rpm in 0.1s, 0.2s and 9.3s respectively. Hydrodynamic oil force at startup was evident to increase sharply incurring a sharp decrease in contact force. Increasing the relative clearance of bearing led to reductions in contact force as well as contact time. Also, high start-up acceleration was found to reduce contact force considerably.

(S. Cui, Gu, Fillon, et al., 2018) investigated the impacts of surface roughness on transient characteristics of hydrodynamic cylindrical bearings during startup. Hydrodynamic pressure was derived based on the modified average Reynolds equation with Finite Element Method (FEM). Rotational speed rose linearly up to 1000 rpm within 0.1s. The study concluded the considerable impact of surface roughness on the transient characteristics of the bearing in the initial phase of start-up.

(ERHUNMWUN & AKPOBI, 2019) traced the influence of changing radial clearance on the variations of fluid pressure profile. The study involved a journal shaft speed of 1000 rpm and an oil dynamic viscosity of 0.19 PA.s. Steady state and constant temperature were involved in the study and a numerical solution for short journal bearing under steady state was also developed. It was recommended to increase radial clearance in the design of journal bearing. In such a way, bearing pressure could considerably be reduced.

(ERHUNMWUN & AKPOBI, 2019) discussed the variation in fluid viscosity combined with changes in lubricant pressure within hydrodynamic journal bearing. Introducing a parametric study in which the Finite Element Method (FEM) was employed, the researchers analyzed the pressure performance of the bearing via Classical Reynolds Equation. The linear relation between Fluid viscosity and bearing pressure was both demonstrated and confirmed.

(Xiang, Han, Wang, Wang, et al., 2019) intended to examine certain journal bearing essential characteristics involving mixed lubrication and wear. A numerical transient Mixed Lubrication-Wear Coupling model was developed. Simulations were obtained and an external force of 1000 N

was exerted on the top of bearing shell along the vertical direction. Based on the simulated outcomes, the distribution trend of lubrication performances was considerably affected by transient wear process. Further, results revealed two wear stages occurring under mixed lubrication condition.

(Xiang et al., 2020) introduced a novel transient tribo-dynamic model for journal bearings. Applying variable speed ranges from 0 up to 4000 rpm and exerting an external load of 1 kN, the researchers assured that severe asperity contact maximized maximum temperature at the initial start-up stage. A short acceleration time was demonstrated to lessen asperity contact pressure and to increase temperature relatively. Also, a smaller radial clearance and a thinner bearing would incur a larger maximum temperature and thermal expansion.

(Dond et al., 2023) carried out a computational fluid dynamics study on the behavior of fluid film journal bearings with variable geometrical designs. CFD approach was applied to identify the performance characteristics of plain and elliptical journal bearings introducing an alternative approach regarding thermo- hydrodynamic analysis. The study involved analytical investigations over a wide range of speeds from 500 up to 1000 rpm and lubricant viscosity at 1000 N load. Theoretical outcomes were validated via computational methodology. Pressure distribution in elliptical bearing exceeded that of plain bearing and reached 370.44 %.

4.1.2 Groove bearing

(Brito et al., 2016) worked on detecting risky strong negative flow rate in one of the grooves testing a wide range of loading angles. Such a serious condition for bearing performance was traced at journal shaft speed of 3000 rpm and load variations from 0.2 up to 10 Mpa. Impacts of grooves in single and twin axial groove journal bearings under variable load directions were also among the main research objectives. Groove flow rate distribution could be optimized via a groove deactivation strategy.

(Sep et al., 2017) were concerned with promoting bearing performance via eliminating abrasive wear of grooved journal bearings. Utilizing clean oil, the study employed ANSYS Fluent application at journal speed of 600 rpm and load carrying capacity was derived relying on hydrodynamic pressure distribution. Abrasive wear resistance could be enhanced by eliminating wear debris or contaminants from contact zones of mating surfaces.

(Chen et al., 2017) applied stabilized term in free boundary problems for optimizing bi-directional-rotation herringbone-grooved journal bearings. Textured groove appearance was optimized applying Fluid Dynamic Bearings (FDBs) to spindle motors. MATLAB-based Code was employed for evaluating groove design. The study involved the variable speed variations of 4000 rpm, 6000 rpm and 8000 rpm subsequently. Load carrying capacity was considerably promoted by increasing bearing length. That is mainly due to the expansion of hydrodynamic-pressure-generating region.

(Y. Zhang et al., 2019) intended to minimize computational costs via calculating fluid film pertaining to a finitely long journal bearing provided by two axial grooves. The study proposed a new semi analytical approach in regard to nonlinear fluid film forces, where pressure distribution

was expressed as a particular solution and a homogeneous solution. Pressure distribution of the particular solution was derived based on Sommerfeld transformation. The study could both introduce fluid film force of a finitely long journal bearing with two axial grooves and offer savings in computational costs depending on Reynolds equation.

(Xiang et al., 2019) traced lubrication performance of micro-grooved journal bearings via a transient hydrodynamic lubrication comparative analysis based on a numerical model. Applying a rotational speed range of 2500 rpm, the study assured the rise in axial movement frequency with the increase of fluctuation amplitude of load capacity. Also, load capacity related to micro-grooved bearing could be reduced by increasing groove angle.

(Chatterton et al., 2019), worked on reducing total power loss resulting from shear stresses in oil-film bearings related to a steel roll forming machine. Performance of all bearings was simulated employing a precise Thermo-Elasto- Hydro- Dynamic (TEHD) model. The introduced analysis involved modelling and experimental test trials were carried out at a rotational speed of 1200 rpm. Two hydraulic actuators with a maximum force of 400 kN were employed to apply vertical loads on top of bearing case. Simulation outcomes referred strongly to the possibility of reducing overall power loss in bearings via utilizing a lubricant with kinematic viscosity of approximately half the reference oil value.

Besides, (N. A. Marey et al., 2024) introduced a novel numerical CGB model for assessing operational conditions in light of simulation analysis. Applying variable journal shaft speeds from 25 rpm up to 125 rpm under versatile load impacts, the study tested the two lubricant grades of 5W40 and 0W30. Maximum oil film pressure could be reduced by 1.17 bar and 0.97 bar when shaft velocity was decreased by 80% for the two lubricants respectively. Additionally, increasing load impact from 1079 N up to 1471 N at the constant speed of 75 rpm incurred reductions in maximum oil film pressure ratio by 0.14 and 0.18 regarding the previously mentioned fluid grades respectively.

4.1.3 Elliptical bearings

(Phalle et al., 2012) introduced a theoretical analysis for the behavior of a 2- lobe worn multi-recess hybrid journal bearing system compensated with numerous flow control devices. Finite Element Method was applied for solving the Reynolds equation governing lubricant flow within clearance space. Optimal selection of the compensating device and offset factor value was assured to achieve tangible improvement in bearing performance.

(Biswas, 2015), investigated the operational behavior of a 3-lobe bearing depending on a three-dimensional and transient computational fluid dynamics analysis. Considering the impacts of surface roughness as well as a gas turbine gravity, the researchers carried out meshing of the part related to oil flooded region utilizing GAMBIT. The study ascertained the increase of total pressure with the expansion of surface roughness area.

(El-said et al., 2017) devised a mathematical model for investigating the behavior and stability of three-lobe journal bearing with a bushing surface textured with uniform micro protrusions.

Maximum pressure of protruded three-lobe bearing has been evident to exceed any other bearing particularly that of plain bearing. All of the attitude angle, friction loss and load carrying capacity could be enhanced by increasing eccentricity ratio of protruded three-lobe bearings. Protruded three-lobe bearing was concluded to outperform plain bearing.

In addition, (Boedo, 2022) presented an analysis regarding steadily loaded, oscillating elliptical journal bearings. The impact of surface ellipticity concerning self-acting partial arc journal bearings under steady load and sinusoidal oscillation for mass conserving cavitation was addressed. Employing a Generalized Warner Bearing (GWB) formulation for computational efficiency, the study ascertained the positive impact of an elliptical sleeve at small oscillation amplitude on bearing performance.

4.1.4 Tilting pad bearing

(Cerda et al., 2013), investigated a tilting-pad journal bearing static and thermal performance under controllable lubrication both experimentally and theoretically. It was possible to enhance modelling of tilting- pad bearing with controllable regime when injection system is switched off. At the same year, (Cha et al., 2013) examined dynamic response of tilting pad journal bearing under bad compliance. Exerting a static load of 30000 N at shaft speed of 3000 rpm, the study demonstrated the increase of journal orbit size and oil film pressure when pad backing compliance was elevated. Bad compliance was assured to have a considerable impact on dynamic behavior of tilting pad journal bearings at higher dynamic loads.

Parallel to that (Hou et al., 2013) traced the influential impacts on local parameters involving eccentricity, preload as well as compressibility. A relatively small attitude angle of Local Bearing Parameters (LBP) was incurred by tilting characteristics of pads. The study proposed some very crucial practical characteristics regarding the design and analysis of Tilting Pad Journal Bearing (TPJB) with LBP configuration.

(Asgharifard & Ahmadian, 2015), proposed a novel technique for modeling and identifying weak nonlinear performance of tilting pad journal bearings (TPJBs). In such a way, an accurate reduced order model with nonlinear impacts could be constructed. The nonlinear model facilitated providing a fast computational tool for investigating nonlinear behavior regarding rotating systems supported on TPJBs.

(Dang et al., 2016), investigated the effects of load direction of static and dynamic characteristics of TPJB. Applying an on-nominal geometry, the study manifested the significant effect of load direction on non-nominal five-pad tilting-pad journal bearings. The study involved a rotational speed of 1200 rpm under a static load impact on each bearing of 5 KN. Load direction was obvious to exert a much more impact on dynamic characteristics than static one.

Besides, (Suh & Choi, 2016) were focused on the effects of pivot design and angular misalignment on tilting pad journal bearing characteristics. Fluid pressure amid two plates in motion at variable velocities was solved based on Generalized Reynolds equation. The novel 3D TPJB numerical model could be applied to rotor dynamic analysis with long rotor simulation featuring angular

misalignment between spinning journal and bearing. Angular misalignment in cylindrical pivot TPJB produced both asymmetric film clearance as well as pressure distribution in axial direction.

(Mehdi et al., 2018) illustrated the dynamic characteristics related to composite tilting pad journal bearing of turbine/generator applications. Fabricating composite tilting pad journal bearings integrating carbon fiber/epoxy composites and a backup metal, the researchers offered guidelines for enhancing performance and durability. Variable bearing loads have been applied and controlled employing a load control system. The analysis results were ascertained via an industrial test bench. The ability of hybrid composite tilting pad journal bearing to tolerate friction and prevent rotor damage in the absence of lubricating oil condition was verified.

On the other hand, (Liu et al., 2023) proposed a thermal elastohydrodynamic lubrication (TEHL) model observing pivot deformation as well as journal misalignment regarding tilting pad thrust bearings. Model verification was achieved employing an electromagnetic hydraulic collaborative controllable loading technology. Based on the conducted study, pivot deformation was evident to enhance the uneven load phenomenon under the journal misalignment. The study recommended considering pivot deformation in numerical calculations due to its significant impact on minimum film thickness.

4.1.5 Surface texturing bearing

(Ganji, 2013) investigated the possibility of estimating load carrying capacity of journal bearing at variable surface texture depths. Utilizing elliptical dimples, the study worked on enhancing journal bearing performance based on both texture density and depth modifications. Applying full texture was assured to promote load carrying capacity. Calculations were carried out and texture density was revealed to increase load carrying capacity.

Employing computational techniques, (Kumar Gupta et al., 2013) introduced the full effects of spherical dimples in regard to the behavior of hydrodynamic porous journal bearing. Applying journal shaft speeds of 2000 rpm and 4000 rpm, the study assured the significant impact of such dimples on bearing performance. Increasing dimple depth was demonstrated to enhance load carrying capacity. Further, load carrying capacity was found to decrease with the increment in permeability parameters.

(Woloszynski et al., 2015) employed a spectral element solver for the Navier-Stokes equations regarding slider finite bearings textured with multiple spherical dimples. In addition, the study introduced the inertia impact of hydrodynamic bearings. Inertia effect was apparently influenced by spatial arrangement of dimples. Increasing Reynolds number was also evident to promote Inertia effect.

(Hamdavi et al., 2016) investigated pressure distribution and load carrying capacity performances under the impact of partially textured surface related to hydrodynamic long journal bearing. Reynolds equation was applied for obtaining pressure distribution and load carrying capacity equations. Partially textured region was concluded to enhance load carrying capacity and pressure distribution pertaining to partially textured journal bearing.

(Y. Zhang et al., 2016) illustrated tribological performance of journal bearing under the impact of sphere dimples. The study pointed out the effects of variable distribution forms and geometry parameters on load carrying capacity as well as friction characteristics. Optimal circumferential range angle and maximum depth of sphere dimples were evident to maximize load carrying capacity and minimize friction factor. Increasing area density of texture was found to promote load carrying capacity.

(Kumhar & Patel, 2017) applied a numerical approach for examining and predicting the performance characteristics related to grooving journal bearing. A CFD Software Fluent was utilized to derive lubricant Flow solutions as well as thermal equations. Applying a shaft speed of 2000 rpm and changing groove diameter, number and pattern, the study assured that increased pressure would have a positive effect on journal bearing performance.

(Gropper et al., 2016) introduced the optimal texturing criteria via employing numerical models. The study confirmed the considerable impact of contact type and operating conditions on texturing parameters. Surface texturing was assured to be a feasible method for promoting contact performance in regard to load carrying capacity, minimum film thickness, friction and wear.

(Tala-Ighil & Fillon, 2017) investigated the operational behavior and evolution of fully and partially textured hydrodynamic main journal bearings utilizing two lubricants. Numerical simulations were conducted to analyze viscosity impact utilizing two different lubricants. The study involved journal shaft speeds of 80 rpm, 600 rpm and 2000 rpm, under the load impact of 667 N. Enhancing friction coefficient and minimum film thickness was assured to be dependent on hydrodynamic lubrication regime, lubricant viscosity and journal shaft speed.

(Meng & Khonsari, 2017) were concerned with the prediction of micro-textured parallel surfaces behavior employing a computational model. The model applied simultaneous solutions regarding Stokes equation as well as energy equation in fluid film. The impact of viscosity wedge regarding pressure distribution and load carrying capacity for textured surfaces was elaborately discussed. Viscosity wedge and geometrical wedge effect were obvious to affect shearing stress of Fluid. Additionally, viscosity wedge effect increased with narrowing texture while it weakened geometry wedge effect.

(Wang et al., 2018) worked on improving the performance of hydrodynamic journal bearing via introducing modifications to surface textures. The impact of multiple texture distributions on performance was investigated. The study involved the development of geometries and dynamic models with pure concave/convex textures. Convex texture enhanced load capacity whereas concave spherical texture reduced it. Introducing a novel concave-convex composite texture was thus recommended for enhanced bearing lubrication behavior.

(Shinde et al., 2018) employed both numerical and experimental analysis for better identifying the performance characteristics related to Conical Shape Hydrodynamic Journal Bearing (CSHJB). Thin film flow physics of COMSOL Multiphysics 5.0 was utilized and partial ellipsoidal dimple shape texturing was tested. Applying a journal shaft speed of 1500 rpm under an external load of

50 N, the study demonstrated the considerable impact of the orientation of ellipsoidal dimples on the static performance characteristics pertaining to CSHJB.

(Gao et al., 2024) employed high speed ball-end milling process for assessing generation method and antifriction behavior concerning discrete micro-pit surface texture. The study traced the primary mechanism related to the interval and distribution of micro-pit texture applying Fluent fluid simulation as well as reciprocating sliding friction test. Textured surface provided by micro-pit features was concluded to yield evident antifriction capability. In comparison, with polished surfaces, textured surface granted a decreased percentage in regard to friction coefficient amounting to 61.5%. Besides, both of oil film bearing capacity and antifriction ability were evidently affected by the interval.

5- Results and discussion

The current study is intended to cover the most significant research efforts for enhancing journal bearing performance based on a number of innovative geometrical designs, variable materials and lubricant grades over a period of roughly 10 years Figure 3. Basically, five patterns of geometrical designs were considered, investigated and analyzed and the most crucial design and operational factors involved have also been extensively studied. The given graphs are meant to illustrate the relation between each of the experimental and theoretical studies on the one hand, and the bearing geometry on the other. Notably, it is observed that the experimental studies, Figure 4, tracing the surface texture bearing have assumed the largest percentage amounting to roughly 26.67%. In comparison, the researches examining surface texture bearing have also come in the first place among the studies conducted theoretically Figure 5, yet with a slightly higher percentage of about 32.43%. Besides, it is noted that the percentages of experimental studies concerned with both elliptical and tilting bearings equaled and accounted for the least portion of researches with just 13.33%. Theoretical researches investigating elliptical bearings represented the least share of studies with a minimized percentage of 8.1%. In addition, it is inferred that the percentages related to the experimental studies and focusing on both plain and groove bearings levelled out where they recorded 23.33%. In contrast, the bulk of theoretical studies having plain bearings as their main focus have marginally exceeded that pertaining to grooved bearings by 5%. Based on the derived outcomes, it is concluded that the investigations focused on surface texture bearings by far exceeded all other examined study fields whether they were carried out on experimental or theoretical grounds.

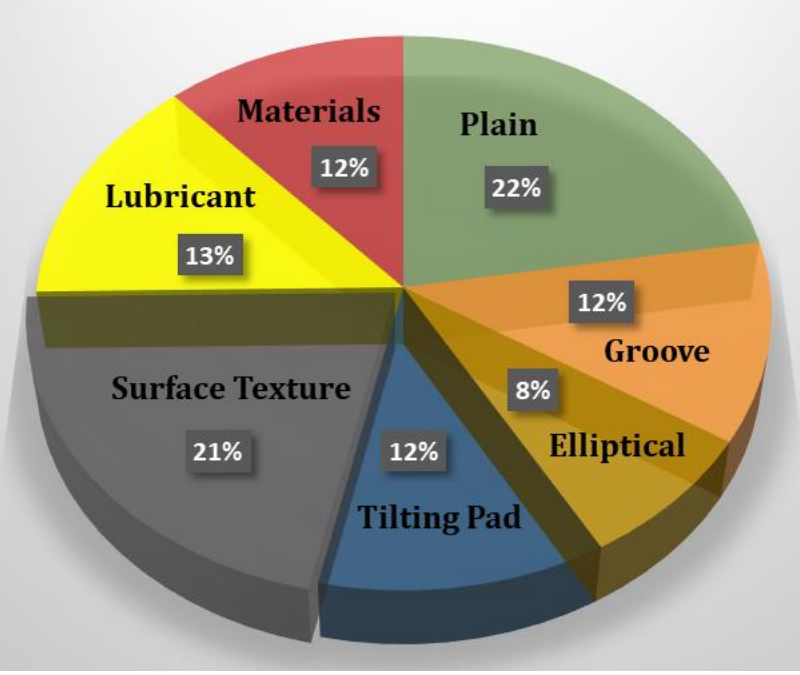

Figure 3: A chart representing the percentages of research efforts towards enhanced journal bearing performance over the covered period.

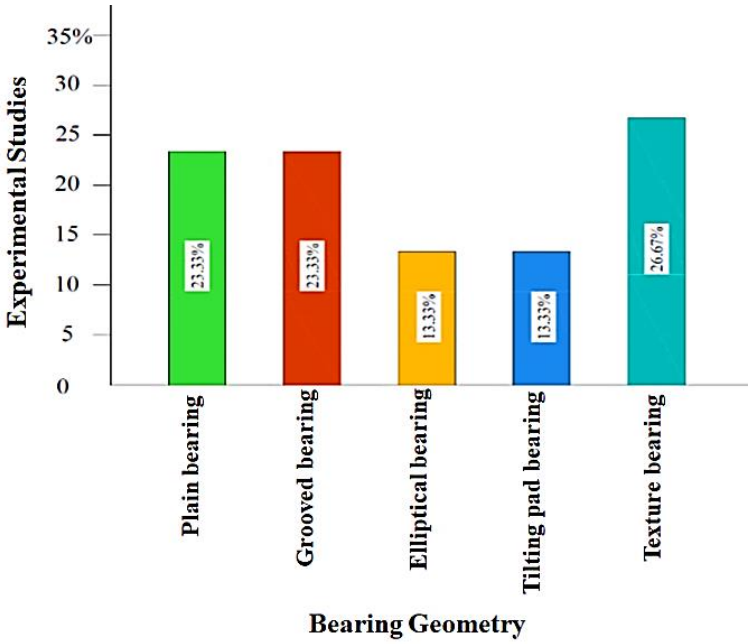

Figure 4: Experimental studies Vs different bearing geometries.

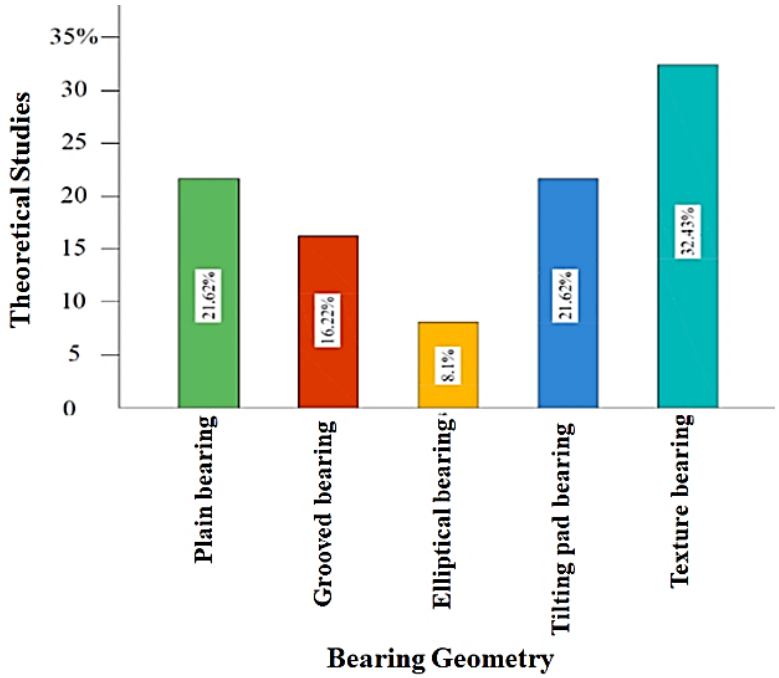

Figure 5: Theoretical studies Vs different bearing geometries.

Figure 6 is an outline of the uninterrupted series of research efforts exerted on the way towards promoting oil film performance concerning a wide range of journal bearing types. In regard to the experimental studies, working on enhancing lubricating oil film via oil film pressure profile apparently accounted for the largest percentage representing 35.5%. In comparison, research investigations employing Reynolds equation represented the greatest share of theoretical studies aiming at promoting oil film performance and accounted for a relatively higher percentage of 53.8%. Studies based on numerical analysis have however occupied the major percentage of 58.6 % exceeding their counterparts conducted theoretically by 27.8 %. On the other hand, the same figure illustrates that the fewest experimental researches were focused on all of the radial clearance, hybrid lubrication and static as well as dynamic load representing a percentage of roughly 3.2%. Furthermore, the least amount of research studies conducted via theoretical means has been in the side of both Navier stokes equation and Sommerfeld number by an equal percentage of 7.7%. Besides, researchers working on oil film performance enhancement numerically and employing Gambit and Comsol have assumed the same percentage of 3.4%. It is obvious that the percentage of experimental studies working on the oil film thickness and that related to numerical studies applying Mat-lab, Gambit and Comsol both acquired a levelled out percentage of 12.9 %. Also, the percentage of theoretical studies based on the theoretical analysis 30.8 % was considerably larger than its peer percentage for experimental studies utilizing friction coefficient 19.4 %. Finally, it is clear that the endeavors towards improving the oil film performance and focusing on the numerical analysis by far exceeded all other research study orientations over the covered period under study.

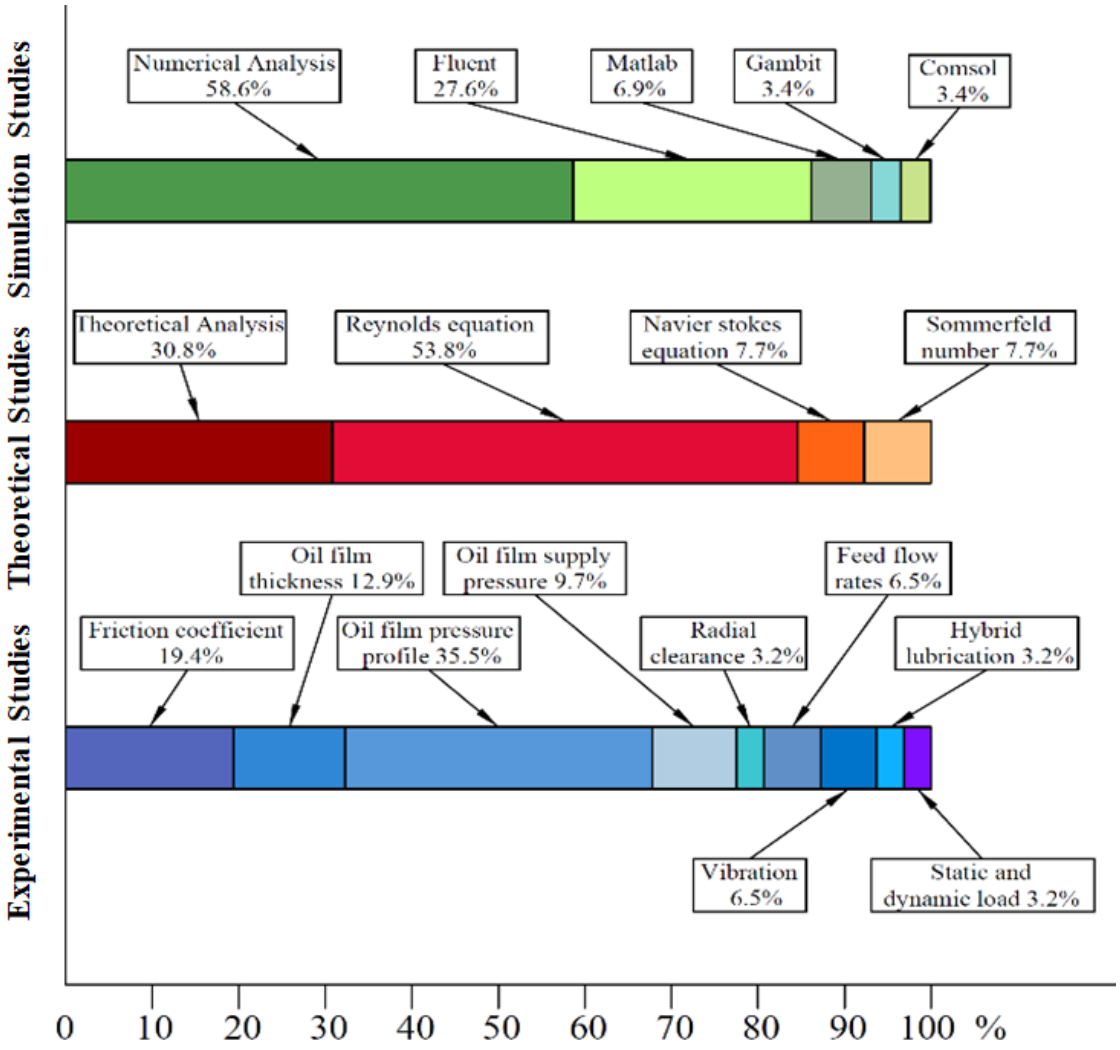

Figure 6: Results based on literature survey of different studies related to journal bearing.

6- Conclusion

A comprehensive survey of previous research endeavors regarding journal bearing performance enhancement based on innovative geometrical designs was thus carried out and reviewed. Notably, the vast majority of the scanned investigations under study worked on such objective depending on introducing novel modifications into surface texture patterns. The bulk of researches related to surface textured bearing accounted for the foremost efforts intended to realize tangible improvements in performance representing the percentages of 26.67 % and 32.43 % in terms of experimental and theoretical investigations respectively. All in all, the current investigation can be said to provide beneficial outcomes based on the analysis of the aggregated data. All such data provide useful guidelines for all those concerned with hydrodynamic lubrication within journal bearing. The analysis outcomes can as well be used to enhance and extend the limitations related to journal bearing design and construction as well as the performance of the lubricating oil film within journal bearing.

7- Recommended future works

Based on the obtained results and the relevant analysis, a number of considerations and design criteria observing surface texture techniques were acquired. Those will definitely be applicable and will as well be of much benefit in the potential future investigations into marine journal bearing. Accordingly, experimental studies utilizing Universal Journal Bearing Test Rig (UJBTR) (Marey et al., 2021) as well as other numerical investigations employing ANSYS Software (Marey et al., 2024) applications applying surface texture laser techniques are intended to be carried out in the near future aiming at effecting a tangible improvement in journal bearing performance for marine application specifically.

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Developments and research directions for collision avoidance in mixed navigation environment for MASS: A systematic literature review with bibliometric analysis.

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المستخلص

تُعزز تكامل التقنيات المتقدمة والعمليات التي تعتمد على تلقائية نقل البيانات وذلك في ظل الثورة الصناعة الرابعة، حيث أهمية الاتصالات بين السفن والبنية التحتية البحرية، وخصوصًا مع ظهور السفن البحرية السطحية الذاتية الحركة (MASS) .يوجد بعض الدراسات الحالية التي تعمقت في قوانين منع التصادم البحري (COLREG) وسفن الملاحة الذاتية، وتقييم المخاطر للملاحة البحرية لـMASS ،و لحصر و تحليل بعض هذه الدراسات، تم عمل مراجعة شاملة ونظامية للأدبيات وتحليل ببليومتري للدراسات الأكاديمية التي تتناول منع التصادم MASS داخل البيئات الملاحية المختلطة، تهدف هذه المراجعة إلى تقديم نظرة عامة موجزة عن التقدم الذي تحقق في البحوث الأكاديمية المتعلقة بالتحديات المرتبطة بـ MASS وسلامة الملاحة في البيئات الملاحية المختلطة. باستخدام مقاييس وأدوات تحليل لفهم مواضيع البحوث الأكاديمية، والتحديات الأساسية، والاتجاهات في هذا المجال. عن طريق استخدام *(PRISMA)*، بما في ذلك الكلمات الرئيسية في قاعدة بيانات *SCOPUS*. أظهرت النتائج أن الصين والنرويج وبولندا وكوريا الجنوبية هي الدول الرائدة في الأبحاث المتعلقة بالموضوع، استنادًا إلى العدد المُرْوَّج للمؤلفين. بالإضافة إلى ذلك، ظهرت مجلة Ocean Engineering ومجلة IFAC-Papers Online كأبرز المجلات للمنشورات في هذا الموضوع. من خلال الأدبيات المحللة، تم تحديد بعض المقترحات للبحوث المستقبلية.

ABSTRACT:

The integration of advanced technologies, data-driven processes, and automation under the Industry 4.0 revolution is fostering increased connectivity among ships and maritime infrastructures, particularly with the emergence of Maritime Autonomous Surface Ships (MASS) and the imperative for safe navigation. Despite existing studies delving into collision regulations (COLREG), autonomous navigation, and risk assessment for MASS navigation, a comprehensive systematic literature review and bibliometric analysis of academic research studies addressing collision avoidance in the context of MASS within mixed navigational environments has, to our knowledge, not been undertaken. This review aims to provide a concise overview of academic research advancements concerning the challenges associated with MASS and the safety of navigation in mixed navigational environments. To achieve this objective, we conducted a bibliometric analysis of pertinent studies, utilizing metrics and analysis tools to discern academic

research topics, primary challenges, and directions in this domain. Our approach adhered to the principles outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) for systematic literature reviews, incorporating tailored keywords in a Scopus search. The results revealed that China, Norway, Poland, and South Korea are the leading countries in MASS collision avoidance, based on the weighted number of authors. Additionally, Ocean Engineering and the Journal of IFAC-Papers Online emerged as the principal journals for publications on this topic. Through the analyzed literature, specific challenges were identified, paving the way for suggested avenues for future research.

Keywords: MASS, Collision Avoidance, Autonomous Navigation, Bibliometric Analysis, PRISMA

2- INTRODUCTION

Continuous technological innovation continues to enhance various facets of human existence. The advent of the Fourth Industrial Revolution (Industry 4.0) has notably strengthened the connectivity among ships, onboard systems, and associated infrastructure (Issa et al., 2022). Within the maritime industry, there is a discernible trend toward incorporating smart systems, particularly in safety-critical areas where artificially intelligent agents are poised to manage collision avoidance and grounding prevention autonomously (Jadhav et al., 2023a). This shift yields several advantages, including enhanced control over the functioning of marine systems, improved precision in monitoring their health, and more effective collaboration between ship and shore personnel. Moreover, it facilitates compliance with emission regulations and propels maritime operations towards greater automation, potentially involving crewless ships (Issa et al., 2022). Despite the ongoing emphasis on Maritime Education and Training and the enhancement of sensor capabilities, groundings and collisions continue to account for a significant proportion of marine accidents. In many instances, collisions result from human errors, leading to consequences ranging from moderate to severe and exerting a substantial impact on both the marine environment and life at sea (Martelli et al., 2023). Research indicates that human error remains a prominent factor in such incidents. Consequently, the maritime industry consistently explores novel autonomy approaches to address and mitigate this persisting issue (Jadhav et al., 2023b).

MASS have garnered substantial attention in recent years, primarily due to their appealing economic advantages and the potential to enhance safety. A key feature of MASS lies in its ability to leverage perception information, thereby replacing Officers on Watch (OOW) and enabling the implementation of varied navigation decisions through expert and intelligent systems (Wang et al., 2022). The introduction of unmanned or minimally manned autonomous ships contributes to reducing the exposure of individuals to risks at sea. Even in cases where autonomous navigation does not directly decrease the number of accidents, it signifies an enhancement in overall safety at sea (de Vos et al., 2021). Moreover, researchers tackle different aspects of research regarding collision avoidance for instance, (C.-C. Chou et al., 2022) presented an innovative model for objectively and quantitatively forecasting navigational risks associated with MASS. In a

complementary vein, (Li, 2023) developed a decision-making model tailored for collision avoidance (CA) involving numerous target ships (TSs). This model is grounded in the principles of ship collision avoidance geometry and the distinctive characteristics of collision avoidance among multiple target ships at sea. Meanwhile, (Liu et al., 2023) conducted a comprehensive review of current research on scene generation methods, with a specific focus on testing ship collision avoidance. The analysis encompasses simulation methods for collision avoidance models and algorithms, drawing insights from both domestic and international research. Furthermore, (Huang and van Gelder, 2020) provided an extensive overview of collision prevention techniques, centering on the fundamental processes of determining evasive solutions, namely motion prediction, conflict detection, and conflict resolution. On a different note, (Zhao and Roh, 2019) proposed an efficient method to address multi-ship collision avoidance challenges using the Deep Reinforcement Learning (DRL) algorithm. This method directly maps encountered ship states to an own ship's steering commands in terms of rudder angle using the Deep Neural Network (DNN). Lastly, (Wu et al., 2019) introduced a fuzzy logic-based approach for ship-bridge collision alerts, considering ship particulars, bridge parameters, and the natural environment.

(Zhou et al., 2024) presented a method for parametric modeling of encounter scenarios for ship avoidance testing in inland waterways, which is employed to automatically generate inland waterway ship encounter scenarios. (Guan et al., 2024) proposed an intelligent navigation approach leveraging PRM (Probabilistic Roadmap) and PPO (Proximal Policy Optimization) algorithms to enhance autonomous navigation and decision-making for collision avoidance in (MASS). (Cui et al., 2024) delved into the interactive collision avoidance challenges arising in mixed navigation scenarios involving both autonomous and manned ships, with the objective of ensuring efficient collision avoidance and safe navigation. The authors advocated for a multi-agent interactive ship dynamic game collision avoidance decision-making method. Within this framework, dynamic game theory is employed to portray individual ships as participants with independent decision-making capabilities, with course alterations representing strategic actions aimed at optimizing safety and socio-economic considerations. (Wang et al., 2024) examined a collision avoidance system tailored for autonomous ships navigating through intricate encounter scenarios, such as congested ports. This system integrates various sensors for object detection and environmental perception. To assist autonomous ships in handling complex and dynamic scenarios, a collision map is generated to depict encounter scenarios, serving as input for a deep reinforcement learning (DRL) model.

These studies aimed at understanding the general MASS collision avoidance challenges in mixed environments, researchers strived to solve different challenges using different techniques and algorithms. Risk assessment models have been proposed, as decision-making systems, fuzzy logic algorithms, and reinforcing deep learning techniques like artificial neural networks. None of the currently available review studies implemented a comprehensive analysis and a thorough bibliometric analysis of the research studies published on the topic of MASS Collision Avoidance. There is a need for a review that would offer a succinct description of the progress in the rising

topic of collision avoidance, summarize the current state of knowledge with a focus on the scientific methods, and distill the findings provided in the various research papers with a focus on the future research and known methodological challenges. The aim of this review is therefore to attempt to answer the following Research Questions (RQs) related to MASS collision avoidance research:

RQ1: What are the primary countries, authors, cluster topics, and relevant journals based on scientific publications' bibliometric analysis?

RQ2: What methodological challenges are reported in these studies and what future research directions do they lead to?

The RQ1 aims at identifying the achieved progress in the topic of autonomous ship navigation in different countries, journals, and established networks of cooperation, RQ2 at the known challenges and potential future research in the area. In this way, a brief description of the progress in collision avoidance of MASS in mixed navigation challenges and future research directions can be realized which is of great support for novel and experienced researchers in the field.

This paper is structured as follows. First, the literature review and bibliometric analysis methodology are presented. Then the investigated research questions are answered using the presented methodology. The paper's limitations are also provided. Finally, we summarize the main review findings in the conclusions section.

3- METHODOLOGY

The review methodology employed in this article adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Liberati et al., 2009), a structured approach for conducting systematic literature reviews. While there are various techniques available for literature reviews, we chose PRISMA due to its widespread use, systematic nature, and user-friendly methodology. In this study, we tailored the PRISMA methodology to address the research questions outlined in the introduction section. The information flow, guided by the PRISMA methodology, is depicted in **Figure 1**, with detailed steps elucidated in the subsequent sections. The same figure also provides information on the number of identified publications and the final selection process.

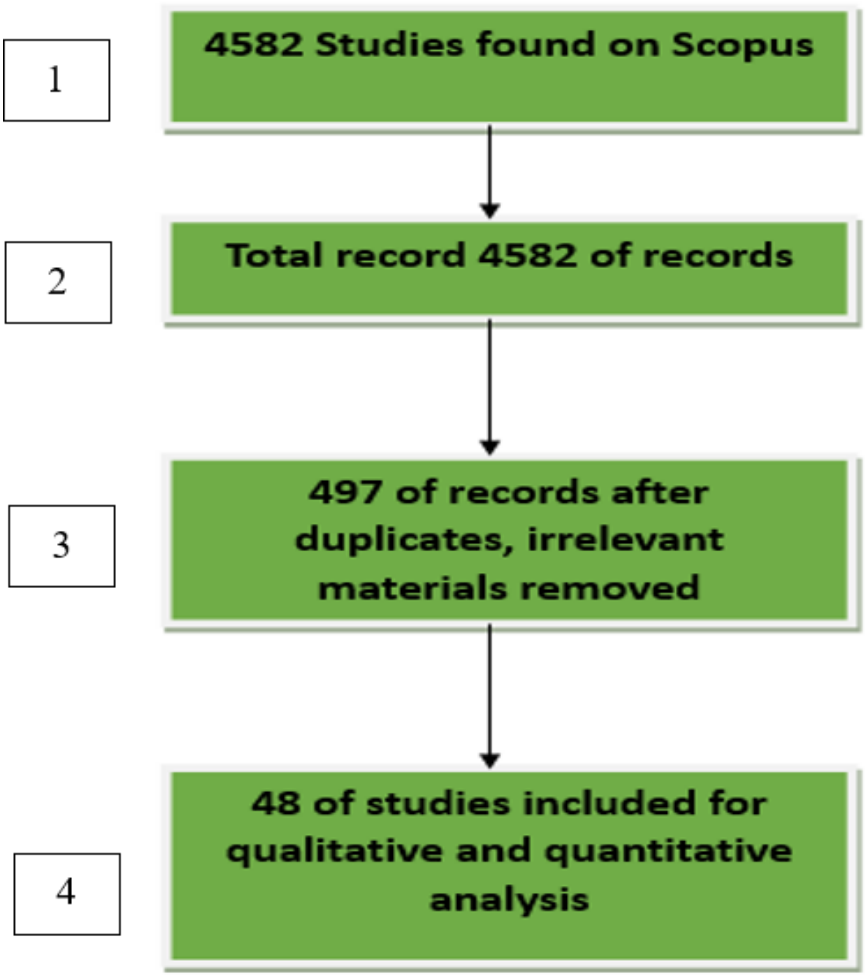

Figure 1: The flow of information through the different phases of systematic literature review. (numbers as of Dec 2023)

Step 1: Identification of research studies

Scopus is used as search engine to find relevant studies. Google Scholar was not used because the results it provided included many publications of low quality, ones that weren't peer-reviewed or were intended for a broader audience rather than an academic one, which is what we were specifically looking for. This decision was made to ensure the focus on scholarly and peer-reviewed sources in our research. Also, identification for the relevant publications in a series of journal publishers is not conducted as the returned results were overwhelmingly large in number including many irrelevant publications, Therefore, by using Scopus we ensured broader coverage. By using the term "Autonomous ships" 4582 entries were received in response, For the identification process generic keywords as below were used as a topic filter for the main keyword:

1. Collision avoidance
2. Autonomous navigation
3. MASS

Autonomous ships are used as a keyword in combination with other keywords during identification as the observant results, although largely similar, included some additional valuable references. Also, it was noticed that the first two keywords collision avoidance and autonomous navigation contributed to the identification of the most research studies that were included in this analysis, So, when the additional keyword MASS was used, a significant number of additional studies was identified. However, very few research studies were additionally included for the collision of MASS in a mixed navigation environment, considering these similar search results, we did not perform research in Scopus for additional keywords that could be additionally considered.

Step 2: Screening of research studies

The screening process aimed to narrow down the number of identified publications for a more in-depth analysis of the most pertinent ones. This involved reviewing the title, abstract, and if needed, a brief overview of the content. The focus was on determining if the research study investigated Collision avoidance of MASS with manned vessels in mixed navigation environments. Additionally, duplicate references were identified and removed during this step. Books were intentionally excluded from the analysis due to their tendency to provide review opinions, limited accessibility, and heavy reliance on findings from previously published conference papers and journal articles. To facilitate further filtration and data analysis using bibliometric methods, the search results were exported to a CSV file. Following the screening, a significant number of initially identified research studies were excluded. Unfortunately, a few relevant studies were inaccessible and had to be excluded as well.

Step 3: Suitability assessment of research studies

In evaluating research studies for suitability, Thorough analysis to the screened studies is conducted and the most fitting ones are chosen for further examination. specific criteria are determined for this, considering where the study was published (whether it was in a reputable journal), the importance of its content (like practical implications and if it showed innovative results), and the reliability of its research methods and results (checking for a meaningful and logical approach and conclusions). To assess journal publications, Scimago's journal ranking is used, and only a few Scopus-indexed journal publications were excluded to ensure we focused on high-quality research. Conference papers were not excluded altogether, as valuable contributions are found in the review. For assessing conference papers, the same criteria are applied. In this step, most of the screened research studies is considered in the analysis to gather diverse perspectives and have enough material to answer our research questions and conduct bibliometric analysis.

Step 4: Included research studies analysis

In the final stage, Bibliometric analysis for the chosen and qualified studies is employed. These particular research studies were exclusively utilized to address the research questions, and the detailed analysis process is outlined in the following sections.

To assess the impact of each country, specific scores/metrics in our analysis of the included research studies are utilized. These metrics encompassed the total number of authors included across all papers, weighted by the overall publication count of the 48 publications. In this analysis,

if an author from a particular country contributed to multiple papers (x times), their contribution was considered x times. The affiliation of each author at the time of publishing, as indicated in the paper, was considered for the analysis, not their actual nationality. In cases of double affiliation, only the first affiliation is counted. Microsoft Excel facilitated this analysis. Additionally, we explored the most prevalent journals covering topics related to MASS collision avoidance, using the number of published articles as a metric, without considering citation counts. Our analysis focused on Scopus-indexed references and top journals, aligned with the Scimago ranking used for eligibility assessment. We employed bibliometric analysis using the open-source software VOS viewer for keywords and term analyses.

For term analysis, we employed the full counting method, which tallies the occurrences of a term in the articles and accord more weight to frequently mentioned keywords.

This marks the final, so far significant, contribution of this article. The identification of challenges involved a thorough examination of the introduction, methodology rationale, and limitations/discussion sections within the inspected publications. To pinpoint directions for future research, the selected studies are analyzed, with particular attention to the discussion, conclusions, and future research sections.

5- Results and Discussion

Figure 2 presents the leading research countries based on the considered metrics, specifically the total weighted number of authors. The legends for the top 10 countries are also provided within the same figure. Notably, countries such as China, Norway, Poland, and South Korea emerge as the primary contributors, as indicated by the metric of the total weighted number of authors in the selected papers. Among the top 10 identified countries, the first four, comprising China, Norway, Poland, and South Korea, account for the majority of contributions to research in MASS collision avoidance, representing 60% of the selected Scopus-indexed publications. This distribution closely aligns with the Pareto principle, suggesting that a substantial portion of the final output (60%) is derived from a smaller percentage of the total input (30%) involving these four countries (Wicksteed and Pareto, 1906). Additionally, it is noteworthy that the majority of researchers referenced, consistently publishing in Scopus-indexed sources, are situated in Europe, with the exception of China and South Korea.

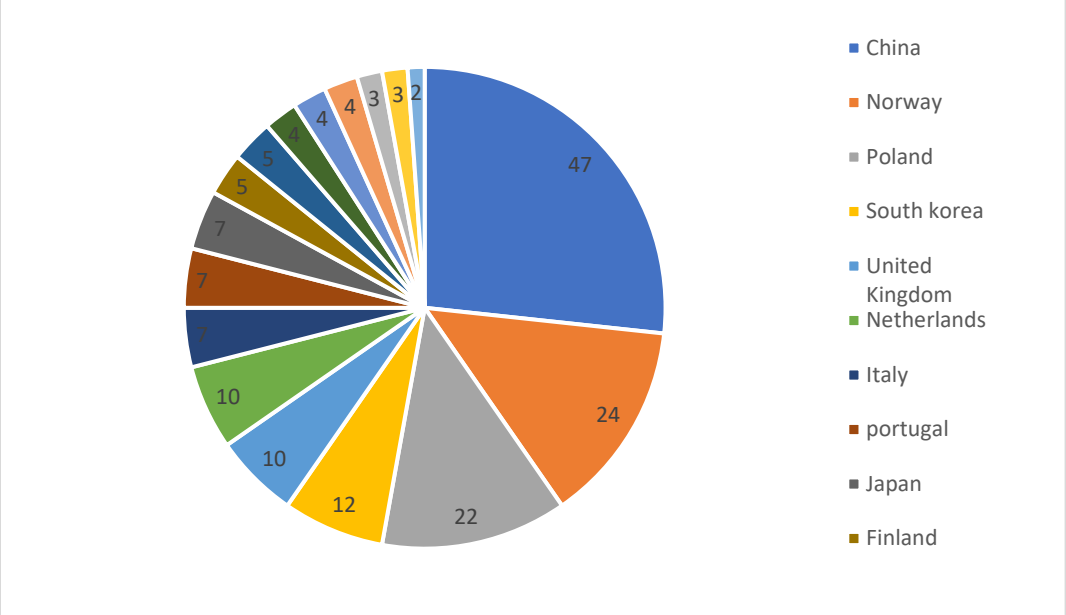

Figure 2: The total weighted number of authors for top countries.

Table 1 shows the top authors with their affiliations and their number of publications. it is noted that China and specially Wuhan University has the top authors publishing in the Topic of MASS collision avoidance which support the finding of the top countries. Moreover, it has been appeared from the number of publications that this topic is a new arising topic under development and needs more attention in the research field.

Table 1: Top Authors with their affiliations

Author	Affiliation	Number of publications
Guedes Soares C.	Universidade de Lisboa, Lisbon, Portugal	3
Lazarowska A.	Gdynia Maritime University, Poland	3
Perera L.P.	University of Lisbon, Portugal	3
Arshad M.R.	Universiti Sains Malaysia (USM), Malaysia	2
Chen P.	Wuhan University of Technology, China	2
Chu X.	Wuhan University of Technology, China	2
Cristofaro A.	University of Camerino, Italy	2
Perez T.	Queensland University of Technology, Australia	2
Mei J.H.	Hebei University, China	2
Zaccone R.	Polytechnic School of Genoa University, Italy	2

Figure 3 presents the most prevalent journals based on the number of selected Scopus-indexed publications focusing on MASS collision avoidance. Notably, Ocean Engineering emerged as the primary journal accommodating a significant number of articles considered in this review. Following closely is the Journal of IFAC-Papers Online, while several other journals, including WMU Journal of Maritime Affairs, Safety Science, and Sustainability (Switzerland), also reported publications on MASS collision avoidance. The figure underscores that authors exhibit a preference for publishing across a diverse array of journals, possibly indicative of the absence of highly specialized journals dedicated to MASS. Given the novelty of the topic, such diversity in journal selection should not come as a surprise.

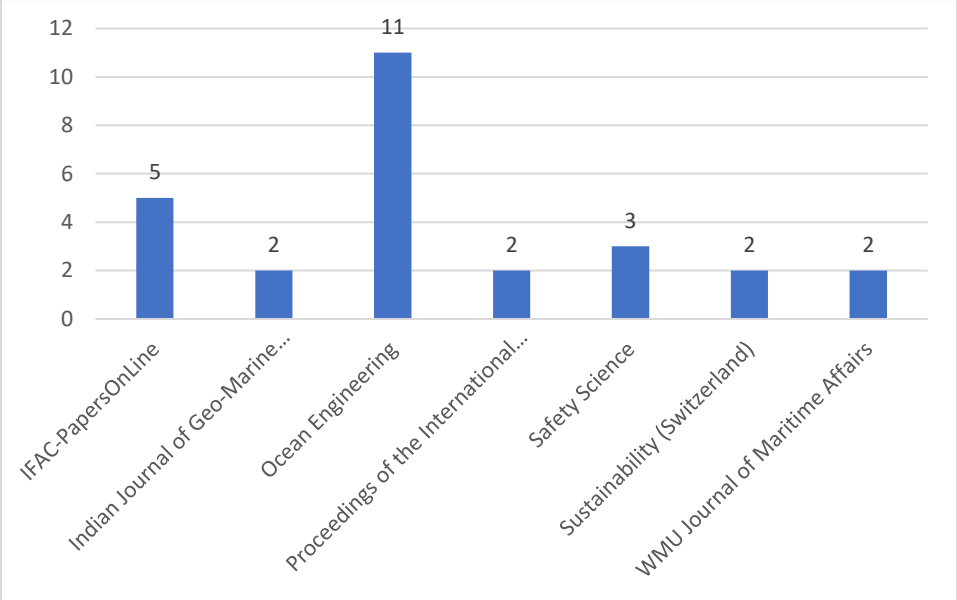

Figure 3: The journals with the most articles related to MASS collision Avoidance

Figure 4 and **Figure 5** display the outcomes of the bibliometric analysis conducted using VOSviewer. These figures illustrate the results of the co-occurrence of terms analysis and Author Keywords Analysis, respectively. The full counting method, as opposed to the binary counting method, was employed to assign greater weight to keywords occurring more frequently. In the first analysis, a total of 1296 keywords were identified, and subsequent filtration resulted in the selection of 26 keywords, each with a minimum of 7 occurrences. For Author Keyword analysis, 155 words were identified, and after filtration, 17 keywords were chosen, each with at least 2 occurrences. The term analysis reveals connections between terms (keywords) that commonly occur together. In addition to evident terms such as "autonomous ship," "MASS," and "collision avoidance," other frequently appearing terms encompass "algorithm," "path planning," "decision support," "hazard," "risk," "situation awareness," "cybersecurity," and "reliability." A closer examination of the keyword analysis suggests that researchers frequently deliberated on methodology, approaches, and risk assessment. There is a notable emphasis on addressing issues related to uncertainty, risk evaluation, situation awareness, and the applicability of different methods.

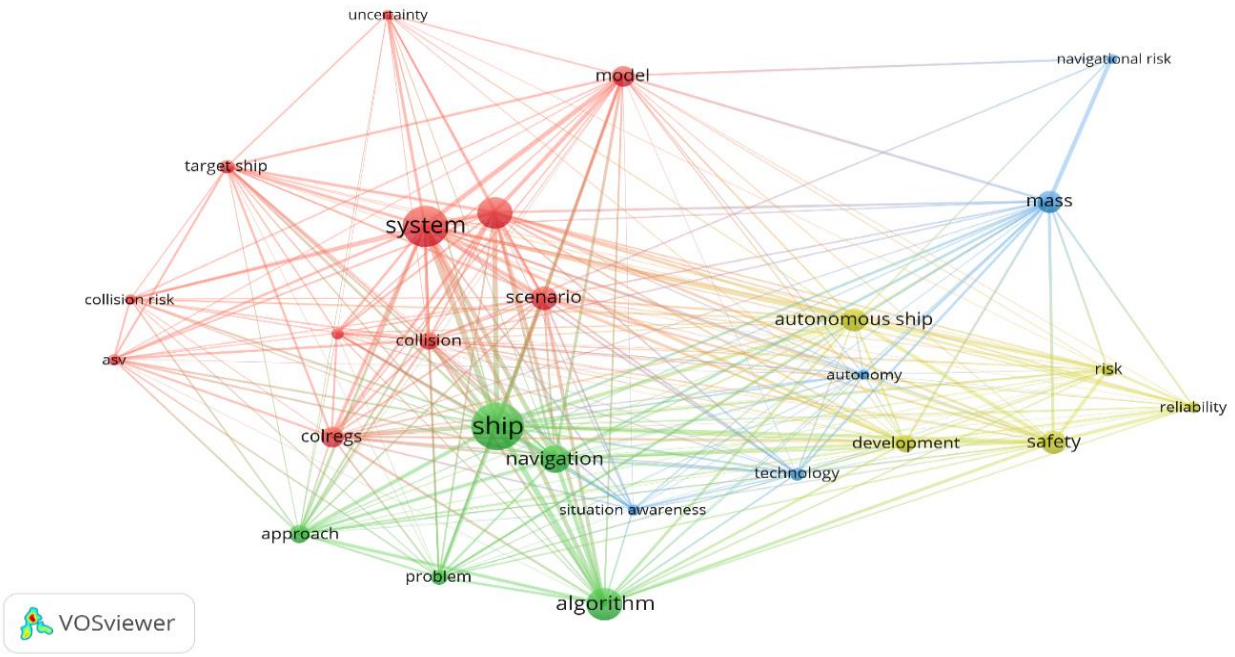

Figure 4: Term analysis map using full counting method, including 26 out of 1296 keywords.

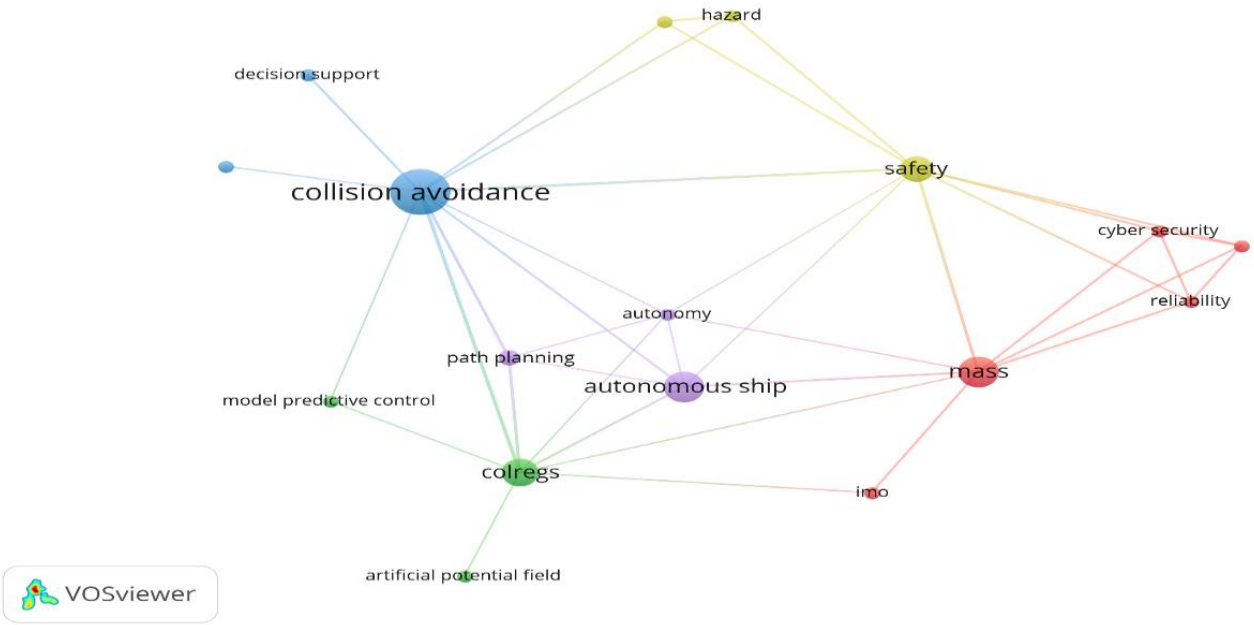

Figure 5: Author Keywords analysis using full counting method, including 17 out of 155 keywords.

Future Research Recommendations

Based on the investigated papers several challenges and research directions and topics were identified. (Papageorgiou et al., 2022) determined 2 considerations into the current scheme of research related to MASS collision avoidance which are: the overall maneuverability capabilities of a target, and the maneuverability restrictions imposed by the geographical properties of the area surrounding the target vessel. (Huang et al., 2020) claimed that the boundaries of the predicted trajectories need further studies, better risk assessment methods are expected and Collision resolution needs more studies in safety validations and extreme conditions for different methods. (C. C. Chou et al., 2022) proposed that in order to reduce efficiently the navigational risk of MASS, future researches must integrate efficiently the path planning algorithms, data sensors, navigational equipment on board and the whole COLREGs.

5- Conclusion

This article conducts a systematic literature review and bibliometric analysis of research studies in Scopus related to MASS collision avoidance. The bibliometric analysis aids in identifying leading countries, prevalent journals, and researchers (RQ1). Additionally, an examination of the analyzed papers reveals research challenges and sets directions for future research (RQ2). Consequently, the article succinctly summarizes advancements in MASS collision avoidance through academic publications. Key findings include:

- China, Norway, Poland, and South Korea demonstrate the highest contributions based on the number of Scopus-indexed publications, with Europe leading in authors with two or more articles.
- Ocean Engineering and the Journal of IFAC-Papers Online boast the highest publication numbers.
- The annual scientific publications on MASS collision avoidance exhibit a consistent upward trend, accompanied by an increase in research topics' diversity and employed methodologies since 2019.
- Several research directions have been identified.

The results from the bibliometric analysis offer valuable insights for policymakers, shedding light on research groups, collaborations, and the direction of research. This information can inform decisions regarding future investments in research. The identified research studies, methodological challenges, and proposed research directions serve as a foundation for conducting focused and innovative research in this domain.

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