مركز الأكاديمية للنشر

ACADEMY Publishing Center

MRT
Maritime Research & Technology Journal

Volume 2 - Issue 1 - June 2023 - ISSN 2812-5622

Academy Publishing Center

MRT Maritime Research and Technology First edition 2022

مركز الأكاديمية للنشر
ACADEMY Publishing Center

Arab Academy for Science, Technology, and Maritime Transport, AASTMT
Abu Kir Campus, Alexandria, EGYPT
P.O. Box: Miami 1029
Tel: (+203) 5622366/88 – EXT 1069 and (+203) 5611818
Fax: (+203) 5611818
Web Site: http://apc.aast.edu
Email: apc@aast.edu

MRT Volume 2, Issue 1 (June 2023)
eISSN: 2812-5622
pISSN: 2812-5614

MRT Maritime Research and Technology

Maritime Research and Technology (MRT) journal is a biannual international peer-reviewed journal which presents a global forum for dissemination of research articles, case studies and reviews focusing on all aspects of the maritime sector and its role in sustainable development.

MRT publishes original research papers in English analysing the international, national, regional or local maritime industry. MRT includes both theoretical and empirical approaches to topics of current interest in line with the editorial aims and scope of the journal. The objective of MRT is to contribute to the progress, development and diffusion of research in the maritime industry.

The manuscripts presented must be unpublished works, which have not been approved for publication in other journals. They must also fulfil all the requirements indicated in the 'Technical Specifications' section. The quality of the papers is guaranteed by means of a process of blind review by two scientific referees and one linguistic reviewer. Although the journal is published in print format, the processes of submission and reception of manuscripts, as well as revision and correction of proofs, are all done electronically.

The journal is open-access with a liberal Creative Commons Attribution, Non-Commercial 4.0 International License which preserves the copyrights of published materials to the authors and protects it from unauthorized commercial use.

The MRT journal does not collect Article Processing Charges (APCs) or submission fees, and is free of charge for authors and readers, and operates an online submission with the peer review system allowing authors to submit articles online and track their progress via its web interface.
The journal is financially supported by the Arab Academy for Science, Technology and Maritime Transport (AASTMT) in order to maintain a quality open-access source of research papers on Maritime Research and Technology.

MRT has an outstanding editorial and advisory board of eminent scientists, researchers and engineers who contribute and enrich the journal with their vast experience in different fields of interest to the journal.

National Advisory Board

Administrative board

Table of Contents

Maritime Research and Technology
MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.001

Towards Enhancing Major Emergency Initial Response Training: A Comparative Study of the STCW and OPITO Standards

Sherif Aly [1a], Hossam Eldin Gadalla [2a] and Ahmed Mohamed Ismail [3a]

[1] Head of OPITO Training Unit, MSI
[2] Head of Quality and International Accreditation Unit, MSI
[3] Maritime Lecturer, MSI
[a] Arab Academy for Science, Technology & Maritime Transport
Abukir, Alexandria,

Emails: cpt_sherifali@aast.edu, hossameldin1@gmail.com, capt_ahmedismail@aast.edu

Received on: 10 November 2022 Accepted on: 04 December 2022 Published on: 01 March 2023

ABSTRACT

Purpose: *The maritime industry has been recognized as a high-risk domain due to its multiple operational risks. This aspect imposes significant challenges to the human element onboard especially in the case of major emergencies when the prompt response of the ship's Master and Officers becomes crucial in controlling the situation and preventing the escalation of threats. In response, the IMO Standards of Training, Certification and Watchkeeping (STCW) 95/2010 convention has developed a range of emergency response competencies. However, data on accidents and incidents in shipping reveal that the human element is still considered a primary factor contributing to most cases of ship loss. Furthermore, several cases have been reasoned for the improper and ineffective management of the emergency. This might raise serious concerns regarding the adequacy of IMO model courses to provide learners with the required knowledge, skills, situational awareness, and confidence to appropriately respond should a real major emergency occur.*

Design/Methodology/Approach: *With the aim of enhancing the current level of maritime emergency management training, the authors of this study intended to identify possible gaps in current STCW training by comparing similar emergency response training standards established by the Offshore Petroleum Industry Training Organization (OPITO). The Qualitative analysis was used to compare three case studies of emergency-related STCW courses with two OPITO-approved courses in terms of their aims, scopes, principles, outlines, number of delegates, outcomes, decision-making processes and assessment criteria. The objective is to assess whether the OPITO emergency response training provides more extensive scope for ensuring the optimum management of an extended range of emergency events rather than the currently presented STCW courses.*

Findings: *The study is concluded by identifying possible gaps and proposing specific modifications to the STCW standards which can be marked as a first step in the direction of establishing effective training for managing and controlling major emergencies onboard.*

Key-words:
Emergency, Response, Training, STCW, OPITO, Comparison.

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.001

1. INTRODUCTION

The maritime industry has been characterized as a high-risk domain because of its various risks and the complexity of its multiple associated operations (Dominguez-Péry C. et al. ,2021).

Recognizing the significant role of the human element in the activities of maritime transport has led to regular improvements in maritime safety training and crew proficiency (Allianz, 2012).

However, the human element has been recognized as a major contributor in more than 75% of maritime accidents (Sánchez et al., 2021). In response, the human element has been acknowledged by the International Maritime Organization (IMO) as a key component of the safety of life on board ships, thus focusing on the human aspect has to be seriously considered for enhancing maritime safety (IMO, 2019a).

Driven by this aim, the Standards of Training, Certification and Watchkeeping (STCW) convention has been adopted by the IMO in 1978 as the first international convention to set the minimum competency requirements for seafarers. Furthermore, realizing that handling major emergencies on ships is a challenging task that could be carried out in very stressful and harsh working conditions, the IMO through its STCW convention has established a wide range of training courses to equip learners with an adequate level of knowledge and skills to timely and effectively respond should a major emergency occur.

In this regard, the ships' Masters and Officers have been given particular attention for their crucial role in managing emergencies on ships without or with limited external assistance in most cases. The convention's objective is to provide the foundations for internationally consistent training standards to enable the Master, being the emergency manager, to carry out his responsibilities for evaluating the situation, defining the appropriate response, and ensuring that the initial action is carried out and a plan is formulated, where the emergency management team must support and back up his decisions (IMO, 2019b).

Recently, in its resolution A.1110 (30), the IMO adopted requirements for human capabilities, limitations and needs in a six-year strategic plan from 2017 to 2023 (IMO, 2017a). However, despite this effort, the human element is still contributing significantly to ships' losses. As demonstrated in Figure (1), the loss of 805 vessels out of 1036 that have been either sunk, wrecked or collided during the period from 2009 to 2018 has resulted from improper ship command, and inadequate bridge team management (Neff, 2020 : P.21). This ratio raises serious doubts regarding the adequacy of IMO model courses to empower learners with the necessary level of knowledge, skills, situational awareness and confidence for performing the appropriate response should an actual major emergency occur.

The number includes only the cases of ships' total losses whereas other accidents that have not led specifically to the loss of vessels have not been counted. This means that the actual number of accidents could be significantly higher. Although there is a decline in ship losses, the number of incidents and accidents is still high (Neff, 2020 : P.21).

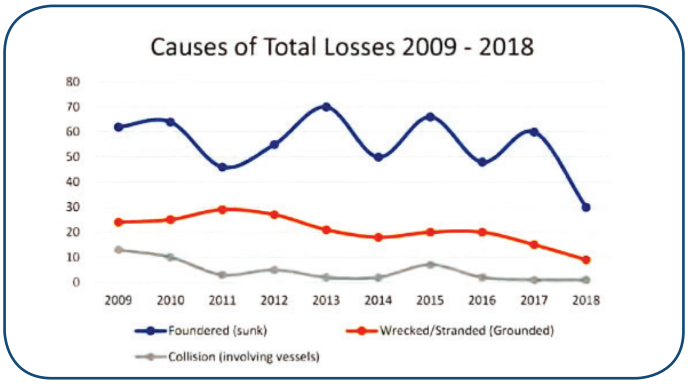


Fig. 1. Causes of total losses of ships (2009-2018)
Source: (Neff, 2020: P.21)

Similarity of Emergency Types in the Oil & Gas and Maritime Industries

In order to enhance decision-making capacities and decrease the likelihood of major ship losses, it is imperative to identify the gaps in current STCW training for emergency management. This could be achieved by analyzing how other high-risk industries prepare their onboard personnel to face similar types of emergencies. In Oil & Gas industry, the Offshore Petroleum Industry Training Organization (OPITO) has established two levels of simulator-based training programs which are specifically concerned with the initial response to a set

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.001

of major emergencies encountered onboard oil and gas installations. The two training standards are the Major Emergency Management Initial Response (MEMIR), and the Offshore Installation Manager Controlling Emergency (OIMCE) training. The common objective of both courses is to boost the performance and confidence of participants through a high-fidelity simulation of actual characteristics of emergencies (OPITO, 2019).

When comparing the common types of emergencies in the Oil & Gas industry with those in maritime transport, a significant level of similarity could be observed throughout a wide array of emergency cases as demonstrated in Table (I). The differences could be only spotted in limited specific types of emergencies that reflect the operational nature of each industry. This can be viewed in the drilling and production of offshore installations where the blowout of wells or release of toxic gases would be highly anticipated, or as in the cargo-related emergency types onboard cargo ships.

Table I : Comparison of Applicability of Emergency Types in O&G and Maritime industries

No.	Emergency Types	Oil & Gas	Maritime Transport
1.	**Well control incident**	Applicable	N/A
2.	**Explosion and fire**	Applicable	Applicable
3.	**Helicopter incident**	Applicable	Might occur, but not in the routine operation
4.	**Pipeline incident**	Applicable	Oil spill
5.	**Collision or wave damage**	Applicable	Applicable
6.	**Loss of stability (Flooding)**	Applicable for the semi-submersible units	Applicable
7.	**Hydrocarbon release**	Applicable	N/A
8.	**Scaffold collapse**	Applicable	Applicable
9.	**Security threat piracy**	Applicable, with a low probability	Applicable, with a high probability
10.	**Dropped load or dropped object**	Applicable	Applicable, in port during loading and discharging
11.	**Chemical release (Pollution)**	Applicable	Applicable, in chemical Tankers
12.	**Person overboard, injury or Epidemic**	Applicable	Applicable
13.	**Grounding & stranding**	Applicable, but rarely happen	Applicable
14.	**Main Engine Fails, Steering Fails**	Applicable for Self-propelled or towed rigs.	Applicable
15.	**Cargo Related Emergencies**	Not Applicable	Applicable

Source: (OPITO, 2022A), (RØdseth, 2012)

Inspired by the significant similarity of emergencies in both the maritime and O&G industries, not least the fact that both demand professional and highly qualified command, the authors of this study intended to identify possible shortcomings in the current STCW training standard in terms of initial emergency response training by conducting a comprehensive comparison with a similar globally recognized OPITO training standard established for achieving the same goal.

For a systematic research plan, the authors seek to first analyze the foundational concepts of three STCW courses and two OPITO-approved training courses as case studies in terms of their structures, and main principles. Secondly, compare the contents of each standard's criteria to elucidate similarities and differences in terms of aims, scopes, principles, outlines, decision-making processes, and assessment to subjectively assess the extent of each standard's

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.001

requirements. Finally, proposing specific modifications to the current STCW training standards to equip the ship's decision-maker with the optimum emergency response-related skills.

The Emergency Training Criteria for Master as per the STCW Convention

The ship's Master has the overriding authority onboard, he is in command and takes full responsibility for the safety and security of assets, personnel, cargo, and environment. The chief officer might carry all these responsibilities at any time, therefore, should have the same adequate level of training. Figure (2) indicates table A-II/2 for function controlling the operation of the ship and care for the Management Level through four columns: competence, knowledge understanding and proficiency, methods for demonstrating competence, and criteria for evaluating competence (IMO, 2017b : P.124).

STCW CODE A II

Table A-II/2 *(continued)*

Function: Controlling the operation of the ship and care for persons on board at the management level *(continued)*

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Maintain safety and security of the ship's crew and passengers and the operational condition of life-saving, fire-fighting and other safety systems	Thorough knowledge of life-saving appliance regulations (International Convention for the Safety of Life at Sea) Organization of fire drills and abandon ship drills Maintenance of operational condition of life-saving, fire-fighting and other safety systems Actions to be taken to protect and safeguard all persons on board in emergencies Actions to limit damage and salve the ship following a fire, explosion, collision or grounding	Examination and assessment of evidence obtained from practical instruction and approved in-service training and experience	Procedures for monitoring fire-detection and safety systems ensure that all alarms are detected promptly and acted upon in accordance with established emergency procedures
Develop emergency and damage control plans and handle emergency situations	Preparation of contingency plans for response to emergencies Ship construction, including damage control Methods and aids for fire prevention, detection and extinction Functions and use of life-saving appliances	Examination and assessment of evidence obtained from approved in-service training and experience	Emergency procedures are in accordance with the established plans for emergency situations

Fig. 2: Management level controlling the operation of the ship as per STCW

Source (IMO, 2017b : P.124)

In column (1) for competence in developing emergency and damage control plans and handling emergencies, the only methods for demonstrating competence are from the in-service training and experience where simulation is not considered as a means of demonstrating competence in decision making for emergency response, which is an important element to be considered.

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.001

SIMULATION TRAINING IN THE STCW CONVENTION

According to the STCW requirement, a wide range of training courses are related to bridge simulation. However, the only mandatory courses are limited to the Automatic Radar Plotting Aids (ARPA) course, and the Radar and Electronic Chart Display and Information Systems (ECDIS) (International Transport Work Federation, 2010 : P.29). Furthermore, either onboard training or onboard experience is accepted by the STCW as evidence of compliance. On the other hand, the simulator could be an equivalent option to cover navigation, ship handling, cargo handling, and Global Maritime Distress Signals System (GMDSS) communication. (International Transport Work Federation, 2010 : P.29). Figure (3) illustrates the Master position with the competency table as per the STCW standard. The evidence of competency might be in the form of a certificate, endorsement, documented proof, or training received while on board. Some positions require revalidation, while others do not (International Transport Work Federation, 2010 : P.29).

Master

NAME OF CERTIFICATE	REVALIDATION	REG.	
National certificate of competence and endorsement	Yes	I/2, II/2,	C/R
Flag state endorsement of recognition	Yes	I/10	E/R
GMDSS endorsement	Yes	IV/2	C/R
Basic safety training - Personal survival techniques - Fire prevention and fire fighting - Elementary first aid - Personal safety and social responsibility	Achieved within previous five years	VI/1	D/P
Medical first aid	No	VI/4	D/P
Survival craft and rescue boats	Yes	VI/2	D/P
Advanced fire fighting	Yes	VI/3	D/P
Medical fitness	Yes	I/9	C/R
Basic safety familiarisation	On assignment	VI/1	T/O
Ship specific familiarisation	On assignment	I/14	T/O
Security familiarisation	On assignment	VI/6	T/O

C/R certificate required. D/P Documentary proof. T/O Training onboard. E/R Endorsement required.

Fig. 3. Master competency table
Source: (International Transport Work Federation, 2010 : P.29)

According to STCW 2010 amendments, in force since the first of January 2017, Ships' Masters and Chief Mates of 500 gross tonnages and above should have adequate knowledge of bridge resource management, in addition to the application of leadership and managerial skills. In this manner, the training courses for emergency management are involving the "Bridge Resource Management" STCW model course (1.22), the "Leadership and Managerial Skills" STCW model course (1.40), and the "Leadership & Teamwork" STCW model course (1.39).

Bridge Resource Management Training

The STCW 1978 convention, as amended in tables A II/1 and A II/2, stated that in order to maintain a safe navigation watch, the duty officer should have adequate knowledge of Bridge Resource Management (BRM). In addition, the STCW Code B-VIII, Part 3-1: Guidance on keeping a navigational watch advises shipping companies to implement the BRM concept on board their vessels (IMO, 2017b). Nevertheless, the human factor is still the major contributor to maritime accidents.

In this regard, improving the Non-Technical Skills (NTS) of the human element could be significantly vital for achieving the optimum utilization of bridge resources. To address this issue, one of STCW's main objectives is to equip bridge teams with adequate NTSs for establishing effective bridge management in normal and emergency situations (IMO, 2017b). Driven by this objective, the bridge resource management course emphasizes the development of bridge teams' soft skills as a vital component for the effective performance of technical duties on board.

The BRM objectives are achieved when learners become able to demonstrate the optimum utilization of all available resources, establish effective communication, assertiveness with leadership, situational awareness, and consideration of team experience and navigation familiarization (IMO,2020b). For this purpose, a ship handling simulator is utilized in the BRM training with specific requirements as demonstrated in Table (II).

Table II: Requirements of the Simulator

1	Course indicator	7	Relative wind direction & speed indicator
2	Speed indicator	8	One means of positioning
3	Rudder angle indicator	9	One ECDIS connected to the navigation system
4	Rate of turn indicator	10	VHF connected to the instructor
5	Engine RPM indicator	11	Internal telephone to the engine room
6	Propeller & Pitch indicator	12	Means of producing the sound signals

Source (IMO, 2020b)

Furthermore, the simulated ship model should be close in terms of dimensions and manoeuvrability characteristics to the trainee's vessel. The training involves demonstrating the use of engines and rudders in different situations with high traffic and at various speeds. Accordingly, the simulator should match the prerequisites of the target group with a maximum number of five participants to achieve the following outlines (IMO, 2020):

- Resource management
- Effective communication
- Assertiveness and leadership
- Obtaining and maintaining situational awareness
- Consideration of team experience
- Navigation familiarization

Ultimately, the BRM practices are meant to improve decision-making accuracy along with skills, technical knowledge, and experience. However, this could be obstructed by multiple factors such as the uncertainty of the situation due to lack of information, time stress, complexity with multi-risks, and personality.

During practical sessions, it is preferred to have a homogeneous distribution of ranks which provides a more effective environment for discussions. In this manner, lecturers should ensure that all trainees have the opportunity to express themselves regardless of their duty in the bridge simulator. A non-technical skills session should be delivered through workshops rather than in a teaching classroom.

Additionally, the quality of decisions has to be reviewed and the outcomes must be compared to the plan. Arguments for effective decisions and detecting error chains must be discussed. Instructors should also demonstrate the hidden pressure over the decision-making process while ensuring that the three levels of situational awareness; perception, comprehension, and projection have been followed (IMO, 2020b).

Finally, the assessment planning should recognize the "SMART" concept (Specific, Measurable, Achievable, Realistic, and Time-bound) through observations, written assessments, assignments, activities, projects, tasks/case studies, simulations, and computer-based tests. Familiarization sessions should be conducted in advance to ensure that trainees are familiar with navigation policy requirements and passage plans.

During the assessment process, the behaviour of the bridge team should be analyzed. Briefing and debriefing sessions are conducted for describing the tasks performed during the exercise with an emphasis on the possibility of encountering emergencies during the exercise to identify gaps. Eventually, trainees would be considered competent when they achieve the minimum competence criterion, otherwise, further improvement, guidance, or evaluation are required (IMO, 2020b).

Leadership and Teamwork Training (LTWT)

The LTWT training course is designed for promoting the application of leadership and teamwork at the operational level. The objectives are meant to provide learners with the knowledge and skills needed for carrying out the duties of the Officer of the Watch (OOW). In line with LTWT, operational knowledge for on-board personnel management and training, knowledge of international conventions and national legislations, ability to apply task and workload management, knowledge, and ability to apply effective resource management and decision-making techniques. In order to achieve those objectives, the need for Role Play and simulators are recognized as one of the tools that can be utilized among other physical resources of the course (IMO, 2013). Regarding the number of learners, it depends upon the facilities to allow good interaction between learners and to achieve the following outlines (IMO, 2013):

- Working knowledge of shipboard personal management and training
- Need for international maritime conventions, recommendations, and national legislation
- Ability to apply task and workload management
- Knowledge and ability to apply effective resource management
- Knowledge and ability to apply decision-making techniques
- Self-awareness, personal and professional development

Accordingly, standardized assessment tools should be used to include written, graphic or oral tests, in addition to a work-based demonstration for real-time, and real events using the simulator. The assessment criteria involve the presence of an authorized assessor or examiner, case study and analysis, solutions, and corrective actions. For the application of leadership and team working skills assessment, evidence of competence can be obtained from approved training, in-service experience and practical demonstration (IMO, 2013).

Use of Leadership and Managerial Skills (LMS)

The LMS training aims to enable trainees to perform leadership and managerial skills in controlling the vessel operation and ensuring the safety of all persons on board at a management Level approach. Learners should be able to prove their ability to apply international and national laws, manage human resources onboard and train everyone on effectively carrying out the amount of work, apply professional techniques for decision making, and implement shipboard standard operating procedures. The course objectives are achieved through a delivered set of theoretical and practical sessions (IMO, 2018).

Regarding the theoretical part, all training spaces should be outfitted with the necessary tools that guarantee the training is delivered effectively throughout lectures, exercises, and discussions for a group of trainees ranging from 1 to 24. In terms of practical parts, some of the practical exercises indicate using full mission simulators, yet this could be optional since comparable outcome-based exercises, which do not employ simulators, are accepted to be developed and executed for a maximum of eight participants to achieve the course outlines indicated in Table (III) (IMO, 2018).

Table III : Course Outline and Timetable for IMO Model Course 1.40

Subject area		Time allotment (in hours)	
		Theoretical	Demonstration/ Practical work
	Course Introduction		
1	Related international maritime conventions and recommendations, and national legislation		
2	Shipboard personnel management and training		
3	Task and workload management		
4	Effective resource management		
5	Decision-making techniques		
6	Development, implementation, and oversight of standard operating procedures		
Conclusion			
Total training hours		**40.0**	

Source: (IMO, 2018)

Based on the fact that practical assessment is a focal point of the assessment process, tasks are divided into four main assessment criteria as follows (IMO, 2018):

- **Shipboard personnel management and training:** The assessment focuses mainly on performing an effective operation using an assigned crew, where performance should be aligned with national/international rules, operating standards, and accepted behaviour. The training objectives should be fulfilled whilst taking into account the operational requirements and the learner's current competence and capabilities.
- **Task and workload management:** The learner is to be informed about his duties as a crew member. Furthermore, expected standards of work and attitude to be followed in line with the learner's duties.
- **Effective resource management:** The learner should be assessed on how he/she prioritized the use of resources to perform vital tasks with the presence of planned operations in advance.
- **Decision-making techniques:** Learners should demonstrate effective leadership behaviour and the essential team should understand precisely the current and expected state of the vessel regarding operation and external environment and the decision taken during the training should be the most effective for the situation.

The OPITO Emergency Response MEMIR Training

The MEMIR training has been established by OPITO to equip learners with emergency management techniques to boost their confidence when performing emergency duties in the event of a major incident. The course aims to deliver formal training on how to perform a command, control, communication and stress management during major emergencies and provides initial emergency management training to staff as a prerequisite for being emergency managers. The training objectives are concerned with the preparation, response and control of a dynamic emergency event through effective communication while recognizing the impact of stress on decisions. The number of participants is limited to six delegates with the support of common physical resources at an Emergency Control Centre (ECC), Emergency Response Plan (ERP), generic or a company procedure, relevant Permits to Work (PTW), alarms, telephones, radios, information boards, systems tools, public address (PA), and simulated background noise for distraction (OPITO, 2022b).

Following the brief classroom instruction, the learners join a "Command Centre Simulator" where they individually experience the realism of numerous major events in the capacity of an emergency manager for at least two scenarios. The learners are then debriefed about their points of weakness and strength. In this regard, an appraisal report should be provided with feedback on the strengths and flaws of the individual and team performances. Upon completion of training, participants are awarded a MEMIR certification in addition to a documented analysis of observed gaps in the form of an appraisal determining the recommended further training required to boost bridging those gaps (OPITO, 2022b).

The course total contact time is 26 hours divided into 35% theoretical, and 65% practical simulation including debriefing sessions. The theoretical part demonstrates multiple types of major emergencies and indicates the role and responsibilities of the emergency manager. The sessions include a familiarization tour of the ECC followed by a brief explanation of stress and how to deal with it. Various examples of a pre-planned and maintained state of readiness within the learner's installation are demonstrated with an explanation of the value of being prepared and ready for emergencies at all times. The practical parts of MEMIR are mainly based on appraising the following nine outcomes (OPITO, 2022b):

- Review, manage, and assess the information available in an emergency promptly
- Establish priorities and take effective action
- Implement pre-determined emergency plans and procedures in the context of the current emergency
- Efficiently communicate information and instructions
- Effectively communicate with all appropriate external agencies
- Monitor and control resources
- Evaluate progress and communicate changes in plans and priorities
- Effectively delegate authority and manage individuals and teams
- Effectively manage themselves and the team during a major emergency including supervising the effects of stress on themselves and others

Additionally, the training is based on three scenarios and the decision should be compatible with how the scenario was written; type (A) Controllable major emergency; type (B) Controllable major emergency with the potential to escalate; and Type (C) Uncontrollable emergency leading to the evacuation (OPITO, 2022b). To assess learners, all theoretical learning outcomes should be informed and understood while the assessment should be carried out through group or individual discussions, oral or written questions, scenarios, or virtual simulations. In addition, the practical assessment plan shall be achieved by using a simulator (OPITO, 2022b).

Accordingly, after each practical scenario, the learner should be debriefed with feedback on his/her individual and team performance. Training scenarios should cover a threat to life, the environment, or the installation. Scenarios should include a suitable combination of the following events (OPITO, 2022b):

- Evacuation, escape or abandonment
- Injured or dead personnel
- Missing personnel or Person Overboard (POB)
- Loss of communication or loss of Containment for the emergency
- Many casualties
- Loss of evacuation facility, muster points or temporary muster points
- Stressed personnel
- Extreme weather and environmental effects
- Loss of effective facilities or essential members
- Information overload
- The unit is unable to keep its operational position

Finally, after completion of the practical training, an appraisal should be handed over to the learner, this appraisal shall include any gaps to be covered by the learner in attending additional training and drills at the learner's workplace according to the decision of the learner's company (OPITO, 2022b).

The OPITO Emergency Response OIMCE Training

Following the MEMIR training, OPITO offers another training not targeting the appraising of the learner, but targeting the assessment of learners who had the potential to be an OIM or an Emergency Manager (EM). The training is constructed based on the recommendations of the appraiser raised during the previous MEMIR training and the duty holder proposals for their employees (OPITO, 2022a).

It must be recognized that this training is only a part of a comprehensive training program that should include company and installation-specific training procedures including drills and exercises. The responsibility of the Duty Holder is to ensure the competency of his future OIM but not exclude the simulated conditions as a beneficial tool to be used. It is important to note that such simulated assessments should be firmly placed in the context of the overall process employed by the Duty Holder. This process should include the company selection, training and on-job appraisal, assessment procedures, competence profile of the OIM together with the record of experience particularly controlling real incidents or emergencies (OPITO, 2022a).

The training aims to assess the learner in the OIM position in a simulated environment during an emergency to achieve the following objectives and outcomes; to ensure learners have the competence for assessing situations and taking effective actions, maintaining proper communications, delegating authorities, managing performance and dealing with stress on individuals and teams (OPITO, 2022a). Additionally, the training is an individual assessment for one delegate at a time either with the learner's real team to achieve a higher record of fidelity or with other teams in the ECC room. Furthermore, ECC must be realistically depicting the learner's working facility with an effective process and communication system to allow him to take proper action at an appropriate time (OPITO, 2022a).

Basically, the training is based on three types of scenarios and the decision should be compatible with how the scenario was written. Additionally, realistic emergency scenarios must be established. Each scenario had a clear and justifiable decision-making requirement and intermediate decision-making points or events. Some responses may be critical or mandatory, others may depend on conclusions. The assessor should identify the proper response at each point in the scenario and must have an equilibrium between situations. Furthermore, the assessor should understand and prepare the scenario and acknowledge the decisions during the assessment and should discuss them in the debrief (OPITO, 2022a).

As a rule, assessment guidance for maintaining a state of readiness should be completed using a formal declaration and supporting evidence from the learner's employer confirming that the learner has achieved the performance criteria in his/her workplace, satisfied the core essential knowledge regarding procedures, hardware, information and human factors in addition to the asset type knowledge criteria requirements. Learners are then required to undertake formal assessments for assessing the situation and taking effective action, maintaining communication, delegating authority to act, managing individual and team performance, and dealing with stress on self and others (OPITO, 2022a).

Altogether, the course learning outcomes should be assessed using an observation method involving a simulator for a minimum of three participants and a maximum of four emergency scenarios. The training simulation should reflect the specific type of installations where the trainees work such as fixed and floating Drilling/Production installations, Mobile/Floating Installations, and Normally Unattended Installations (NUI)). The assessment must be formally recorded, and the certificate will only be awarded if the learner is successfully assessed against the outcomes and criteria. Scenarios should include a suitable combination of events and must be designed based on a different major incident from the range specified below (OPITO, 2022a):

- Well-control incident
- Explosion and fire
- Un-ignited hydrocarbon or toxic gas release
- Accommodation fire
- Helicopter incident
- Pipeline incident
- Collision or wave damage causing structural collapse
- Loss of stability (for mobile assets only)
- Foundation failure (for Jack ups)

To sum up, the assessment should be performed through continuous observation by an assessor and a discipline expert from the trainees' company. Nevertheless, the discipline expert could be also assigned by the duty holder or the training centre after being agreed with the duty holder (OPITO, 2022a).

COMPARISON BETWEEN STCW AND OPITO EMERGENCY TRAINING APPROACHES

General Concept

Referring to the STCW convention and pointing to the emergency management in table A-II/2 columns (1) for competence as shown in Figure 3, it can be observed that relevant methods of demonstrating learners' competence were mainly depending on the in-service training and previous experience while simulation has not been mandated as a vital component of a comprehensive program. This is opposite to the OPITO approach which recognizes simulation as an essential tool for the development and assessment of competencies.

Target Group

According to the STCW Manilla 2010, seafarers at the managerial level should have resource management knowledge; however, as per the BRM course target group, the training was assigned to an operational level, similar to the LTWT course. When compared with equivalent OPITO MEMIR training, it can be noted that the course is targeting the ECC team as an appraisal for learning and a pre-requisite of a follower OIMCE assessment training that has to be achieved before considering a trainee a qualified emergency manager. In the STCW, the sole training targeting the managerial level is the LMS while the OPITO OIMCE is an assessment training that has no equivalent for the Managerial level in the STCW standard.

Physical Resources

As per the OPITO standard, simulators are mandatory requirements for delivering the MEMIR, and OIMCE courses. The aim is to demonstrate a simulated environment that effectively depicts the actual characteristics of the offshore installations where learners are currently performing their duties. On the other hand, the use of simulators is optional as per the STCW standard, even for the assessment of the targeted NTS in BRM, LTWT and LMS courses.

Maximum Number of Learners

The optimum number of participants is the one that reflects the real work environment. On comparing the duties on the bridge and the ECC offshore, the emergency functions that have to be performed by the bridge team and the ECC seem to have a significant similarity as demonstrated in Table IV.

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.001

Table IV: Duties in an Emergency from Command Centers

No.	Function	Bridge	ECC
1	**Emergency Manager**	Master	OIM
2	**Technical actions**	N/A from the bridge (Technical team by radio)	Control Room Operator (CRO)
3	**External Communications by telephone**	Master	OIM
4	**External Communication by Radio**	Master or Bridge Officer/OOW	Radio Operator
5	**Internal Communication by Radio to Control Teams**	Master	Deputy and plotted on a board the location of the emergency with resources used in a real-time
6	**Internal Communication and Log for Mustering**	Master	Muster Checker on a board
7	**Key event logging**	N/A owing to the presence of a Voyage Data Recorder (VDR)	Key Event Personnel on a whiteboard
8	**Logistics log**	N/A (VDR) and OOW	Radio Operator on whiteboard
9	**Wheel Steering**	AB or OOW	N/A
10	**Navigational equipment**	OOW	N/A
11	**Look out**	AB or OOW	N/A

Source: (Authors, 2022)

Table IV summarized the responsibilities of both command centers. Concerning the bridge team, three positions are listed; Master, OOW, and AB. However, certain tasks such as wheel steering and lookouts need to be separated, especially in an emergency event in a crowded sailing area, so its interpretation is that in such a case, one more bridge member would be needed bringing the total up to four.

On the other hand, it is preferable to split between external and internal communications to avoid stress resulting from information overload. In this manner, an increase in the bridge team by one more member would be needed. The advantage is to have the Master relieved for decision-making towards safe navigation and emergency control. On the other hand, the ECC requires six persons as per the OPITO standard with at least four Notice-Boards.

This supporting tool for demonstrating the update of data could be significantly vital for providing real-time events in front of the decision-maker. Subsequently, the stress could be decreased as the Master's level of situational awareness is enhanced. The bridge simulator in the STCW training is one step ahead with the ability of maneuvering, steer and control the dynamic environment surrounding the vessel, yet still would be furtherly improved by utilizing the Notice-Board tool during emergencies. Accordingly, the optimum number of the bridge team would be a maximum of five participants as stated in the BRM model course. However, for the LMS, the number is accepted to be raised to eight participants while the LTMT has not been identified, which could be unreliable for achieving the intended learning outcomes of the emergency training.

Outlines and Outcomes

The studied five courses provide resource management, effective communication, stress management, decision-making, and situational awareness. However, theoretically, the BRM briefly explained the situational awareness skill. On the other hand, the MEMIR intensively demonstrates the importance of pre-planning and maintaining a state of readiness. Regarding the practical outlines, the OPITO outcome is concise in only nine outcomes for MEMIR, and five for the OIMCE leading to the "SMART" assessment concept, especially when there is a differentiation between the practical and theoretical outcomes. This is achieved only in the LMS training but without having the simulator compulsory for assessment purposes.

Decision-Making Process

With a particular focus on the assessment of decision-making through the outlines or outcomes, decision-making skill has been covered by all the studied courses in variable scopes but with a relatively broader scope in the cases of OPITO-approved MEMIR and OIMCE courses. This would provide a learning environment that is effectively flexible to allow increasing the integration of multiple types of emergency scenarios thusly boosting the trainees' decision-making skills.

Assessment Plan

Regarding the theoretical assessment, multiple techniques have been widely used in all STCW Courses including observation, written assessments, assignments, activities, projects, tasks and/or case studies, simulations, computer-based tests, writing reports, and drawing sketches. For the MEMIR training, the theoretical assessment is carried out through group or individual discussions, oral or written questions, scenarios, virtual simulations, and online learning. The practical part is executed using the simulator. In the OIMCE there are not any theoretical sessions as only the practical assessment using a simulator is utilized.

Assessment Criteria

In the BRM, the simulator is used to identify whether the learner is (Unsatisfactory, Needs Improvement, or Meets Expectations). For the LTWT, learners could be assessed either by an approved training or approved in-service experience or practical demonstration using a simulator to ensure that they achieved the learning outcomes while the LMS is to be observed in the simulator to ensure that the intended learning outcomes are fulfilled.

The use of the simulator is similar in MEMIR and OIMCE. In the case of OIMCE, more focus is placed on increasing the variety of scenarios and types of emergencies that might affect the installation including well control incidents, explosion and fire, hydrocarbon or toxic gas releases, accommodation fires, helicopter incidents, pipeline incidents, collision or wave damage causing structural collapse, loss of stability of mobile installations, and foundation failure of jack-up rigs.

Furthermore, this is integrated with a combination of different events including evacuation, escape or abandonment, injured or dead personnel, missing personnel or person overboard, loss of communication or loss of containment for the emergency. In addition, the escalation of the emergency is simulated by increasing casualties, loss of evacuation facilities, new muster points or temporary muster points, stressed personnel, extreme weather effects, environmental concerns, loss of effective facilities or essential members, and information overload. Deciding that the unit is unable to keep its operational position depends upon a written approved scenario to simulate if the emergency case is controllable or uncontrollable.

PROPOSED MODIFICATION TO THE ASSESSMENT IN THE STCW STANDARDS

Simulation is a part of a wider development program; thus the assessment of the Master should have two parties involved; an independent assessor, and a discipline expert from the learner's company. Based on the learner's knowledge, technical skills, and experience, the assessment decision should be taken based on the integration of future needs of the industry through a reliable and innovative assessment method to ensure that the Master can cope with dynamic changes in an emergency.

Moreover, the simulator should be as close as possible to the real vessel specifications and preferably with the same team operating the original asset. The proposed assessment course, as depicted in Appendix (1), is a proposal for a competence-based assessment process for a proposed STCW training titled Master Controlling Emergency (MCE). The design is mainly based on a mixed selection of all the assessment methods analyzed in case study courses by integrating the knowledge of BRM with the proper use of leadership and managerial skills from the master towards himself/herself and his/her team to enhance decision making in any emergency, as to ensure that the Ship's Master had the competent personality and the required NTS that enable him/her to take the proper decision in an appropriate time.

This assessment course should be based on five members in the bridge including the Master with a recommendation for each bridge to have a single whiteboard. In addition, as an emergency duty, one bridge officer should be assigned for performing internal communication along with promptly logging all the data related to the emergency on a whiteboard.

The scenarios used in the simulator should be written and pre-approved by the duty holder and should cover either a threat to life, a threat to the environment, or a threat to the vessel itself. Furtherly, the scenarios should be based on three main categories as follows:

1. Controllable emergency
2. Escalating emergencies
3. Uncontrollable emergency leading to abandonment

In this regard, the scenarios should focus on the worst case of emergencies which might affect the vessel as required in the OIMCE but as a matter of maritime transport domain. Furthermore, the scenarios should be written with a combination of different events as required in the MEMIR training where the assessment of each learner should be based on the outcomes of three scenarios up to a maximum of four different scenarios.

CONCLUSION

Given the comparison outcomes regarding the fundamental approaches articulated in the studied STCW and OPITO courses through their aims, scopes, principles, outlines, decision-making processes, and assessment criteria for each course, it can be recognized that the studied OPITO-approved courses are furtherly appropriate for providing an array of emergencies that adequately depict what can be experienced in real events of complicated emergency scenarios.

This is attributed to several factors including an elevated level of situational awareness, a systematic and adequate approach towards managing a combination of different events, and high-fidelity simulation of actual characteristics of emergencies on offshore installations which significantly enhance the physical, behavioural, and operational realism. Furthermore, the involvement of an independent assessor and a discipline expert from the learner's company enriches the consistency of the assessment process. Given these findings, this study concludes that although both standards are formulated with similar objectives, the OPITO emergency response courses provide a more extensive scope that can benefit the Maritime Education and Training institutions in building a more impactful and innovative training environment.

For improved consistency in the training outcomes, specific modifications to the currently implemented methods of assessment throughout the emergency response-related STCW courses could provide better consistent educational outcomes regarding advanced communication and innovative assessment methods. The proposed modifications include the inclusion of innovative instructional practices and enhanced interaction during both the instructional and assessment processes. Additionally, the assessment must be carried out by a high level of industry experts with the appropriate educational qualifications to ensure that the quality of training and assessment is consistently monitored more clearly and reliably. Ultimately, these modifications could lead to establishing an effective and reliable assessment framework that benefits the accomplishment of the training purpose and objectives while adhering to the preferences and demands of learners, dutyholders , and all other stakeholders in the maritime industry.

APPENDIX 1

Master Controlling Emergency (Simulator Assessment)

Function: Controlling the operation of the ship and care for persons on board at the management level

COMPETENCE-BASED ASSESSMENT PROCESS

Competence:	Develop emergency and damage control plans and handle emergencies
Knowledge-understanding-performance	Assessing situations and taking effective actions, maintaining proper communications, delegating authority, managing the performance of himself/herself and the team, and how to deal with stress for the individual and the team.
Method of evaluation	In-service training, experience, and simulator
Criteria	Agreed scenarios with the duty holder.

Assessment Domains: Cognitive (K), Psychomotor (S), Affective (A)

	Tasks, Knowledge, and Learning Objectives	Education Domain (K-S-A)
1	Assessing the situation	K, S
2	Taking effective action with the optimum use of all available resources	K, S, A
3	Maintain proper internal communication	K, S, A
4	Maintain proper external communication	K, S, A
5	Delegating authorities with feedback	K, S
6	Managing the performance of the Master and the Team	S
7	Control stress for the Master and the Team	K, S, A
8	Maintain a safe navigational watch	K, S

	Task	Weight	Parameters	Grade	Averaged weighted grade
1	Assessing the situation	1	5 min		1
2	Taking effective action with the optimum use of all available resources	1.5	7 min		1.5
3	Maintain proper internal communication	1.5	1 min		1.5
4	Maintain proper external communication	1.5	10 min		1.5
5	Delegating authorities with feedback	1			1
6	Managing the performance of the Master and the Team	1			1
7	Control stress for the Master and the Team	1.5			1.5
8	Maintain a safe navigational watch	1			1
Total		**10**			**10/10**

REFERENCES

Allianz.(2012) *Safety and Shipping 1912-2012: From Titanic to Costa Concordia*, An insurer's perspective from Allianz Global Corporate & Speciality. Available from: https://www.allianz.com/content/dam/onemarketing/azcom/Allianz_com/migration/media/press/document/other/agcs_safety_shipping_1912-2012.pdf [Accessed 4th June 2015].

Dominguez-Péry, C., Vuddaraju, L. N. R., Corbett-Etchevers, I., & Tassabehji, R. (2021) *Reducing maritime accidents in ships by tackling human error: A bibliometric review and research agenda - journal of shipping and trade, SpringerOpen.* Springer Singapore. Available at: https://doi.org/10.1186/s41072-021-00098-y .

IMO. (2013) *Model course 1.39 leadership & Teamwork, Scribd.* International Maritime Organization. Available at: http://www.scribd.com/document/437237373/Model-Course-1-39-Leadership-Teamwork [Accessed: July 13, 2022].

IMO. (2017a) *Resolution A.1110(30) adopted on 6 December 2017 Strategic Plan for The Organization For The Six-Year Perios 2018 to 2023.* International Maritime Organization Assembly 30th session.Agenda item 7 .IMO. Available at: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/AssemblyDocuments/A.1110(30).pdf [Accessed 8th November 2022].

IMO. (2017b) *The Manila amendments to the international convention on standards of training, certification and watchkeeping for seafarers, 1978 (STCW). part A STCW code (STCW/CONF. 2/34).* London.IMO Publishing

IMO. (2018) *IMO Model Course 1.40. Use of Leader Ship and Managerial Skills, Scribd.* IMO. Available at: https://www.scribd.com/document/446161269/5-3-2-add1-pdf [Accessed: June 13, 2022].

IMO. (2019a) *Human Element. International Maritime Organization.* IMO.Official Website. Available at: https://www.imo.org/en/OurWork/HumanElement/Pages/Default.aspx [Accessed 10th July 2022].

IMO. (2019b) *International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). International Maritime Organization.* Available at: https://www.imo.org/en/About/Conventions/Pages/International-Convention-on-Standards-of-Training,-Certification-and-Watchkeeping-for-Seafarers-(STCW).aspx [Accessed 15th July 2022].

IMO. (2020b) *IMO Model course 1.22. Bridge Resource Management. The Sub-Committee of Human Element, Training and Watchkeeping.* London. IMO. Available from: https://www.gob.mx/cms/uploads/attachment/file/555564/HTW_7-3-3-Add.1__Proyecto_de_curso_modelo_revisado_1.22_sobre_gesti_n_de_los_recursos_del_puente__Secretar_a_.pdf [Accessed 13th May 2022].

International Transport Workers Federation. (2010) *A Guide For Seafarers Taking into account the 2010 Manila amendments*. ITF. Available from: https://www.mptusa.com/pdf/STCW_guide_english.pdf [Accessed 12th September 2022].

Neff Jürgen (ed). (2020) *Improving bridge resource management human factors in maritime safety.* Hanburg. PMC Media House GmbH. Available from: https://www.pmcmedia.com/en/all-titles/maritime/420/improving-bridge-resource-management?c=26 [Accessed 18th August 2022].

OPITO. (2019) *Guidelines for the management of competence and training in Emergency Response in the Oil and Gas Industry. OPITO International. Issue No 1, Revision 0 (November 2010) Amendment 9 (June 2019).* OPITO. Available from: https://downloads.opito.com/downloads/6.ENGLISH_International_ER_Guidelines_Final-rev-0-Amendment-8_MASTER-June-2019.pdf [Accessed 15th September 2022].

OPITO. (2022a).7025.*OIM controlling emergencies standard OIM controlling emergencies.* OPITO. Available at :https://downloads.opito.com/downloads/OIM-Controlling-Emergencies-Rev-6-March-2022.pdf [Accessed 1st April 2022].

OPITO. (2022b) .7228. *Major emergency management initial response training (MEMIR). OPITO.* Available at :https://downloads.opito.com/downloads/Major-Emergency-Management-Initial-Response-MEMIR-Revision-4-March-2022.pdf [Accessed at 1st May 2022].

RØdseth, Ø.,J.(ed).(2012). *(PDF) standard on emergency management - research gate.* Research gate. Report Number: Flagship deliverable D-C1.1.Available at: https://www.researchgate.net/publication/280714136_Standard_on_emergency_management [Accessed 12th May 2022].

Sánchez-Beaskoetxea, J., Basterretxea-Iribar,I., Sotes, I., &Machado, De Maria. (2021) "Human error in marine accidents: Is the crew normally to blame?," *Maritime Transport Research,* 2, p. 100016. Available at: https://doi.org/10.1016/j.martra.2021.100016.

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.018

Exploring the Usage of the LNG as Fuel for Offshore Vessels

Ahmed Salem and Mohamed Hassan

Arab Academy for Science, Technology and Maritime Transport, Egypt
Maritime Transport Department,

Emails: ahmed-salem@egypt.aast.edu, capt.hassan@egypt.aast.edu

Received on: 21 October 2022 | Accepted on: 13 February 2023 | Published on: 10 March 2023

Abstract

Purpose: *This paper evaluates the benefits of using natural gas in offshore vessels and the challenges faced by using natural gas in offshore vessels.*

Design/Methodology/Approach: *A comprehensive questionnaire was developed and distributed to experts in offshore vessels. The crucial critical factors were selected utilizing an AHP technique from those found common characteristics.*

Findings: *The results found that operational challenges are considered the most important ones as they come in the first place, while technical challenges come in the second place, safety challenges in the third place, and systematic challenges in the fourth place.*

Key-words:
Offshore vessels, natural gas usage, challenges of natural gas, fuel challenges in maritime.

INTRODUCTION

The shipping sector is about to undergo a significant change in order to enhance its environmental emissions profile, particularly those to air. Among other things, the development of Liquefied Natural Gas (LNG) as a practical clean fuel source has been impacted by present national, municipal, and projected worldwide environmental legislation. Despite the fact that the world's LNG carrier fleet has been utilizing it for more than 40 years, other marine businesses, such as Offshore support vessels (Is it support or supply? As in next page?? (OSVs), have only lately begun using LNG. As a result, designs for LNG-fueled boats, including OSVs, are being developed globally for this market, and some LNG-fueled vessels have already been delivered or ordered (Hodgson and Lee, 2012).

There are currently just a few LNG distribution trucks for the few LNG-fueled vessels used, like passenger ferries, as well as small-scale stations offering direct bunkering from shore installations. These facilities serve the LNG shipping industry. Despite the brief history of LNG as a ship fuel, it is now prepared to take off. The first classification criteria for gas-powered ships were created by DNV in 2000, while the first LNG-fueled ferry in the world was being constructed (Blikom, 2012).

In order to promote domestic natural gas usage and virtually eliminate local emissions from the ferry operation, the Norwegian government made it plain that they intended this particular boat route to be powered by natural gas. This project involves building the first LNG-fueled ferry in the world. Currently, the fleet consists of 22 gas-powered ships, including ferries, offshore supply ships, and coast guard boats. All of them are active in Norwegian waters, and the ongoing efforts of the Norwegian government are crucial to their continued existence. After ten years of use, however, ship owners and their crews seem to be mostly in agreement with their positive experiences with this type of fuel (Blikom, 2012).

There has never been a time when the significance of Natural Gas (NG) has been more crucial than now, when strict environmental regulations, improved energy security, and growing competition drive up demand for natural gas while expanding supply and infrastructure to ensure its availability at affordable prices. The constant demand for NG produces enough money and interest to research many facets of the natural gas supply chain with the goal of making it both lucrative and energy efficient. The majority of the vessels in use today are propelled by heavy fuel oils. Although these fuels are inexpensive, they generate a lot of harmful emissions. NG is becoming a compelling alternative for merchant ships in order to comply with International Maritime Organization (IMO) regulations (Burel et al., 2013).

Therefore, this paper evaluates the benefit of using natural gas in offshore vessels and the challenges faced by using natural gas in those vessels.

OFFSHORE VESSELS

Offshore support vessels (OSV) are important players in the global oil and gas sector. The offshore service sector provides goods and services to offshore activities. These services include delivering supplies, equipment, gasoline, water, and food; towing rigs and installing and removing rig anchors; and helping with offshore construction projects. Workers are also transported to, from, and between offshore locations and rigs. All offshore activity, whether it occurs in the (Give full name in the first usage) (GOM) or any other offshore basin worldwide, shares some features even if each operation is unique and job-specific. Supply vessels provide assistance for all exploration and production tasks, such as development, production, and abandonment (Kaiser and Snyder, 2010).

The logistics of offshore oil and gas operations are essential to their effectiveness but have received little attention in the academic literature due to the operations' complexity and the difficulties connecting service vessel utilization to offshore activities. Quantitative models of ship and helicopter movement (Gribkovskaia et al., 2007), fleet design (Aas et al., 2009), information management (Holland et al., 2005), outsourced decision-making (Aas et al., 2008), sustainability (Matos and Hall, 2007), market constraints (Cairns and Harris, 1988), geographical difficulties

(Parola and Veenstra, 2008), and facility siting regulation (Gale and Albright, 1993) have been the main topics of academic research on offshore logistics.

The logistics of the upstream offshore industry have been the subject of numerous studies, but neither have they been thoroughly developed nor rationally harmonized. Additionally, no empirically based analyses or models have been created. It is also unclear how many OSV visits are necessary to support a particular activity. This essential knowledge is necessary to address a variety of academic, planning, and policy concerns (Kaiser and Snyder, 2010).

While OSVs are referred to be the "workhorse" of the industry and the "trucks" of the ocean, crew boats are largely used to transport workers to and from manned platforms and rigs. OSVs are designed to carry a variety of cargo, moving supplies both above and below deck. The wide-open bay ("well") astern, high bow, and forward accommodations of the OSV make it perfectly suited for the storage and delivery of containers, drill pipe, tubing, anchors, and other large and gigantic equipment. The refrigerated cargo holds and special-purpose tanks make it easier to transport commodities like food, drinking or industrial water, diesel fuel, drilling fluids, mud, cement, methanol, and other things below deck. OSVs are normally 10 to 12 knots in speed and range in length from 160 to 260 feet (Aas et al., 2009).

The main types of offshore vessels include: PSV (Platform Support Vessels), AHTS (Anchor Handling, Tug, Supply), and OSCV (Offshore Construction Vessels). PSVs carry supplies to drill ships, offshore construction vessels, and production platforms from a base on land. Storage tanks for liquid and dry bulk cargo are located beneath the deck, which is generally the open area of the ship's aft cargo deck. To maintain the ship close to the platforms while the cargo is being unloaded, it needs good maneuverability and dynamic placement (Erikstad and Levander, 2012).

Platform anchors are correctly positioned, retrieved, and repositioned as needed using AHTS vessels. A ship that has a large bollard pull capability as well as greater anchor handling winch pulling power is required due to the weight of lengthy chains in deep sea. Platform and drilling rig towing also need powerful machinery and a lot of pulling force. The construction and upkeep of platforms, well heads, pipelines, power cables, and undersea pumping systems all include the usage of offshore construction vessels. Moon pools, pipe storage, spacious open work decks, and cable carousels are among the amenities. Additionally, they frequently have remote-controlled underwater vehicles and diving equipment (ROV). Accommodations are required for both the crew of a ship and the labor force working on construction projects. OSCVs occasionally serve as landing pads for helicopters to transfer troops from one ship to another (Erikstad and Levander, 2012).

THE BENEFIT OF USING NATURAL GAS (NG) IN OFFSHORE VESSELS

Heavy fuel oils (HFOs) are used today by the majority of vessels for ship propulsion. Although these fuels are inexpensive, they generate a lot of harmful emissions. LNG is emerging as a viable alternative for vessels to comply with IMO regulations.

Burel et al. (2013) examined the potential economic benefits of using LNG as a fuel for vessels and evaluated the environmental implications of its use. To determine which types of merchant ships would most benefit from using LNG as a fuel for ship propulsion, a statistical analysis of maritime traffic was conducted in the first section. The world ship traffic data for the months of May 2008, 2009, and 2010 were examined. The best prospects for using LNG are roll-on/roll-off (RoRo) and tanker vessels because they spent the majority of their time at sea in Emission Control Areas. The utilization of LNG was particularly advantageous for tanker ships. The operational expenses and the decrease in pollutant emissions for tanker ships were calculated in the second section. Results indicated that using LNG reduced operational expenses by 35% and CO_2 emissions by 25%. Analysis of the potential for increasing energy efficiency on board took into account the cleaner exhaust gas heat recovery combustion gases produced by LNG. Simple heat recovery and heat recovery to power a turbine were the two possibilities that are examined Give the full name first time (ORC). The findings demonstrated that a 15% fuel usage reduction is feasible.

Hao et al. (2016) clarified significant information on NG life-cycle emissions in comparison to conventional petroleum-based fuels for marine. While local air pollutants like sulfur oxides and particulate matter will be lessened by NG, the effects on greenhouse gases depend on how the NG is produced, processed, delivered, and consumed. Using a technological warming potential approach (TWP), NG as a maritime fuel reaches climate parity with conventional fuels in 30 years for diesel-ignited engines, while it may take as long as 190 years for spark-ignited engines. The use of NG as a maritime fuel was increasingly popular, and in some areas, the right conditions already existed for a quick switch. Where NG-friendly economics were combined with governmental air pollution targets, LNG in marine transportation was likely to be encouraged. In comparison to conventional marine petroleum fuels, LNG fuels offered significant local pollution emissions advantages in the maritime transport sector. When used in maritime transportation applications, NG significantly lowers both proposed and current emissions regulations for traditionally fueled marine diesel engines while maintaining NOx emissions for critical criterion air pollutants (SOx and PM10). When NG was compared to high-sulfur fuels, air emission reductions are larger, especially for SOx and PM10. These savings would be realized right away and would last for the whole lifespan of gas-powered marine engines with the conversion to NG.

Cleaner fuels and fewer emissions from all maritime operations are now required by new environmental rules. Mariners can use NG as a fuel to comply with rules, although there are few data on the emissions of NG used in maritime activities. Peng et al. (2020) evaluated the effects on pollutants, human health, and climate change after measuring emissions of criterion, hazardous, and greenhouse pollutants from a dual-fuel marine engine that could run on either NG or diesel fuel. The results showed that switching from diesel to NG reduced particulate matter (PM), black carbon (BC), nitric oxides (NOx), and carbon dioxide (CO_2) by 93%, 97%, 92%, and 18%, respectively. For the numerous port communities that struggle to fulfill air quality regulations, reductions of this size offer a useful tool. Formaldehyde (HCHO), carbon monoxide (CO_2), and methane (CH4) increased significantly when these pollutants were decreased.

Due to their effects on the environment's degradation, particularly the atmosphere's global warming, emissions from vessels are a serious environmental problem. Therefore, the IMO gives careful consideration to environmental preservation through the reduction of exhaust pollution and enhancement of energy efficiency through technological and operational measures. When it comes to the recommendations made by the IMO, NG is preferred over other fossil fuels for usage as an alternative. Elkafas et al. (2021) explored how employing NG in a dual-fuel engine affected the environment and energy efficiency. An inquiry has been made into a container ship. According to the analysis findings, employing a dual-fuel engine powered by NG instead of a diesel engine powered by HFO would result in CO_2, NOx, and SOx emission reductions of roughly 30.4%, 85.3%, and 97%, respectively. Additionally, it was discovered that the dual-fuel engine's NOx and SOx emission rates complied with the IMO 2016 and 2020 limits, respectively. Additionally, the Energy Efficiency Design Index value for a dual-fuel engine is around 30% lower than the value for a diesel engine, and it will be 77.18%, 86.84 %, and 99.27% of the needed value for the first, second, and third stages, respectively, according to IMO advice.

CHALLENGES FACED BY USING NATURAL GAS (NG) IN OFFSHORE VESSELS

Using NG in offshore vessels has received a lot of positive opinions and comments, but there are still several systemic, operational, technological, and safety obstacles to be resolved. These challenges can be summed up as follows in their essential elements (Aymelek et al., 2014):

Systemic Challenges

The hardest obstacles for business owners to overcome so as to accomplish micro-level goals are those on a macro scale. Major systemic obstacles that employ NG in offshore vessels would confront systematic challenges including political instability, the risk of war, the financial crisis, the volatility of NG prices, and potential future environmental regulation. The ability of Microsystems to adapt directly relates to overcoming systemic difficulties (Aneziris et al., 2020).

Operational Challenges

The availability of LNG bunkering facilities in ports of call and the sustainable supply of LNG to bunkering stations are the main operational concerns associated with employing NG in offshore vessels. Another operational obstacle for swiftly fulfilling ship-owner orders for LNG-fueled ships is new-generation strategic shipping alliances on deep-sea container shipping liner services with recently constructed enormous ships (Peng et al., 2021).

Technical Challenges

For an LNG bunker to have the same weight as HFO, a ship's fuel tanks would need to be about 80% larger. Therefore, creating a design with enough LNG tanks on ships is a difficult technological task. Replacement of the LNG fuel system for existing ships should be done correctly in accordance with the ship's operational characteristics and stability (Foretich et al., 2021).

In addition, it costs a lot of money to adapt LNG to ships through retrofitting or new construction and to supply LNG to ships for bunkering. Investments in ships powered by LNG are generally 15-20% more expensive than those powered by HFO+MGO. It also accounts for the costs of technical and educational adaption for businesses. Companies require assurances about the suggested conjectures and the LNG bunker supply and demand balance. As a result, gas producers and bunker suppliers are reluctant to make the infrastructure investments required for LNG bunkering until there is enough commercial shipping demand for LNG fuel. Moreover, if there is no improvement in the supply of LNG bunkers on major shipping routes, ship-owners will lose interest in LNG-fueled ships (Wang and Notteboom, 2014).

Safety Challenges

The biggest issue with using NG in offshore vessels is safety. Asphyxiation risk of bunker workers, cold material handling capabilities of relevant ship structures, pool fires, vapor cloud fires, explosions, and rapid phase transitions may all be regarded as safety challenges that should be avoided by further technological advancement and, in particular, by crew and bunkering employee training (Park et al., 2018).

RESEARCH METHODOLOGY

Based on literature review and discussions with the experts, a comprehensive questionnaire was developed and distributed to experts in offshore vessels. Subsequently, the returned questionnaires were examined, and the most prevalent standards approved by various organizations were determined. The crucial critical factors were selected utilizing an AHP technique from those found common characteristics. Figure 1 illustrates the steps of the solution methodology used in this investigation.

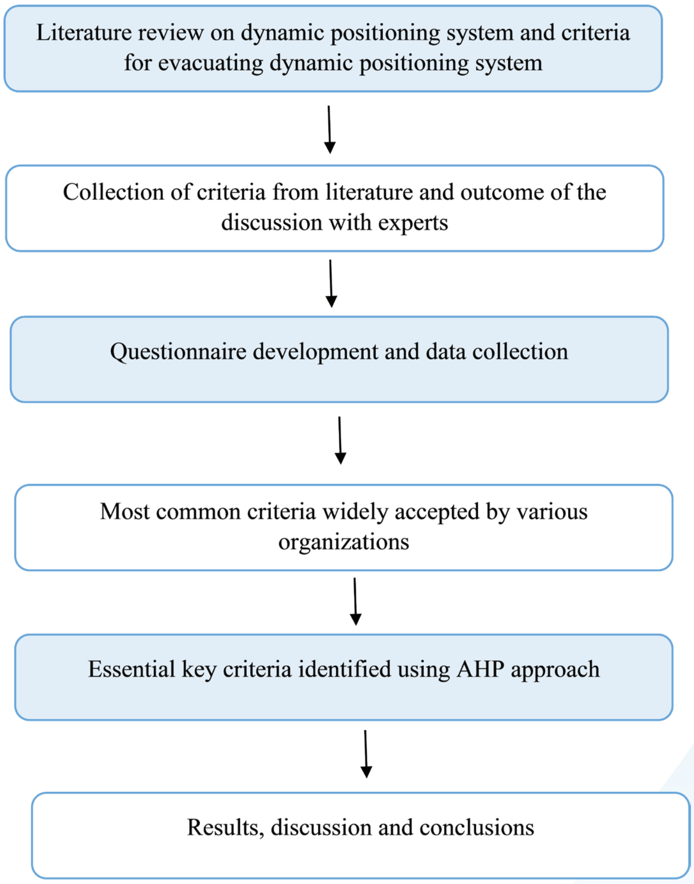


Fig. 1. Flowchart of Research

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.018

The analytical hierarchy process (AHP) is a Multicriteria decision-making procedure that offers a systematic strategy for evaluating and integrating the influences of different factors. It involves numerous tiers of dependent or independent qualitative as well as quantitative information (Uyan, 2013). The AHP method capacity to combine subjective and objective impressions, or physical and intangible assessments based on straightforward pair-wise comparison matrices, is one of its key advantages (Ahmad and Tahar, 2014). It has been defined as a straightforward and practical methodology that enables pair-wise comparisons within the analyst's area of expertise (Govindan et al., 2014).

AHP uses the idea of paired comparison along with a hierarchical structure or network analysis to choose the best option from a list of viable options. An AHP's main objective is to choose an alternative from a list of options that best meets a given set of criteria, or to calculate the weight of the criteria in any application by employing the decision maker's or expert's experience or knowledge in a matrix of pair-wise comparison of attributes (Aminbakhsh et al., 2013).

The AHP methodology uses a natural, pair-wise mode to compare criteria or alternatives in relation to a criterion. The three parts of the AHP approach are: (1) identifying obstacles and designing a hierarchy prioritizing model, (2) creating a questionnaire and gathering data, and (3) figuring out normalized weights for each category of barriers and each individual barrier (Haq et al., 2014).

DATA ANALYSIS

In this section, it will be shown how to apply AHP to evaluate the challenges faced by using NG in offshore vessels.

Application of AHP to Assess the Criteria of Dynamic Positioning System

Three main criteria for the challenges faced by using NG in offshore vessels will be considered, which are: (1) Systemic Challenges (SC); (2) Operational Challenges (OC); (3) Technical Challenges (TC); and (4) Safety Challenges (STC).

A recognized pair wise comparison matrix of the challenges faced by using NG in offshore vessels, provided by one of the specialists involved in the investigation, is shown in Table 1. Operational challenges are given the most weight, followed by technical challenges, safety challenges, and systematic challenges.

Table 1: A Pair wise Comparison Matrix for Main Four Challenges

Challenges	SC	OC	TC	STC	CW	GM	W	WSV
SC	**1**	**0.25**	**0.2857**	**0.4**	0.48535	0.41487	9.276%	1.94
OC	**3.88**	**1**	**1**	**1** **0.5**	1.85094	1.55807	34.836%	7.32
TC	**3.33**	**1**	**1**	**1**	1.59191	1.36014	30.410%	6.41
STC	**2.625**	**0.66**	**1**	**1**	1.31308	1.13952	25.478%	5.36
Sum	**10.85**	**2.92**	**3.28**	**3.92**		4.47261	1	

CW = ΣSC+OC+TC+STC / 4

Then, λ max, Consistency Index (CI) and Consistency Ratio (CR) are determined by summing the results of multiplying the pair wise comparison's overall value by each of the system's weights.

• λ MAX = Σ (WSC n / CW n)
λ Max= ((1.94/0.48535) + (7.32/1.85094) + (6.41/1.59191) + (5.36/1.31308)) /4 = 4.0166106
• CI = λ MAX / total of criteria – 1
CI= 4.0166106-4 / 4-1 = 0.0055369
• CR = CI / 0.9
For validation
CR = 0.0055369/ 0.9 = 0.0061521 (CR < 0.1 valid)

The pair wise determination is declared valid with this CR value when the CR value is less than 0.1. Table 1 values are acceptable and consistent because CR is less than 0.1.

The pair wise compression matrix's consistency is verified before the decision matrix is obtained as follows:

Table 2: Decision Matrix for Main Four Challenges

Criterion	CW	Rank
SC	0.48535	4
OC	1.85094	1
TC	1.59191	2
STC	1.31308	3

According to Table 2, it could be observed that operational challenges are considered the most important ones as they come in the first place, while technical challenges come in the second place, safety challenges in the third place and systematic challenges in the fourth place.

The weight of the individual system is shown in Figure 1. It could be observed that operational challenges are considered the most important ones as they come in the first place, while technical challenges come in the second place, safety challenges in the third place and systematic challenges in the fourth place.

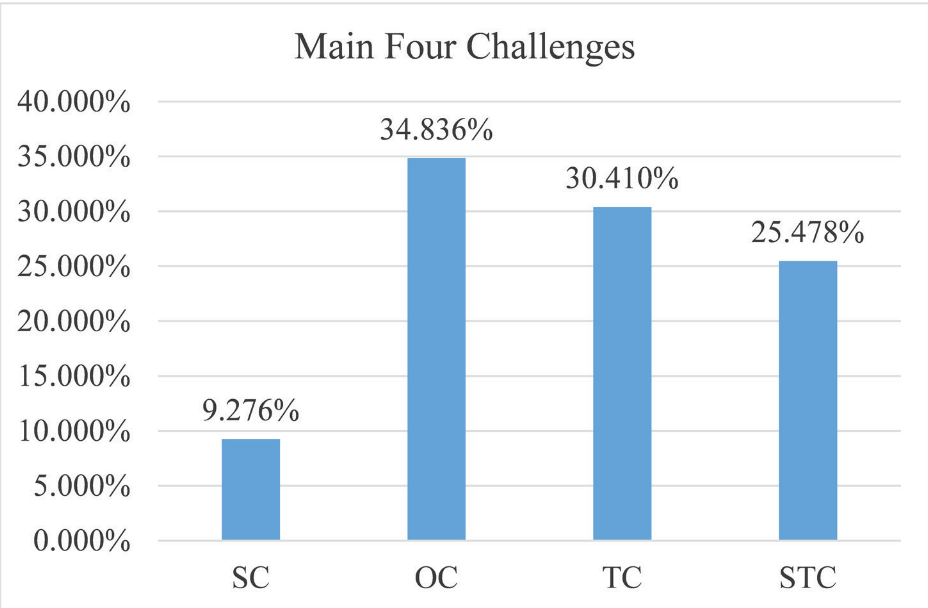


Fig. 2. Weight of Main Four Challenges According to Table 1

CONCLUSION AND DISCUSSION

For offshore vessels, NG is regarded as a viable fuel choice. IT has important economic and environmental opportunities that cannot be ignored despite systemic, operational, safety, and conjectural problems. By 2030, NG is anticipated to rank among the primary fuel sources for offshore boats due to rising costs, increased competition, and environmental regulatory enforcement in shipping.

A questionnaire for challenges faced by using NG in offshore vessels has been provided. The study found that operational challenges are considered the most important ones as they come in the first place, while technical challenges come in the second place, safety challenges in the third place, and systematic challenges in the fourth place.

REFERENCES

Aneziris, O., Koromila, I. and Nivolianitou, Z. (2020) 'A systematic literature review on LNG safety at ports', *Safety Science*. Available at: https://doi.org/10.1016/j.ssci.2019.104595.

Yun, S. *et al.* (2015) 'Conceptual design of an offshore LNG bunkering terminal: a case study of Busan Port', *Journal of Marine Science and Technology (Japan)*, 20(2). Available at: https://doi.org/10.1007/s00773-014-0266-1.

Aymelek, M. *et al.* (2015) 'Challenges and opportunities for LNG as a ship fuel source and an application to bunkering network optimisation', in *Maritime Technology and Engineering - Proceedings of MARTECH 2014: 2nd International Conference on Maritime Technology and Engineering.* Available at: https://doi.org/10.1201/b17494-102.

Blikom, L.P. (2012) 'Status and way forward for LNG as a maritime fuel', in *RINA, Royal Institution of Naval Architects - International Maritime Conference 2012, Pacific 2012.*

Erikstad, S.O. and Levander, K. (2012) 'System Based Design of Offshore Support Vessels', *Proceedings 11th International Marine Design Conference—IMDC2012* [Preprint], (January 2012).

Breivik, M., Kvaal, S. and Østby, P. (2015) 'From Eureka to K-Pos: Dynamic Positioning as a Highly Successful and Important Marine Control Technology', in *IFAC-PapersOnLine.* Available at: https://doi.org/10.1016/j.ifacol.2016.01.001.

Hodgson, M. and Lee, D. (2012) 'LNG as a fuel for offshore vessels - Bunkering technology', in *Offshore Technology Conference, Proceedings.* Available at: https://doi.org/10.4043/23421-ms.

Burel, F., Taccani, R. and Zuliani, N. (2013) 'Improving sustainability of maritime transport through utilization of Liquefied Natural Gas (LNG) for propulsion', *Energy*, 57. Available at: https://doi.org/10.1016/j.energy.2013.05.002.

Elkafas, A.G. *et al.* (2021) 'Environmental protection and energy efficiency improvement by using natural gas fuel in maritime transportation', *Environmental Science and Pollution Research*, 28(43). Available at: https://doi.org/10.1007/s11356-021-14859-6.

Foretich, A. et al. (2021) 'Challenges and opportunities for alternative fuels in the maritime sector', *Maritime Transport Research*, 2. Available at: https://doi.org/10.1016/j.martra.2021.100033.

Hao, H. *et al.* (2016) 'Natural gas as vehicle fuel in China: A review', *Renewable and Sustainable Energy Reviews.* Available at: https://doi.org/10.1016/j.rser.2016.05.015.

Mauro, F. and Nabergoj, R. (2016) 'Advantages and disadvantages of thruster allocation procedures in preliminary dynamic positioning predictions', *Ocean Engineering*, 123. Available at: https://doi.org/10.1016/j.oceaneng.2016.06.045.

Park, S. et al. (2018) 'A study on factors affecting the safety zone in ship-to-ship LNG bunkering', *Ships and Offshore Structures*, 13. Available at: https://doi.org/10.1080/17445302.2018.1461055.

Peng, W. et al. (2020) 'Comprehensive analysis of the air quality impacts of switching a marine vessel from diesel fuel to natural gas', *Environmental Pollution*, 266. Available at: https://doi.org/10.1016/j.envpol.2020.115404.

Peng, Y. *et al.* (2021) 'A systematic literature review on port LNG bunkering station', *Transportation Research Part D: Transport and Environment*, 91. Available at: https://doi.org/10.1016/j.trd.2021.102704.

Peng, Z., Wang, D. and Wang, J. (2016) 'Cooperative Dynamic Positioning of Multiple Marine Offshore Vessels: A Modular Design', *IEEE/ASME Transactions on Mechatronics*, 21(3). Available at: https://doi.org/10.1109/TMECH.2015.2508647.

Tomera, M. and Podgórski, K. (2021) 'Control of dynamic positioning system with disturbance observer for autonomous marine surface vessels', Sensors, 21(20). Available at: https://doi.org/10.3390/s21206723.

Wang, S. and Notteboom, T. (2014) 'The Adoption of Liquefied Natural Gas as a Ship Fuel: A Systematic Review of Perspectives and Challenges', *Transport Reviews*, 34(6). Available at: https://doi.org/10.1080/01441647.2014.981884.

Xu, D. et al. (2018) 'Formation control in dynamic positioning of multiple offshore vessels via cooperative robust output regulation', in *2017 IEEE 56th Annual Conference on Decision and Control, CDC 2017.* Available at: https://doi.org/10.1109/CDC.2017.8264256.

Xu, S. *et al.* (2020) 'A fuzzy rule-based PID controller for dynamic positioning of vessels in variable environmental disturbances', *Journal of Marine Science and Technology (Japan)*, 25(3). Available at: https://doi.org/10.1007/s00773-019-00689-2.

Maritime Autonomous Surface Ships (MASS) in Gulf of Suez: Safety of Navigation Precautionary Measures

Amr Samir Nossir, Samy Ismail A. M. Youssef and Mohamed Essallamy

Arab Academy for Science, Technology and Maritime Transport,

Emails: amrnossir@yahoo.com, yasser21107@gmail.com , messallamy@gmail.com

Received on: 01 September 2022 Accepted on: 27 September 2022 Published on: 05 January 2023

Abstract

Purpose: *It is widely acknowledged that automation has detrimental effects on both safety of navigation and environmental protection. Improvements to Maritime Autonomous Surface Ships (MASS) may help remove human error and significantly boost overall safety, but they are also likely to cause new threats, especially given the marine industry's increasing interest in MASS. This is certainly relevant in light of the fact that MASS are gaining popularity.*

Design/Methodology/Approach: *Due to the fact that the Gulf of Suez (GOS) is of paramount importance to the global trade and economy, this paper focuses on the threats posed by MASS activities when sailing through the GOS. Therefore, research was conducted on well-selected threats within the area with the objective of finding and prioritizing their potential impacts. In this study, a hybrid approach of research was used, consisting of both observations and a survey using a structured questionnaire.*

Findings: *The results were summarized as follows: The greatest threat to the effective potential completion of MASS operations is "Malfunction of the System" such as inability to locate the ship because of AIS or GPS signal spoofing followed by "Object detection and communication with human-operated ships," "the threat of cyber-attacks," "the human element," and "equipment failure." Based on the reseachers' findings, this study sheds light on the impact of MASS by the most significant threats to the safety of navigation and the protection of marine environment in the GOS and suggests procedures, requirements, and policies for MASS passage in this international shipping area.*

Key-words:
MASS, Threats, Safety of navigation and Gulf of Suez.

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.027

INTRODUCTION

Maritime Autonomous Surface Ships (MASS) is defined as “ships which, to a different degree, can function independently of human involvement” (IMO, 2018). IMO has recognized four autonomous ship categories: (a) automated systems manned to help control the ship systems, (b) a crewed remote-controlled ship, personnel manage the ship systems, (c) a remote-controlled ship with no crew, yet in command, and (d) completely self-driving ships, where Artificial Intelligence (AI) pilots the ship. The development of these automatic control systems and alternative solutions is continuing. In some cases, both positive and negative factors can influence development research (IMO, 2018).

It is hoped that MASS will enhance areas such as safety, environment protection, operational costs, and human resource management. The IMO is examining how to include MASS into existing conventions such as: International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW 78, as amended) and the International Regulations for Preventing Collisions at Sea (COLREG 1972, as amended) (IMO, 2018).

The extensive expenses of establishing new infrastructure, the high cost of repairs, and the technical challenges inherent in the design of ships and their operational systems in addition to the shortage of qualified crew members, the high cost of training, are cons of MASS. Moreover, there are other challenges that need to be solved.

(Chia et al., 2021) argue that there is insufficient evidence to validate the safety deployment of MASS because they consist of several interconnected systems, some of which are based on novel or advanced technologies. So, using MASS can cut down on mishaps caused by humans, but it will not be able to prevent them entirely. They also singled out five primary threats that cannot be avoided in the current ship configuration:

1. Failure of the propulsion mechanism.
2. Errors in identifying and categorizing objects of middle and small sizes.
3. Extremely heavy weather may hinder the ship’s ability to maneuver safely.
4. Contact with other ships.
5. Ships collisions can occur if object detection fails.

It is vital to evaluate the severity and unpredictability of MASS due to the great conceptual risk posed by the threat they pose. There is insufficient data to construct conceptual risk models for the analysis of MASS threats.

This research focuses on some the threats that could be posed by MASS in case it navigates in the Gulf of Suez (GOS), the southern entrance to the Suez Canal. The safety of navigation in this region has been a major concern to international shipping stakeholders. This research will investigate these threats and their associated risks that have the potential of jeopardizing the safety of navigation as well as the global economy.

To the best knowledge of the researchers, the impact of MASS on the safety of navigation and the protection of the environment, if any, while transiting the GOS in the future, has neither been investigated nor analyzed; therefore, this research attempts to bridge this gap.

APPLICATIONS OF MASS

Japanese Long-distance Autonomous Ship Operating Demonstration

Japan has recently finished its fifth demonstration and test as part of its Fully Autonomous Ship Program (MEGURI2040). The initiative was launched in February 2022 with participation from approximately 30 companies and 60 organizations. Using containerships and ferries, autonomous ship maneuvering, docking, and departure were demonstrated. In the test, a coastal cargo ship sailed vast distances and busy waterways for four days.

Suzaku, a Japanese cargo ship, was outfitted for an endurance test (IMO number 9853357). The 1800-dwt, 279-foot ship can reach 12 knots. The cargo ship departed Tokyo Bay on February 26 for the Port of Tsu-Matsusaka in Ise Bay, located south of Tokyo on Honshu, a 424-nautical-mile round trip as shown in Figure 1. The vessel was connected by satellite and terrestrial connectivity to a fleet operation centre and its autonomous navigation system. During the cruise, remote maneuvering and engine anomaly prediction were evaluated in order to manage a completely autonomous ship from land.

The trial mimicked future ships with complete autonomy by modelling numerous incidents. For offshore, bay, coastal, and berthing maneuvers, a fully autonomous navigation system was deployed. The most difficult aspect of the trail was sailing Tokyo Bay, which averages 500 vessels each day.

The autonomous functioning of the vessel was governed by the trial-specific navigational system. The ship was monitored and supported by an information system and shore-based system, including remote ship handling functions (Insurance Marine News, 2022).

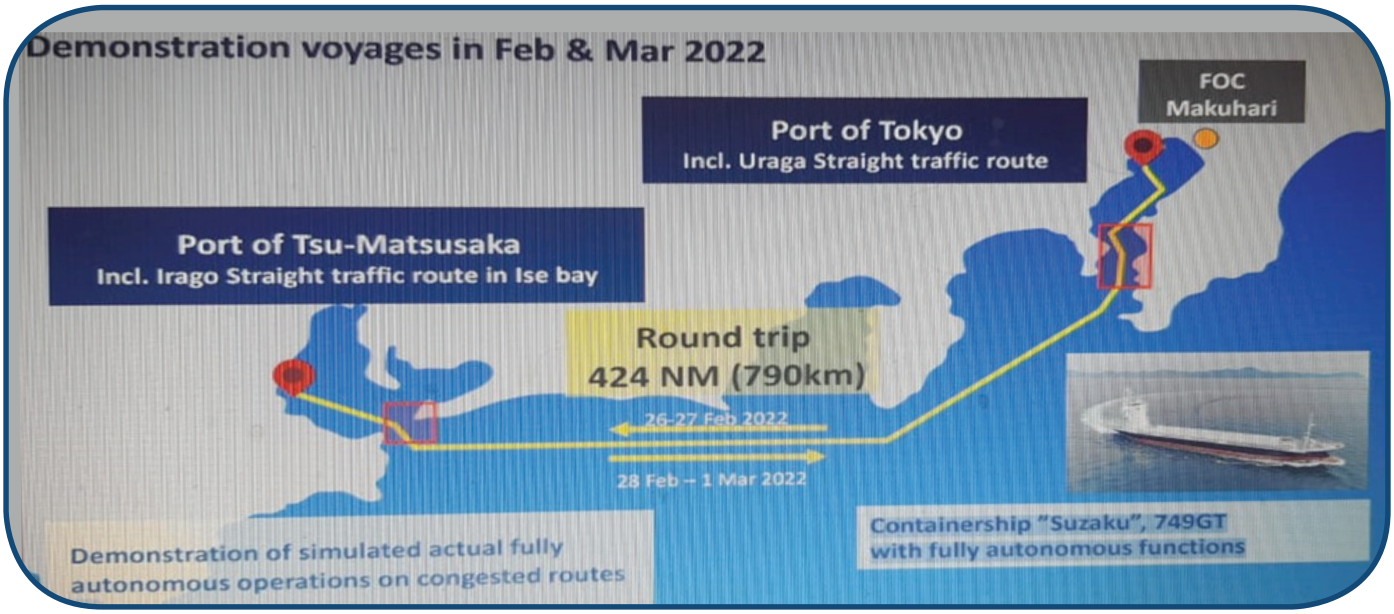


Fig. 1. Japanese long-distance autonomous ship operating demonstration
Source: IMO Seminar on Development of a Regulatory Framework for MASS, 2022

NYK Undertakes the World's First MASS Trial

NYK line has undertaken the world's first experiment in compliance with the IMO's Interim Guidelines for MASS trials, as the company continues testing to attain its objective of manned autonomous ships for safer operations and reduced crew workload.

The NYK line-managed 70,826 GT Iris Leader sailed from the port of Xinsha, China, to the port of Nagoya, Japan, from the 14th to the 17th of September, 2019, and from the port of Nagoya to the port of Yokohama, Japan, from the 19th to the 20th of September 2019 as shown in Figure 2. The crew performed their customary duties while circumnavigating Japan's coastline, avoiding entering any of its bays. During the experiment, an enhanced navigation support system's performance was evaluated in real sea conditions. This involved evaluating the risk of collision, automatically identifying the safest and most cost-effective optimal courses and speeds, and then guiding the ship autonomously. NYK was able to confirm the viability of enhanced navigation support system and its contribution to safe and efficient operations by utilizing data and knowledge gathered during this trial that were not accessible via simulators on land (NYK line news releases, 2019).

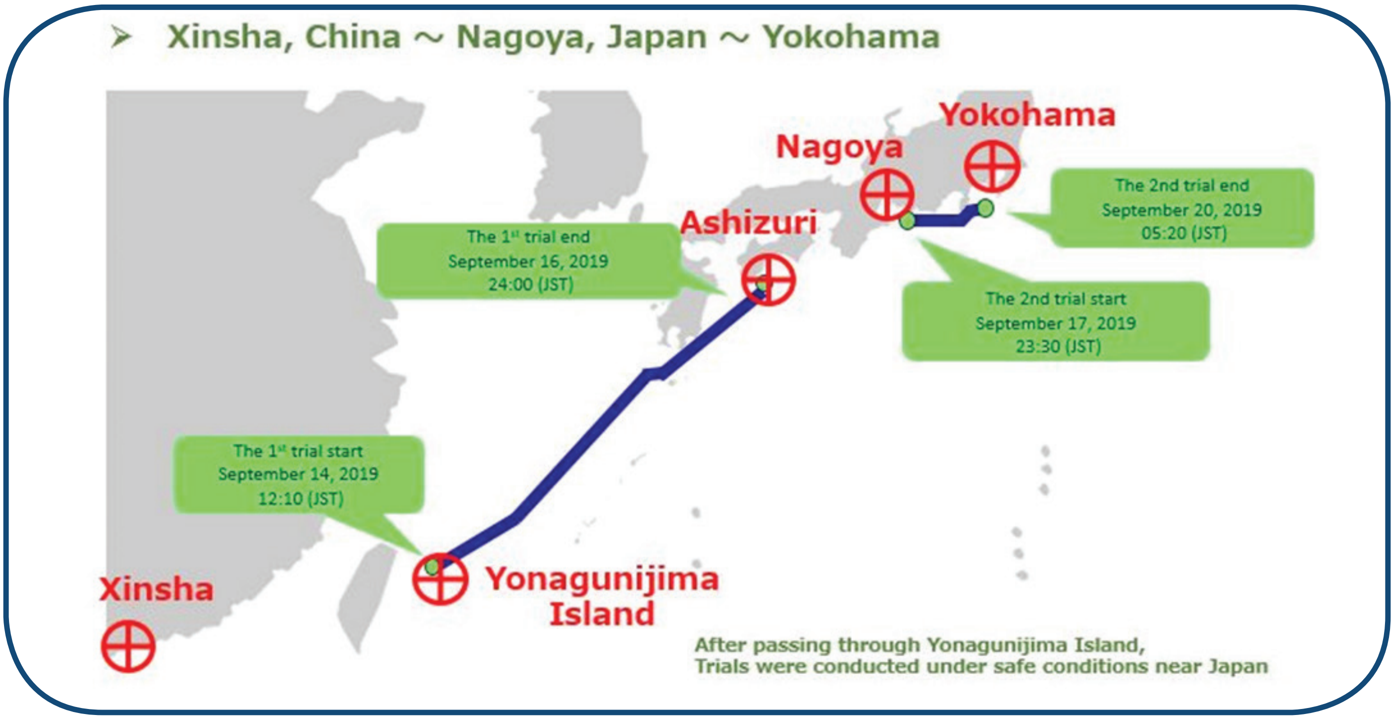


Fig. 2. NYK world's first autonomous ship trial voyage from China to Japan
Source: NYK line news releases (2019)

Advantages of Autonomous Ships

As autonomous technologies grow more prevalent, the prevalence of autonomous ships will increase. Advantages include: First, an improvement in human safety; according to the ILO, approximately 2.2 million people die every year in workplace accidents. Auxiliary ships are unmanned or have a limited crew, hence lowering the likelihood of accidents. In addition, limited system understanding, and fatigue can contribute to human error. Autonomous systems and AI have the potential to significantly minimize human error (Dinç, 2020).

Furthermore, the removal of the accommodation structure results in a 6% decrease in fuel and a 5% reduction in construction costs, i.e., resulting in less light ships weights and has more cargo stowage capacity (Dinç, 2020; KatsIvela, 2021).

Finally, ships operation cost would decrease for labor costs, i.e., account for up to 36% of total costs (Bogusławski, Gil, Nasur and Wróbel1, 2021).

Disadvantages of Autonomous Ships

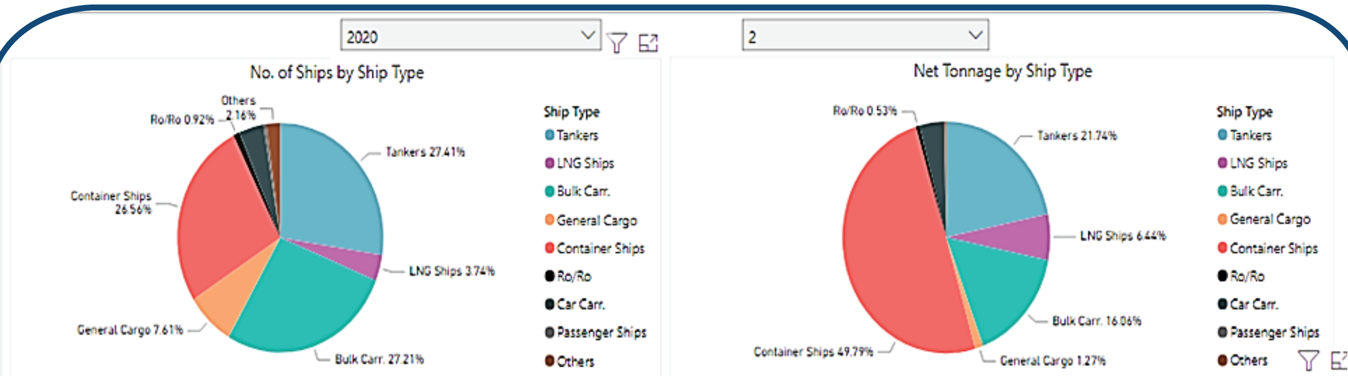
Disadvantages of MASS include: first, cyber-attack threat: Unauthorized access to sensitive data may have financial, commercial, and reputational implications. Avoiding these cyber-attacks also carries operation costs for cyber security plans (KatsIvela, 2021). With expanding shipping connections, cyber-attacks became a major problem requiring a complete risk assessment. In January 2021, IMO Resolution MSC.428 (98) requires cyber threats to be handled in safety management systems (IMO, 2017). Second, as automated ships network component's connections grow, the system becomes more complex. Network complexity is costly and ship-borne equipment and communication fees are expensive (KatsIvela, 2021). Moreover, many MASS legal and technical aspects need to be issued or amended. Finally, automated ships will most likely change employment requirements; as a result, crew unions are concerned about the safety and cost-effectiveness of autonomous ships (KatsIvela, 2021; IMO, 2022).

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.027

NAVIGATIONAL HAZARDS AFFECTING THE SAFETY OF NAVIGATION IN THE GULF OF SUEZ (GOS)

The GOS is one of the most important global shipping routes since it provides a passageway for vast numbers of ships bound to and from the Suez Canal and the Red Sea. This includes ships of the northern and southern convoys of the Suez Canal as well as service vessels for oil platforms and rigs, and tankers that discharge oil in Ain Sukhna, Ras Shuqair, Zaafarana, and Jabal al-Zeit. The safety of navigation and protection of the marine environment may be compromised in the event of an accident in this vital area, resulting in significant economic damages.

The number of ships that passed through the Suez Canal in February 2019 reached 1,525 with a total net tonnage of 99,902 tons, according to a report issued by the Suez Canal Authority in 2020 and depicted in Figure 3. As illustrated in Figure 4, the marine traffic website for 2019 also reveals that more than 229,000 ships navigated the northern Red Sea and GOS, which confirms the high ship density in the GOS. Accordingly, there is an urgent need to identify the most hazardous areas in the GOS in order to determine the extent of their impact on navigational safety and the marine environment, particularly during the potential navigation of MASS ships in these areas (Suez Canal Authority, 2020; Marine Traffic, 2019).



No. of Ships (Vessel)

State	Laden			Ballast			
Ship Type	N/S	S/N	Total	N/S	S/N	Total	Total
Tankers	176	130	306	12	100	112	418
LNG Ships	7	25	32	19	6	25	57
Bulk Carr.	223	80	303	1	111	112	415
General Cargo	49	49	98	0	18	18	116
Container Ships	211	190	401	0	4	4	405
Ro/Ro	7	3	10	2	2	4	14
Car Carr.	25	33	58	1	1	2	60
Passenger Ships	3	3	6	1	0	1	7
Others	18	15	33	0	0	0	33
Total	719	528	1,247	36	242	278	1,525

Net Ton (1000 Ton)

State	Laden			Ballast			
Ship Type	N/S	S/N	Total	N/S	S/N	Total	Total
Tankers	8,910	5,165	14,075	342	7,301	7,643	21,718
LNG Ships	725	2,971	3,696	2,149	591	2,740	6,436
Bulk Carr.	8,919	2,389	11,308	8	4,725	4,733	16,041
General Cargo	486	600	1,086	0	183	183	1,269
Container Ships	26,224	23,418	49,642	0	97	97	49,739
Ro/Ro	293	109	402	41	90	131	533
Car Carr.	1,630	2,076	3,706	55	60	115	3,821
Passenger Ships	82	12	94	7	0	7	101
Others	140	104	244	0	0	0	244
Total	47,409	36,844	84,253	2,602	13,047	15,649	99,902

Fig. 3. Suez Canal report in February 2020
Source: Suez Canal Authority (2020)

ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.027

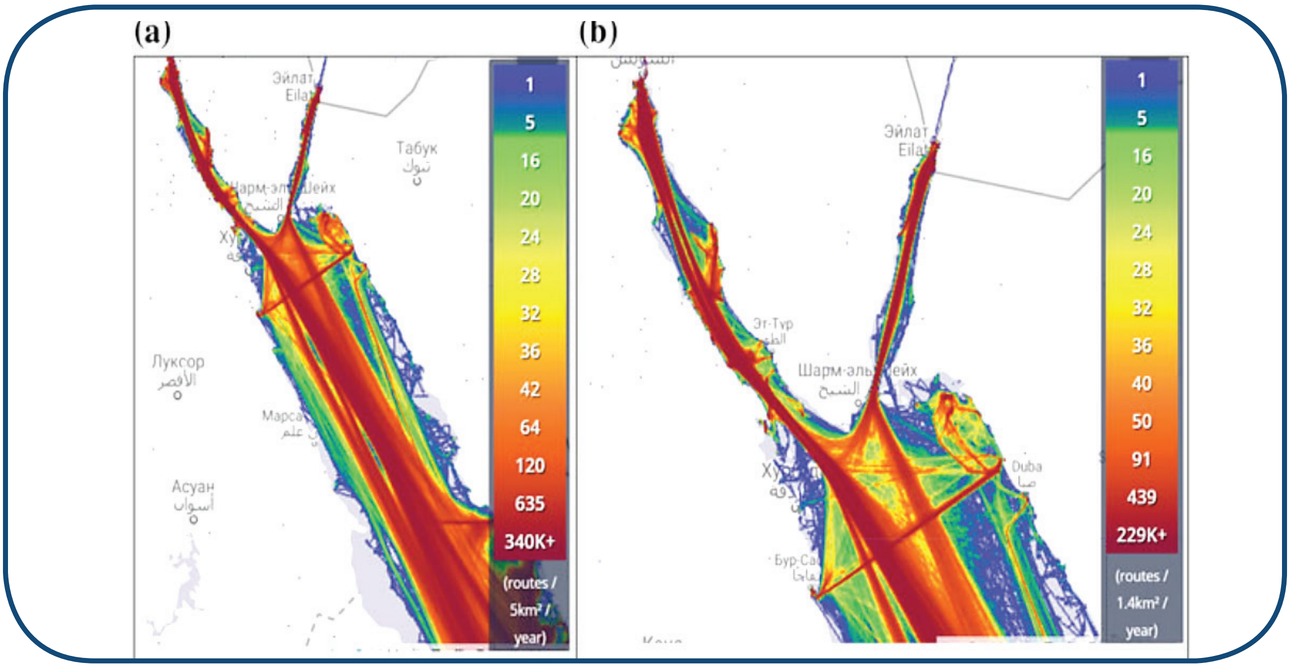


Fig. 4. The marine traffic density in the northern part of the Red Sea and GOS
Source: Marine Traffic (2019)

The most hazardous zones in the GOS have been identified as (the Strait of Jubal in the south of the GOS and the Ras Shuqair area in the middle of the GOS and the north of the GOS. As MASS ships will pass through certain regions in the future, the level of hazard in these regions could increase.

Strait of Jubal

Strait of Jubal zone was chosen due to (i) the presence of a rocky mountain on the eastern edge of the ship transit area in the traffic separation scheme (TSS) region, (ii) the absence of a navigational aid to direct ships away from this area, and (iii) the narrow safe navigational route for navigation in this area, which is less than 1 nautical mile, as depicted in Figure 5.

These considerations pose a direct impact on the safety of navigation and the marine environment in this crucial region, which encompasses the most popular touristic diving spots in Egypt and where numerous oil platforms are installed. The passage of MASS ships through this hazardous zone will raise the likelihood of accidents, which could result in major economic and environmental consequences.

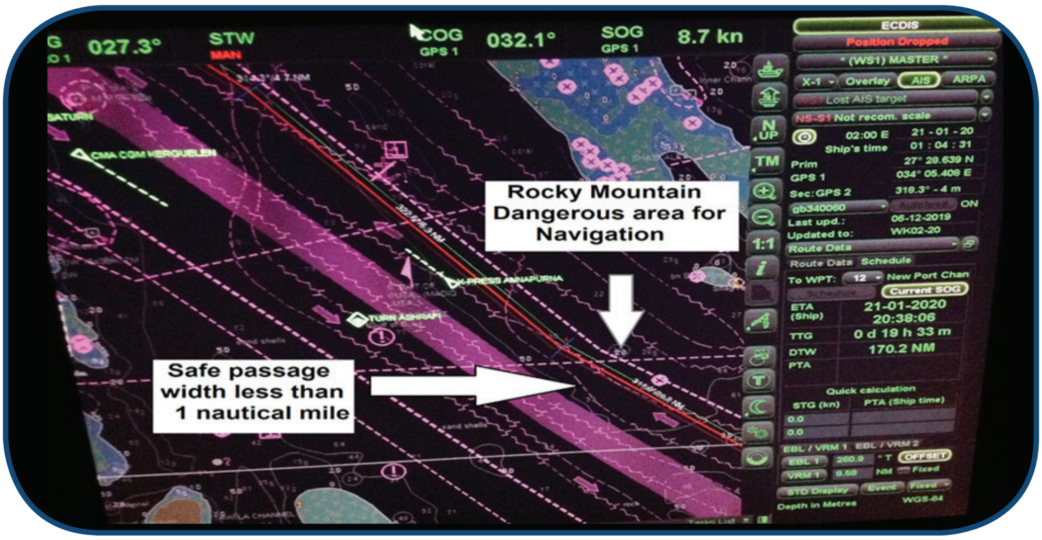


Fig. 5. Dangerous area for navigation in (Strait of Jubal)
Source: Photo by Transas ECDIS of Aida IV (01/2020)

Ras Shuqair Area

Ras Shuqair is one of the most hazardous areas in the GOS due to the existence of a high number of oil platforms and rigs, as well as isolated danger areas in the north-east and south-west that are not provided with any navigational aids, as shown in Figure 6.

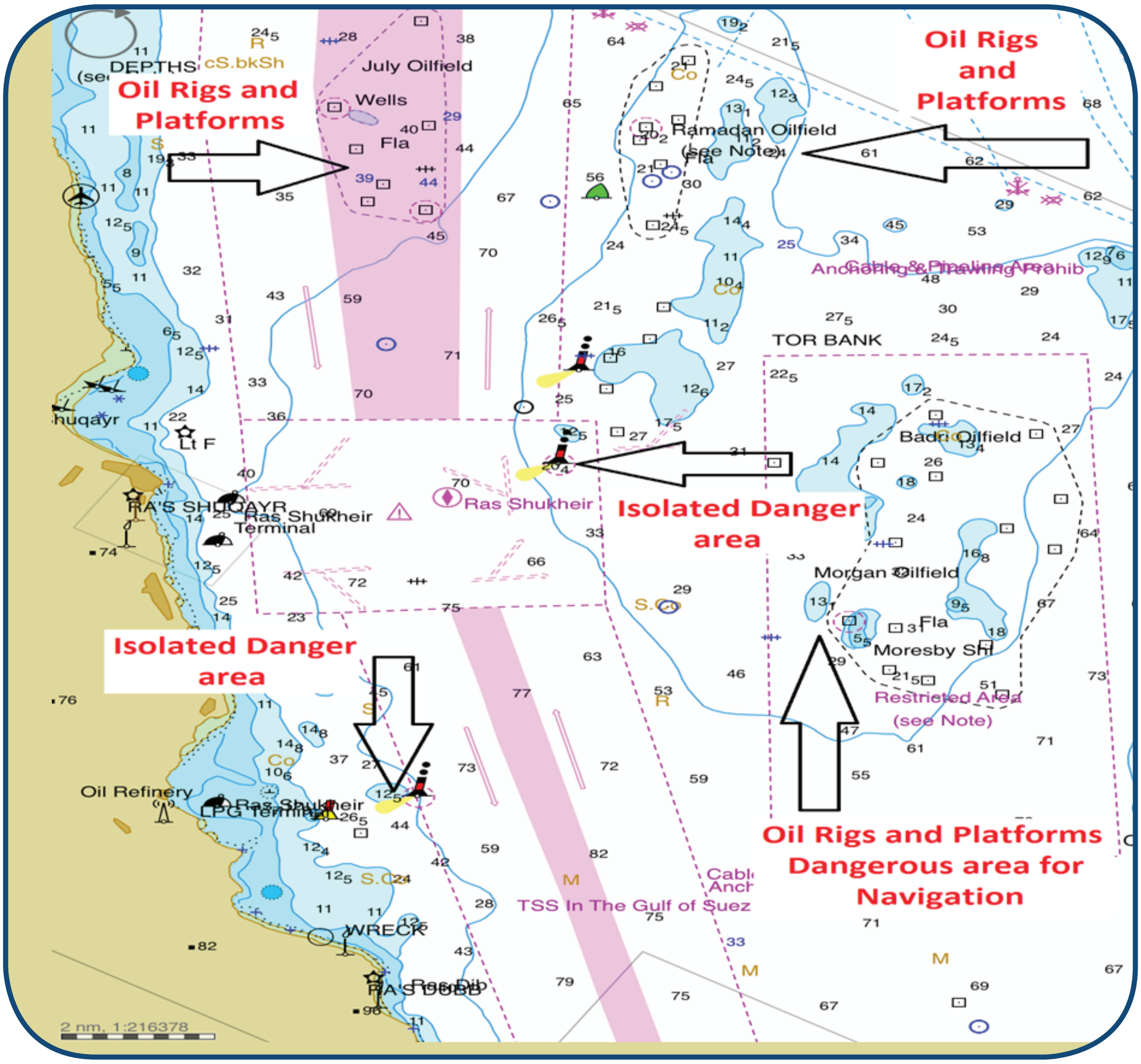


Fig. 6. Dangerous area for navigation in Ras Shukheir
Source: Photo by Transas ECDIS of Aida IV (09/2020)

Furthermore the presence of large numbers of fishing vessels in this area, with no commitment to conduct fishing activities far from the shipping lanes in the Traffic Separation scheme (TSS), will lead to a negative impact on the safety of sailing of ships, especially MASS vessels, thus leading to a diverse impact on the safety of navigation and the marine environment, as well as the safety of oil platforms in this important navigational and economic area.

Northern Gulf of Suez

The northern GOS region is one of the most important navigational and economic areas in the GOS due to the presence of coastal touristic places, oil-discharging tankers of the Sumed Company in the Ain Sukhna area, the southern entrance to the Suez Canal, and the port of Ain Sukhna, as well as the large density of ships in the eastern and western anchorage areas waiting to cross the Suez Canal and entering the port of Adabiya, as shown Figure 7.

With the anticipation of future passage of MASS ships through the GOS, now it is time for the Egyptian Maritime Authority to begin implementing the necessary precautionary measures and procedures to preserve the safety of navigation for MASS ships along this vital route.

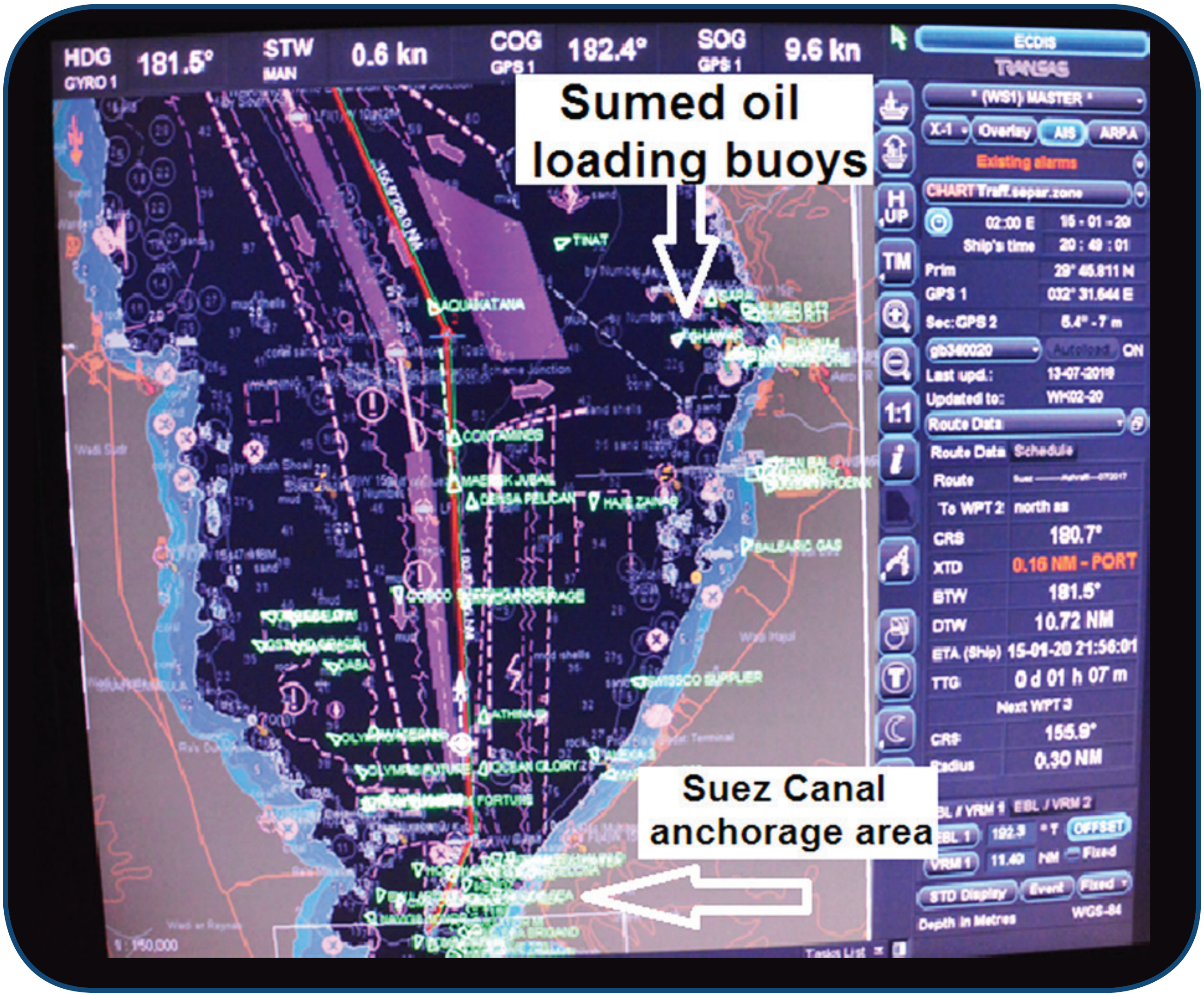


Fig. 7. North Gulf of Suez and southern entrance of Suez Canal
Source: Photo by Transas ECDIS of Aida IV (01/2020)

THREATS IN MASS OPERATIONS WHILE SAILING IN THE GULF OF SUEZ

The primary threat categories associated with MASS operations have been identified and are outlined in Table 1 as a result of an exhaustive analysis of the relevant literature. The researchers are aware that there is a serious shortage of published research in this field; however, there is a growing body of work devoted to MASS, which includes a few survey-based papers. Munim (2019) examines the development projects for autonomous ships and discusses the economic, environmental, and social benefits that have resulted from these projects. Dreyer and Oltedal (2019) review the difficulties associated with the operation of autonomous ships. Kim et al. (2020) examine the impact of MASS on various regulations, technologies, and industries. Wróbel et al. (2020) conduct a thorough literature review of the operational characteristics of remotely controlled vessels with the third-highest level of autonomy. This review is based on System-Theoretic Process Analysis (STPA) principles and identifies current and potential future research directions in the field of autonomous vessels. (Chia, Christos, Qing and Zaili, 2021).

Because of the difficulty of navigation in the GOS due to a number of the previously mentioned factors, including the presence of a rocky mountain in Gubal Strait at the southern entrance of the navigational route in the GOS, isolated navigational dangers, the large number of rigs and oil platforms in the Ras Shuqair area, and oil loading and unloading areas in Ain Sokhna, Zaafarana, Ras Shuqair, and Jabal Al-Zit, which will have a negative impact on the safety of navigation and the marine environment along one of the world's most crucial shipping routes.

As a result of the researchers' review of the pertinent literature, they have determined the threats categories listed in Table 1, which have been evaluated after carrying out a Questionnaire by a group of professionals to determine threats impact of MASS on the safety of navigation and the marine environment in the GOS.

Breakdown of Equipment

Failure of equipment during voyages is a key category of threat. In the event of a problem, since there is no crew onboard an autonomous ship, it must be immobilized and wait for the repairing company to arrive. Sensor failure, temporary loss of electricity (e.g., owing to black-out), failure of the ship's IT system (e.g., due to a fire in the server room), total loss of propulsion, and entire loss of rudder are examples of equipment failure. Moreover, Wróbel et al. (2017) list all potential scenarios for preventing or responding to fires on a MASS and assert that a fire accident is an exceptionally difficult obstacle in MASS operations.

Engagement with the Physical Reality

This type of threats may include extreme weather, reduced visibility, icing, ice pathways, and strong tidal waves. Winter passage in ice areas for a MASS would likely demand the help of an ice breaker, which poses a threat because of the closeness of the ships. To prevent the structural damage to the ship, heavy weather may necessitate slower maneuvering. Traditionally, all of these maneuvers are executed using manual steering (Banda et al., 2015).

Human Element

Despite the fact that MASS will aid in decreasing human error, the researchers can argue that human error or incompatibility between person and task cannot be totally avoided because the design and remote control still contain human elements. Due to the wide scope of coding and programming, human error may transfer from the incident time to the pre-voyage time. The associated systems cannot be exhaustively studied or tested before the commencement of actual ship operations. Due to the huge number of software package programming and the complexity of the coding, there is a possibility that software engineers will make wrong decisions during the design or programming process and, as a result, introduce vulnerabilities into the system. Inadequate design and interaction will also lead to an increase in operational human element concerns (Ahvenjarvi, 2016). Since operators in the Shore Control Centre (SCC) may be uninformed of the actual scene conditions, they bear the same or even new human error threats. Additionally, autonomous ships require periodic remote or in-person maintenance. In either scenario, human error will play a role, and this must be viewed as a threat to MASS operations.

In the future era of autonomous shipping, non-technical skill requirements are also vitally crucial and will differ greatly from those of conventional ships. Future ships will eliminate some human jobs and replace them with remote controllers (MUNIN, 2015).

Malfunction of the System

Since autonomous ships mainly rely on information technology (IT), it is possible to debate whether or not these systems are as competent as humans. Autonomous systems rely on machine learning, which requires considerable training to cover the vast majority of conceivable real-world scenarios. Due to the unpredictability of the system's behavior, however, it cannot account for all circumstances, and extraordinary circumstances are associated with the most difficult and dangerous system faults. In addition, systems and software should be designed to tolerate unanticipated failures. It is not easy to quantify the tolerance required to make the system work smoothly while assuring the safety of the voyage. It is believed that communication link failures are the new threats posed by the operation of MASS (Ahvenjarvi, 2016).

Object Detection and Communication with Human-operated Ships

Although Komianos (2018) asserts that MASS can substantially reduce the risk of collision and is compliant with COLREGs, they also argue that MASS does not comply with Rule 5 of COLREG, which requires a proper look-out by sight and sound on every ship to assess the situation and the risk of collision. A substantial amount of research also focuses on collision avoidance and guidance systems; for instance, Perera et al. (2018) who propose a ship collision situation avoidance algorithm based on fuzzy logic to support decision-making systems in autonomous ships, and Xu et al. (2019) who use AIS data to propose a path generation system.

The Threat of Jamming and Cyber Attacks

The CEO of CyberKeel, Lar Jensen, asserts that "autonomous ships will not become a mainstream reality in the next few years due to unresolved cyber-security issues on the technology". This quote is supported by recent examples of attacks including the events at COSCO US in 2018, Maersk in 2017, and the Port of Antwerp in 2011 and 2012. Hence, proof that cyber-attacks and jamming, which is usually caused by interference to the signals at Global Navigation Satellite Systems (GNSS) frequencies, are seen as one of the most serious threats in MASS operations because of the reliance of autonomous ships on information and communication technologies (Chia, Christos, Qing and Zaili, 2021).

Jammers represent a threat to GNSS since they intentionally interfere with signals and cause damage. Hence, the autonomous ship will rely heavily on the GNSS receiver for its positioning requirements. Even though it provides precise location data, the system's upkeep is in jeopardy. Multiple instances of significant GPS interference have been reported by ships operating in the Eastern and Central Mediterranean Sea (U.S. MARAD Alert 013, 2019).

The United States Maritime Administration (MARAD) has released Advisory 2019-013, which provides the following information: Ships operating in the Eastern and Central Mediterranean Seas have reported multiple instances of serious GPS interference. In the Eastern Mediterranean, most of these reports have been centered around Port Said, Egypt, the Suez Canal, and the Republic of Cyprus. There were additional reports of interference between Hadera, Israel and Beirut, Lebanon. This interference is causing GPS signals to be lost, impacting bridge navigation, GPS-based timing, and communications equipment. Additionally, satellite communications equipment may be affected (U.S. MARAD Alert 013, 2019), (Felski and Zwolak, 2020).

CONDUCTING A QUESTIONNAIRE TO EVALUATE THE MASS THREATS

A questionnaire was carried out to evaluate the MASS threats when passing through the GOS by 15 professionals in the field of maritime transport which are 11 lecturers from AASTMT (Sea Training Institute) and four officers onboard M/V Aida 4. The respondent assessment questionnaire consists of six groups for a total of 25 MASS threats that were asked to fill out a questionnaire as a source of information as shown in table 1. By using Likert scale questions which provides more granular information on respondent's attitudes towards a subject than a simple yes/no question type. Each respondent ranks each threat on a scale from one to five, with one being the lowest and five the highest. Figure 8 explains the overall score of MASS threats based on the questionnaires. According to the data shown in table 1, group no. (4) had the greatest score of (76) out of (100) as shown in Figure 8. This value indicates a negative impact on the safety of navigation and the marine environment in the GOS due to the malfunction of the System such as (inability to locate the ship because of AIS or GPS signal jamming or spoofing or an error caused by a disrupted communication link). Group no. (2): Engagement with the physical reality such as (Failure occurs due to a significant tidal effect, collision due to Low-visibility) had the lowest score of (64) out of a possible (100).

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.027

THREATS POSED BY MASS

Table 1: MASS Threats Evaluation Questionnaire

	Threats posed by MASS	Score
Group (1) Breakdown of equipment		
1	Complete lack of thrust.	3.2
2	Blackout or other temporary disruption of power supply - a lack of ability to manage a situation.	3.7
3	Inadequate sensing causes loss of control.	3.7
4	Absence of all rudder functionality.	3.1
5	IT system failure (e.g., server room fire) results in loss of control.	3.5
6	Loss of ship or systems due to fire.	4.1
Group (2) Engagement with the physical reality		
1	Failure occurs due to a significant tidal effect.	3.3
2	Low-visibility collision.	2.6
3	Failure because of ice navigation.	3.2
4	Heavy weather-caused failure.	3.7
Group (3) Human element		
1	Ineffectiveness because of a faulty remote control centre software.	3.4
2	The complexity of the system's coding and programming leaves room for human error throughout the design phase.	3.6
3	Problems made by humans not knowing how MASS will respond to an unusual situation.	3.1
4	Ineffectiveness caused by faulty on-board software design.	3.3
5	Inaccuracy in repair work caused by humans using remote controls.	2.8
Group (4) Malfunction of the System		
1	Inability to locate the ship because of AIS or GPS signal spoofing.	3.7
2	An error caused by a disrupted communication link.	3.9
Group (5) Object detection and communication with human-operated ships		
1	Failure to notice an object or ship can cause a collision.	4.0
2	Unable to locate objects drifting partially submerged	3.3
3	Inability to detect low-visibility targets, such as abandoned or broken objects	3.2
4	Failing to properly interact with a human-operated ship(s) in a dense traffic situation can lead to a collision.	4.3
5	Not knowing what to do around ships that are towing, have limited manoeuvrability, or are trawling.	3.5
Group (6) The Threat of Jamming and Cyber Attacks		
1	The operating system crashes because of harmful hacking attempts.	3.2
2	Cybercriminals disrupt ship-to-shore communications.	3.5
3	Jammers represent a threat to global navigation satellite systems (GNSS) and cause damage.	3.8

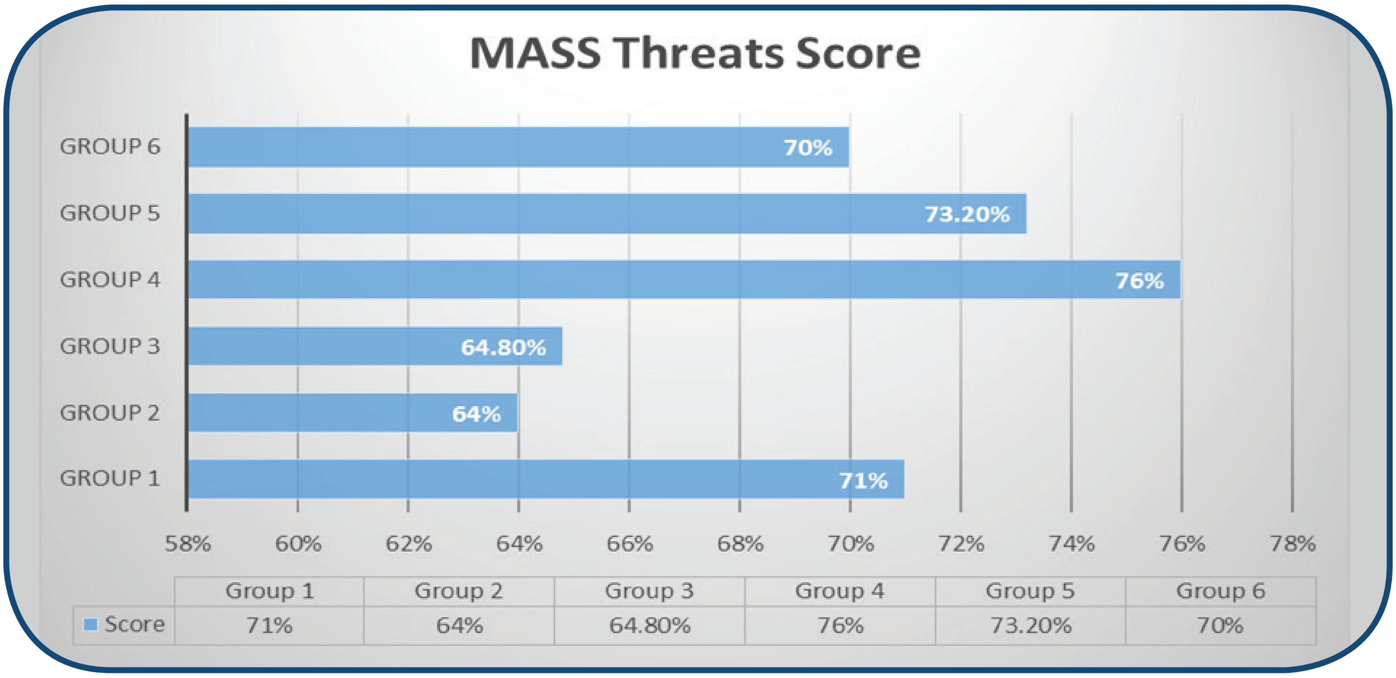


Fig. 8.. MASS threats score

The total score of respondents' assessment questionnaire is (1287) out of a possible (1875), which represents maximum value for a (68.50%) average and which indicates a high threat to the safety of navigation and the marine environment in the GOS.

There are values that need to be determined before the total questionnaire findings can be evaluated. Here are some examples of such values:

1. The maximum value=1875
2. The minimum value =375
3. The median (Q2) = 1125
4. The first quartile (Q1) = 750
5. The third quartile (Q3) = 1312.5

By using a box plot which is a method to summarize a set of data that is measured and used in explanatory data analysis. The threats of MASS based on the minimum value, the first quartile, the median, the third quartile, and the maximum value. Score between the third quartile and the maximum value will be extremely high threats (1312.5.-1875), score between the median and the third quartile will be high threats (1125.-1312.5), score between the first quartile and the median will be medium threats (750-1125.), and score between minimum value and the first quartile will be low threats (375.-750). The total score for the questionnaire, which included fifteen experts who judge a total of twenty-five potential MASS threats that were broken down into six groups, was 1287 which is high threats between the median and the third quartile (1125-1312.5) as shown in Figure 9. Based on the results of the questionnaire, it has become clear that MASS pose a threat to the safety of navigation and the marine environment in the GOS, which requires most appropriate measures to be taken to allow these MASS ships to sail in the GOS.

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.027

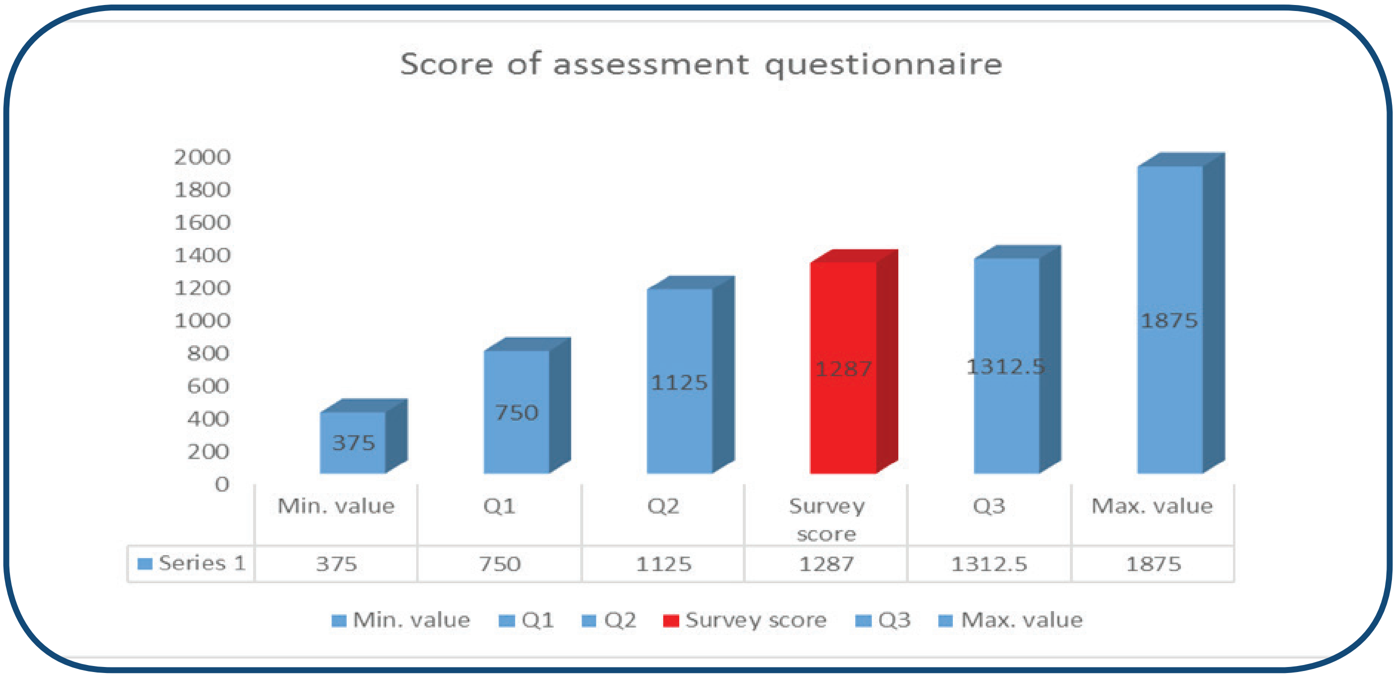


Fig. 9. Score of assessment questionnaire

Proposed Control Actions for MASS Transit in GOS

1. Establishment of three land stations for command, control, and guidance in the areas of (Al-Zafarana - Ras Ghareb - Ras Mohammed) after dividing the GOS into three sectors as depicted in Figure 10, to be able to utilize the MASS guidance system by connecting to terrestrial networks and satellites.

2. Establishment of a group of Tug Stations (TS) for tugboats that will escort on request MASS in areas that pose a threat to the safety of navigation and the marine environment, namely: the southern entrance to the Suez Canal, Ain Sukhna, Ras Ghareb, Ras Shukair, the Strait of Jubal, and south of the GOS, to be equipped with Moor Master System due to the significance of the system in escorting MASS without the need for the human element or the mooring lines.

3. Forming a committee affiliated with the Egyptian Authority for Maritime Safety (EAMS) to develop training requirements for the officers and crew operating the ground stations for commanding, controlling, and monitoring MASS, and submitting a proposal to the IMO.

4. Forming a committee affiliated with the Egyptian maritime transport sector to discuss proposals and special requirements to expedite the Egyptian House of Representatives' consideration and issuance of legislations regarding the passage and entry of MASS into territorial waters, Egyptian ports, and the Suez Canal, following consultation with the IMO.

5. Establishing a committee from the Egyptian maritime transport sector to meet with the classification societies, companies owning MASS and insurance companies to study the most appropriate procedures for issuing a special international certificate for MASS that transit the GOS after ensuring the implementation of all requirements and safety procedures that will be agreed upon and presented to the IMO to be binding on all MASS, while setting periodical dates to discuss any developments and/or improvements that may arise in the field of MASS.

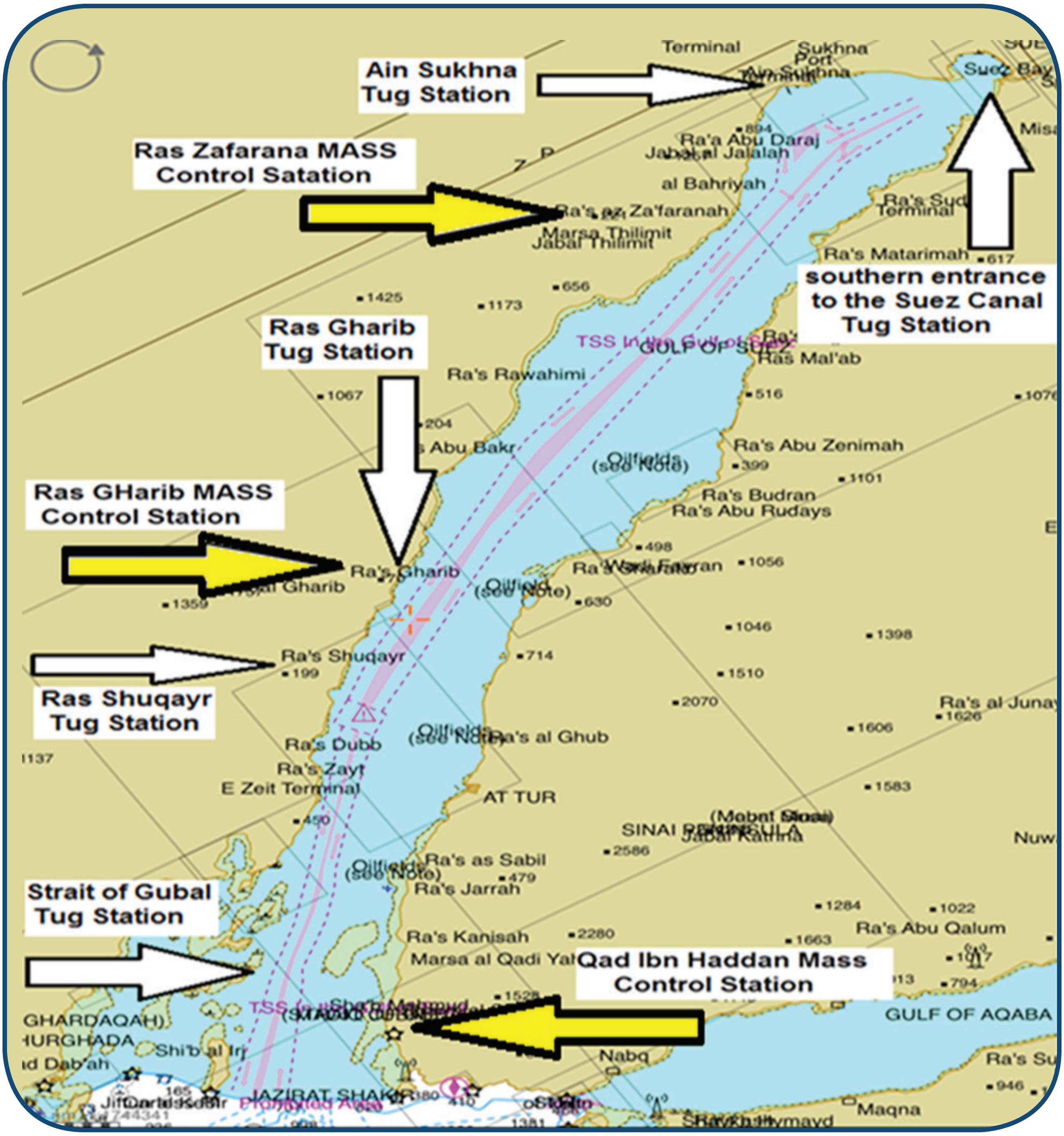


Fig. 10. Proposed MASS control stations and tugboat mooring stations in the GOS
Source: Photo by Transas ECDIS of Aida IV (08/2022)

CONCLUSION

The primary objective of this research paper is to demonstrate the impact that the sailing of MASS in the GOS could have on the safety of navigation, maritime security, and environmental protection. The most significant advantages and disadvantages of MASS highlighted in this study are based on the most recent literature available at the time this paper was written.

Due to the significance of the GOS to world trade and economy, ensuring that ships can navigate through it safely should be a top priority, and any potential threats to this safety should be in continuous and thorough investigation.

The purpose of this paper was to protect both the safety of navigation and the marine environment by conducting a comprehensive investigation of the six primary threats and their effects on the GOS. According to the results of a questionnaire completed by fifteen maritime transport experts, MASS operations in the GOS will have a negative impact on the quality of the marine environment protection, the safety and security of navigation.

When comparing the findings of this study with those of other studies that have been published in the past, we can conclude that the current findings confirm the presence and effects that have been established in the past. Even so, there are divergent views regarding its order of priority. This is evidence that the GOS region is distinct from other regions and has its own distinctive features. This emphasizes the significance of taking measures to ensure the safety of navigation in this vital region and putting those measures into effect. Therefore, before allowing MASS to navigate through the GOS, regulations, precautionary measures, and policies must be developed and evaluated, as suggested by the researchers.

Ultimately, Developers and operators could use the findings of this paper to concentrate their efforts on the areas of autonomous shipping safety where they are most needed to make the shipping industry safer.

REFERENCES

Ahvenjärvi, S. (2016) The human element and autonomous ships. TansNav, The International Journal on Marine Navigation and Safety of Sea Transportation, 10(3), pp. 517-521. Available from: DOI: 10.12716/1001.10.03.18 .

Valdez Banda, O.A. et al. (2015) 'A risk analysis of winter navigation in Finnish sea areas', *Accident Analysis and Prevention*, 79. Available at: https://doi.org/10.1016/j.aap.2015.03.024.

Bogusławski, K. et al. (2022) 'Implications of autonomous shipping for maritime education and training: the cadet's perspective', *Maritime Economics and Logistics*, 24(2). Available at: https://doi.org/10.1057/s41278-022-00217-x.

Chang, C.H. et al. (2021) 'Risk assessment of the operations of maritime autonomous surface ships', *Reliability Engineering and System Safety*, 207. Available at: https://doi.org/10.1016/j.ress.2020.107324.

Numan, D. (2020), Autonomous Ships: A Review, a Research, a Project Available from: https://www.academia.edu/44533352/Autonomous_Ships_a_Review_a_Research_a_Project.

Dreyer, L. O.and Oltedal, H.A. (2019), Safety Challenges for Maritime Autonomous Surface Ships: A Systematic Review. Available from: https://www.hvl.no/contentassets/64ae7d1b669c4d91ab5d8080ce76611e/safetychallengesformaritimeautonomoussurfaceships_dreyer.pdf.

Andrzej, F and Karolina, Z. (2020), The Ocean-Going Autonomous Ship—Challenges and Threats, Journal of marine science and engineering. Available from: https://pdfs.semanticscholar.org/d437/838e2ac3f8f772b4c2a37c6b3141ecd41703.pdf?_ga=2.18658681.1350919313.1672176127-1941943219.1643150761 .

International Maritime Organization (IMO) (2017). MSC: Maritime Safety Committee (MSC).428(98): Maritime Cyber Risk Management in Safety Management Systems, London: International Maritime Organization Available from: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MSCResolutions/MSC.428(98).pdf [Accessed: 18th September, 2022].

International Maritime Organization (IMO) (2018).MSC: Maritime Safety Committee (MSC), 100th session, 3-7 December 2018: Outcome of the Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS), London: International Maritime Organization Available from: https://www.imo.org/en/Media Centre/MeetingSummaries/Pages/MSC-100th-session.aspx [Accessed: 15th September, 2022].

International Maritime Organization (IMO) (2022). MSC-LEG-FAL: Maritime Safety Committee, Legal Committee (LEG) and Facilitation Committee (FAL) Joint Working Group on Maritime Autonomous Surface Ships (MASS), London: International Maritime Organization Available from: https://www.imo.org/en/MediaCentre/ MeetingSummaries/ Pages/ Joint-MSC-LEG-FAL-Working-Group-on-MASS.aspx [Accessed:16th September, 2022].

Insurance Marine News (2022). Japan demonstrates long distance autonomous ship operations Available from: https://insurancemarinenews.com/ insurance-marine-news/japan-demonstrates-long-distance-autonomous-ship-operations/ [Accessed:10th August, 2022].

Marel, K. (2021) Colregs and Autonomous Ships: Legal and Ethical Concerns under Canadian Law, Maritime safety and security law journal, Issue 8. Available from https://www.marsafelawjournal.org/wp-content/uploads/2021/07/ MarSafeLawJournal content/uploads/2021/07/ MarSafeLawJournal_Issue-8__Katsivela.pdf/

Kim, T. eun and Mallam, S. (2020) 'A Delphi-AHP study on STCW leadership competence in the age of autonomous maritime operations', *WMU Journal of Maritime Affairs*, 19(2). Available at: https:// doi.org/10.1007/s13437-020-00203-1.

Komianos, A. (2018) 'The Autonomous Shipping Era. Operational, Regulatory, and Quality Challenges', *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, 12(2). Available at: https://doi. org/10.12716/1001.12.02.15.

Marine Traffic, (2019) the marine traffic density in the northern part of the Red Sea https://www. marinetraffic.com/en/ais/home/. Cited on 17th August 2022 Available online.

MUNIN (2015) D9.2: Qualitative assessment. Available at: http://www.unmanned-ship.org/munin/ wp-content/uploads/2015/10/MUNIN-D9-2-Qualitative-assessment-CML-final.pdf Cited on 19th August 2022 Available online.

Munim, Z.H. (2019) 'Autonomous ships: a review, innovative applications and future maritime business models', *Supply Chain Forum.* Available at: https://doi.org/10.1080/16258312.2019.163 1714.

NYK line news releases (2019): NYK completes world's first autonomous ship trial voyage from China to Japan Available from: https://www.seatrade-maritime.com/asia/nyk-completes-world-s-first-autonomous-ship-trial-voyage-china-japan. [Accessed: 18th August, 2022].

Perera, L.P. (2018) 'Autonomous ship navigation under deep learning and the challenges in colregs', in *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering - OMAE*. Available at: https://doi.org/10.1115/ OMAE2018-77672.

Suez Canal Authority (2020): Navigation statistics report, monthly number & net ton by ship type February, 2020 Available from: https://www. suezcanal.gov.eg/English /Navigation/Pages / NavigationStatistics.aspx [Accessed: 15th August, 2022].

U.S. MARAD Alert 013 (2019): GPS Interference in both the Eastern Mediterranean and Central Mediterranean Available from: https://www.maritime.dot.gov/msci/2019-013-easterncentral-mediterranean-sea-and-suez-canal-gps-interference [Accessed: 18th August, 2022].

Wróbel, K., Gil, M. and Montewka, J. (2020) 'Identifying research directions of a remotely-controlled merchant ship by revisiting her system-theoretic safety control structure', *Safety Science*, 129. Available at: https://doi.org/10.1016/j.ssci.2020.104797.

Wróbel, K., Montewka, J. and Kujala, P. (2017) 'Towards the assessment of potential impact of unmanned vessels on maritime transportation safety', *Reliability Engineering and System Safety*, 165. Available at: https://doi.org/10.1016/j.ress.2017.03.029.

Xu, H., Rong, H. and Guedes Soares, C. (2019) 'Use of AIS data for guidance and control of path-following autonomous vessels', *Ocean Engineering*, 194. Available at: https://doi.org/10.1016/j.oceaneng.2019.106635.

Maritime Accidents Analysis Using Maritime Human Factors and Analysis Model

Eslam A. Youssef [(1)], Sameh F. El-Sayed [(2)] and Said Abdelkader [(3)]

[(1), (2)] Maritime Postgraduate Studies Institute, AASTMT, Alexandria, Egypt
[(3)] Mechanical Engeniring, College of Maritime Transport & Technology, AASTMT, Alexandria, Egypt

Emails: eslamadel79@student.aast.edu, samfarahat@aast.edu, abdelkader500@ aast.edu

Received on: 13 September 2022 Accepted on: 22 October 2022 Published on: 27 January 2023

Abstract

Purpose: *The majority of global trade is still carried out by the commercial shipping sector although it lags behind other transport sectors in terms of safety and accident reduction. Human error is recognized as the most likely cause of maritime accidents. As such, the literature focuses on the impact of human error on maritime safety. Human Reliability Analysis (HRA), Human Error Identification (HEI), and accident analysis are the most common techniques used to examine the human error. The initial goal of this paper is to give a general overview of the various types of analysis models and methods that are accessible. The goal is not to give a thorough overview of analysis methods. Instead, it serves to inform the readers of the broad ideas that underlie each category and to offer them a point of reference for any further research they choose to conduct. So, the paper focuses on the accident analysis division of accident investigation techniques.*

Design/Methodolgy/Approach: *In particular, this paper thoroughly examines the Human Factors Analysis and Classification System (HFACS) as a qualitative analytic model to assess active and latent failures reported in maritime accident reports. A collision accident is taken as a case study, a step-by-step analysis is undertaken, and human error causal factors are singled out.*

Findings: *The HFACS-MA approach was assessed for its potential as a way of analyzing maritime accidents in the current research, and it was determined to be quite suitable.*

Key-words:
Maritime Accidents, Accident analysis, Human Factors Analysis and Classification System (HFACS), HFACS maritime version.

BACKGROUND

Accidents normally happen due to negligence, but their consequences are permanent and lasting. The impact includes not only humans but also marine life, as well as marine environment and ecosystems. There are several causes of maritime accidents.

A significant proportion of maritime accidents can be directly related to human error. This means that crew members must be well-trained and alert to dangerous situations. Some of the causes of human error that lead to accidents at sea are (i) lack of sleep leading to fatigue, (ii) lack of experience and preparation, (iii) long voyages, (iv) personal relationships on board, (v) reckless behavior, including abuse of drugs and alcohol, (vi) bad decision-making and/or neglect, and (vii) pressure and stress during the service, among others.

LITERATURE REVIEW

Inshore and offshore workers face many dangers. The specific dangers that must be faced depend largely on the type of work their ship is doing. The crew who work at sea for an extended period of time faces hazards other than those on an offshore oil rig. One thing remains the same, working at sea is dangerous. Examples of typical maritime accidents include explosions, fires, relocation of improperly secured cargo, leading to injuries, skid, and fall, poor/misplaced equipment, control/navigation failures, grounding, collisions with other vessels or fixed structures, and many more (Shaw, 2021).

Akyuze et al. (2016) proposed a methodological approach by integrating Human Factors Analysis and Classification System (HFACS), Analytic Hierarchy Process (AHP), and majority rule to quantify the Error-Producing Conditions (EPCs) for the marine industry. Furthermore, Chan et al. (2016) investigated past research on maritime accidents attributed to human error with emphasis on the accident of MV Sewol that occurred in 2014 due to overloading. They concluded that human error could be reduced by increasing control and survey, increasing the usage of alert signs, using accurate working standards, improving Standards of Training, Certification, and Watch-keeping (STCW), implementing International Safety Management (ISM) Code, installing more alert tools, having more onboard hierarchical risk assessment system, and increasing the simulator-based training.

Another approach based on a safety assessment theory was introduced by Islam et al. (2017a) which identified the most important factors that influence seafarers to make an error during maintenance activities in marine and offshore operations. The factors are extreme weather, extreme workplace temperature, high ship motion, high level of noise and vibration, work overload and stress, which increase the likelihood of human error as well as potential accidents. To do so, they revised and modified the conventional Human Error Assessment and Reduction Technique (HEART) to estimate the Human Error Probabilities (HEPs) for the maintenance procedures in marine operations during various environmental and operational conditions.
Another study was performed by Islam et al. (2017b) which developed a monograph for assessing the likelihood of human error in marine operations that can be applied to instant decision-making. That monograph supports the decision-making process in a short period of time and enables chief engineers or captains to select the most suitable seafarers to complete maintenance tasks successful. It can also help them to be better prepared and to prioritize marine operation activities. Besides, it can help tackle the frequency of human error and serves to increase the overall safety of maintenance procedures in marine operations through the use of the Success Likelihood Index Method (SLIM) to estimate the (HEPs).

Furthermore, Islam et al. (2018) highlighted the concern associated with human performance during maintenance operations on ships as a part of maritime quantitative risk assessment by studying the generalization of data identifying the relative importance of the performance-affecting factors, collecting data to develop human error assessment techniques for more accurate (HEPs) estimation in marine environmental conditions, identifying the relative importance of performance-affecting factors for the maintenance operations of marine systems by structured questionnaire method, and then analyzing the collected data for normality and for a pairwise significance test.

In addition, Nosov et al. (2019) noted that the subjective entropy or lack of order or predictability, gradually falling into disorder, is an indication of negative human error in maritime transportation. They introduced the development of a data system to identify negative manifestations of human error to use the proposed formal methods, patterns, and algorithms to ensure maritime safety. These methods form the basis of navigator behavior analysis in emergency situations and determine the mathematical expectations of navigator behavior in emergency situations. The formal methods have been confirmed by the simulation patterning using the navigation simulator "Navi-Trainer Professional 5000" NTPRO 5000.

More recently, Zogorsky (2020) presented the validity of the Human Factors Analysis and Classification System - Fishing Vessel (HFACS-FV), using ten-year data documenting the causes of fatal accidents in the commercial fishing industry, by developing and evaluating a version of Wiegmann and Shappell's (2003) HFACS, that is the analysis of human factors for the causes of marine accidents and retrospective analysis of accidents using advanced human error methodology in commercial fatal accidents on fishing vessels.

The aim of the paper is to bring to the readers a panoramic picture of maritime accident techniques, but not to give a detailed rundown of these techniques. In doing so, the different techniques will first be categorized, and a general understanding of the concepts that underlie each category will be furnished, thus providing a point of reference for any forthcoming research in this field.

METHODOLOGY

An analytical descriptive methodology is used herein. The open literature on accident investigation and analysis, with particular emphasis on maritime accidents, is first reviewed and relevant sources are collected. The general classification of accident investigation models is first presented briefly and the most important models in each class are singled out. Then, a closer focus is made on accident analysis models. Salient features, as well as points of strength and weakness of each model, are discussed. Application of potential models of this class is highlighted and a particular model for further use in maritime accident analysis is selected. Reasons behind this selection are given and a detailed procedure for applying the model to analyze a maritime collision accident is furnished. A typical collision accident is taken as a case study and human error factors, whether active or latent and likely to have caused the accident, are singled out.

Techniques to Investigate Human-error-based Accidents

Based on the above literature review it becomes possible to classify techniques used to investigate maritime accidents caused by human error into three main categories: (i) Human Reliability Assessment (HRA) such as (CREAM - HEART), (ii) Human Error Identification (HEI) such as (ATHEANA - SHERPA), and Accident Analysis (AA) such as (HFACS - STAMP) Zohorsky (2020).

The HRA is the probability of humans conducting specific tasks with satisfactory performance. Tasks may be related to equipment repair, equipment or system operation, safety actions, analysis, and other kinds of human actions that influence system performance. Further details can be found in HSE (2009), Calixto (2016), Bai and Jin (2016), and Alexander (2019).

The HEI provides a proactive strategy for studying human errors in complex sociotechnical systems, identifying potential errors and determining their causative factors, consequences, and recovery strategies. For more details, the reader is advised to consult Salmon et al. (2010), and Alexander (2019).

The third category includes the AA models, which are dealt with herein in greater detail, since one of the main objectives of this endeavor is to select a suitable AA model for application in the maritime field, particularly in the analysis of human-error-based maritime accidents. The most important models used in accident analysis included human errors count to some (29) models. According to Hollnagel and Goteman's (2004), these models are divided into three subcategories, some which are shown in Figure 1.

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.044

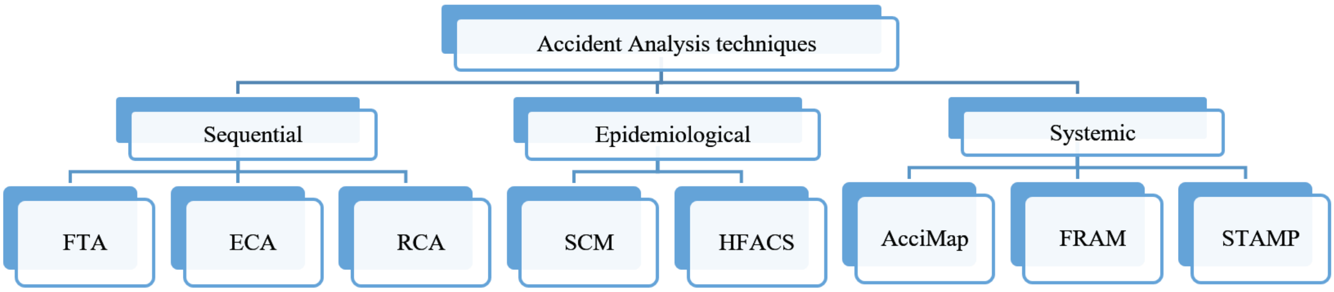


Fig 1: Examples of different techniques used in accident analysis
Source: Hollnagel and Goteman (2004)

1- Sequential techniques that evaluate the cause and effect of a linear accident, and include (a) fault tree analysis, (b) event/consequence tree analysis, and (c) root cause analysis.
2- Epidemiological techniques, which take into account latent and active contributions
to accidents and were named for their similarities to the distribution of illness
and disease as compared to how latent factors adversely affect the organizational and supervisory conditions within the system. Examples of epidemiological techniques are (a) The Swiss cheese model (SCM) and (b) HFACS.
3- Systemic techniques, which evaluate the interaction between system components as a systematic approach, which is essential to understanding how a system works or fails (Underwood, Peter, 2019). Examples of Systemic techniques are (a) the AcciMap model, (b) the FRAM model, and (c) the STAMP model.
To increase safety, one must first understand why accidents happen and how to avoid them in the future. The accident analysis techniques are a crucial tool for achieving this insight. Therefore, in this paper, only the accident analysis techniques will be studied.

Hulme et al. (2019) outlined HFACS research statistics in literature reviews through July 31, 2018. After searching four databases (PubMed, ScienceDirect, Scopus, Web of Science), a total of 690 articles were identified. After removing 197 duplicates and examining 493 titles and summaries, a total of 43 HFACS studies were included; 14 studies were published between 2000 and 2009 (9 years), and 29 studies were published between 2010 and July 31, 2018 (8 years and 6 months). Utilization of the HFACS model in studies approximately doubles over the same period. They also noted that more than 60% of the studies used HFACS in a modified form to analyze how a network of interacting latent and active factors contributed to the occurrence of an accident.

HFACS Model

The Human Factors Analysis and Classification System (HFACS) model was first developed by Shappell and Wiegmann (2000) and further modified by them (2003) to include four stages of failure based on Reason's (1990) idea of latent and active failures as illustrated in Figure 2.

ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.044

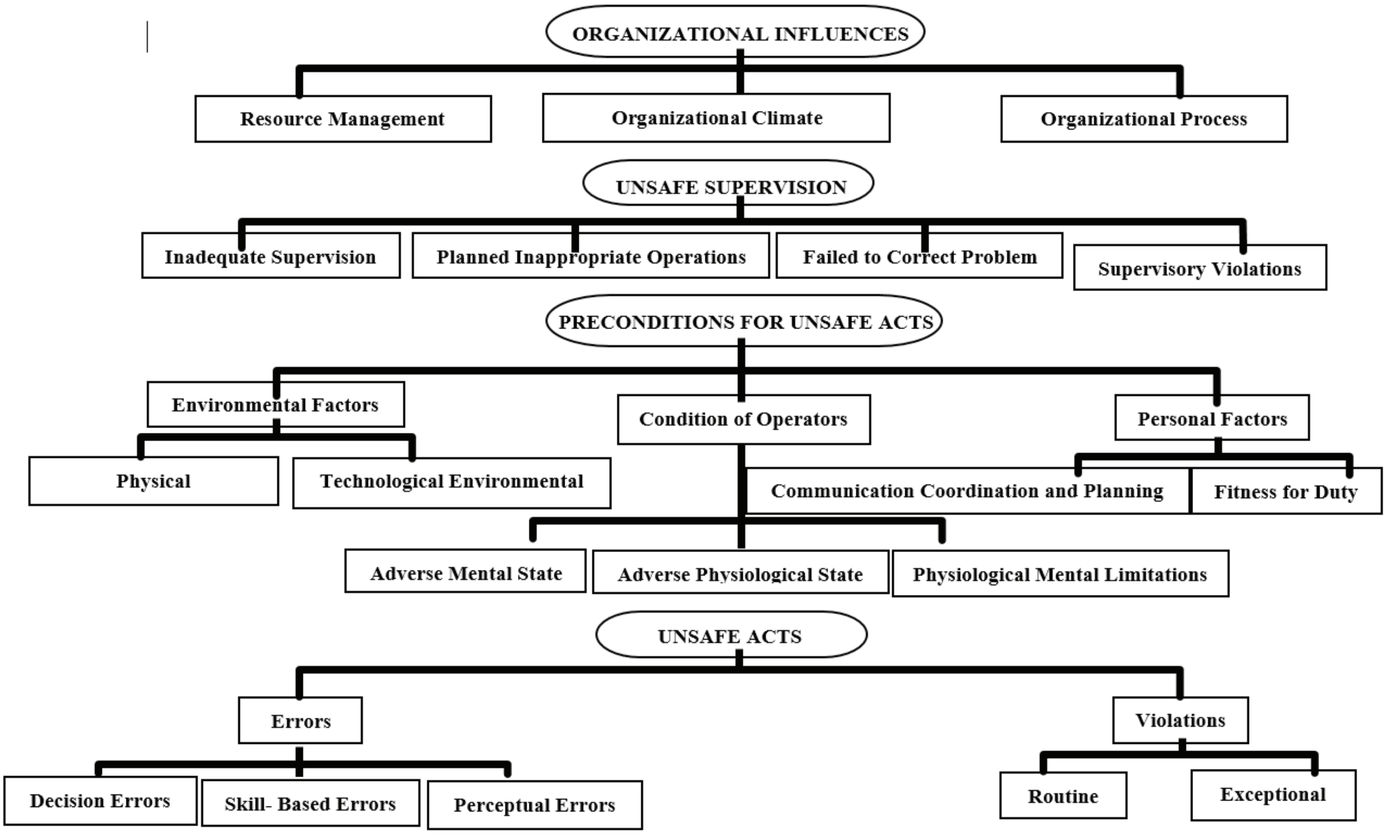


Fig 2: HFACS Framework

Source: Shappell and Wiegmann (2003)

Over the years, new versions of HFACS have been developed; some of which are of particular importance to maritime accident investigation specialists, such as the HFACS-MA model, which is considered herein. Details of these versions can be found elsewhere, Scarborough and Ponds (2001), Krulak (2004), U.S. Department of Defense (2005), Reinach and Viale (2006), Li and Harris (2006), Australia Government Department of Defense (2008), Patterson and Shappell (2010), Schröder-Hinrichs et al. (2011), Kim et al. (2011), Chen et al. (2013), Chauvin et al. (2013), Mazaheri et al. (2015), Soner et al. (2015), Theophilus et al. (2017), Cohen et al. (2018), Ugurlu et al. (2018), Zohorsky (2020), J. Wang et al (2020), Sarıalio˘glu et al (2020), Lin et al (2021), and Yang and Kwon (2022).

HFACS-MA Version

In this paper, the HFACS-MA framework, recently developed by Kim et al. (2011), was used to analyze human factors related to towing vessel accidents. As shown in Figure 3, the HFACS-MA model divides into three stages: organizational influences, preconditions for unsafe acts, and unsafe acts.

Application of HFACS-MA

An example will show how to use the HFACS-MA model to analyze maritime accidents, as shown in Figure 4.

MRT ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.044

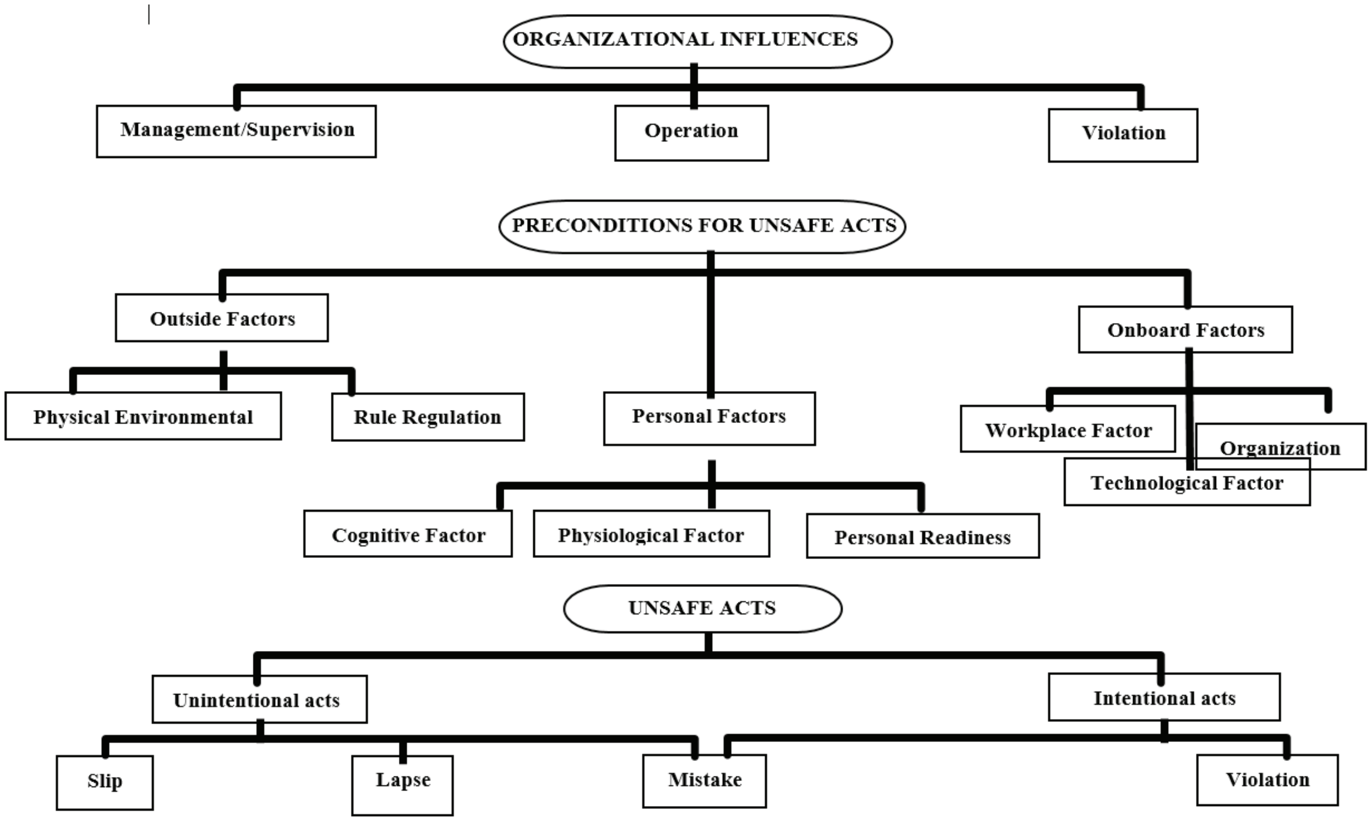


Fig 3 : HFACS-MA framework - Source: Kim et al. (2011)

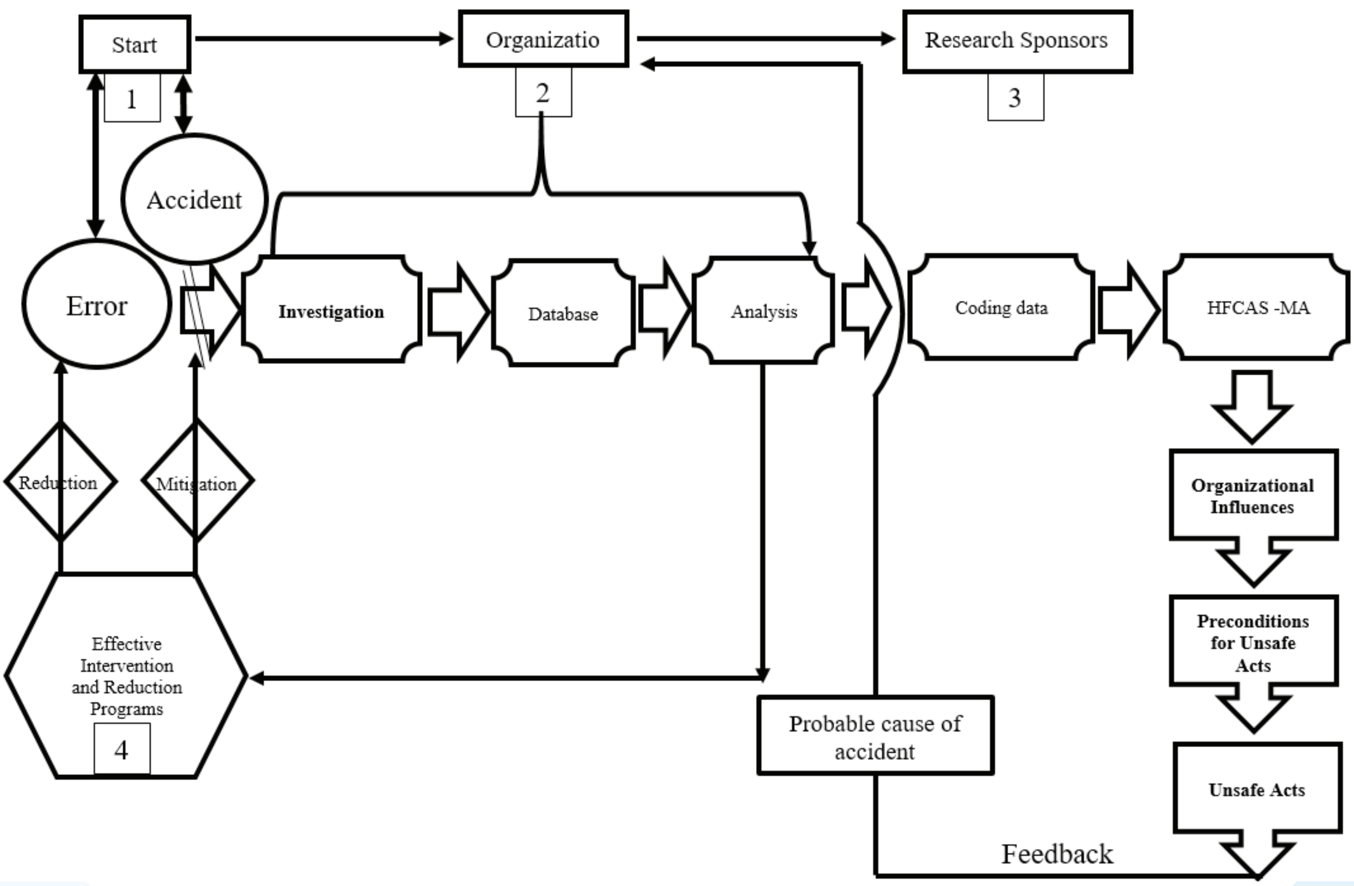


Fig 4: Flowchart of HFACS-MA application prepared by the authors

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.044

Identification of human errors

At the start, human errors which may have caused the accident are singled out and the accident report is prepared and analyzed by the organization. The report should usually include the sequence of events gathered data and analysis.

Investigation/ Database/ Analysis

A maritime accident report that was created by the National Transportation Safety Board (NTSB) in the U.S.A. is considered the sequence of events. In this example, a maritime collision accident between the offshore supply vessel Cheramie Bo Truc No. 22 and the articulated tug and barge (ATB) Mariya Moran/ Texas is considered, brief description is shown in table 1. The accident report prepared by the NTSB (2019) is available; a detailed sequence of events, data selection, and data analysis are explained in the report, which is not included here for brevity.

Table 1: Brief description of collision of towing vessel Maryia Moran

Owner/operator	Moran Towing Corp.
Port of registry	Wilmington, Delaware
Year built	2015
Official number (US)	1257668
Persons on board	9
Accident time	At 0415 on November 14, 2019
Accident location	Sabine Pass Jetty Channel, Port Arthur, Texas 29°40.90′ N, 093°50.12′ W
The number of injuries	None
Property damage	1,854,572 dollars est.
Environmental damage	Estimated 6,641 gallons of diesel oil released
Weather	Visibility 6 miles, light rain, winds northeast-by-north 6 knots, gusts 8 knots, ebb current 0.16 knots, air temperature 44°F.

Research sponsors

The authors of this article will play the role of research sponsor, using the HFACS-MA framework classified into three levels of organizational influences, precondition for unsafe acts, and unsafe acts are sought then make a relation of causal factors between levels to extract the results. In terms of the Maryia Moran accident, 13 accident causation factors are identified according to the authors' experience, and the accident causation factors are listed in Tables 2 and 3.

Table 2: Description of categories involved in the HFACS-MA framework

		Latent Failures		Category	Code	Authors' identification
HFACS-MA	Precondition for Unsafe Acts	Outside factor	Physical environment	Weather	a.1	
				Vessel over-traffic	a.2	
				VTS failures	a.3	✓
				Obstacle	a.4	
				Inappropriate navigation aid	a.5	✓
				Poor navigation aid	a.6	
				Inappropriate Notice to Mariner	a.7	
				Mismanagement of waterway	a.8	✓
				Inappropriate port facilities	a.9	
				Shallow water	a.10	
				Narrow waterway	a.11	
				Strong current	a.12	
				Frozen condition	a.13	
				Drift ice area	a.14	
				Pilot failures	a.15	
				Etc.	a.16	
			Rule regulation	Local special navigation regulations	b.1	
				International regulations & Codes	b.2	✓
				Flag State regulations	b.3	
				Port State regulations	b.4	
				Others	b.5	
		Personnel factors	Cognitive factor	Complacency	c.1	
				Mental fatigue	c.2	
				Nerves	c.3	
				Haste, Flustration	c.4	
				Distraction	c.5	
				Negative affectivity	c.6	
				High-self confidence	c.7	
				Low-self confidence	c.8	
				Low work satisfaction	c.9	
				Immoderate reliance on automated system	c.10	
				Personality	c.11	
				Mental disease	c.12	
				Others	c.13	
			Physiological factor	Physical fatigue	d.1	
				Physical disease	d.2	
				Alcohol, Drugs	d.3	✓
				Sight or hearing disability	d.4	
				Body condition	d.5	
				Motor ability	d.6	
				Age, Sex	d.7	
				Others	d.8	

			Personal readiness	Inadequate qualification (physical, aptitude, etc.)	e.1	
				Lack of knowledge	e.2	
				Mis-knowledge	e.3	
				Lack of skills	e.4	
				Estimate of the situation inability	e.5	✓
				Erroneous assumption, prediction, prejudice	e.6	✓
				Inappropriate habit	e.7	
				Previous accident experience	e.8	
				Others	e.9	
		Onboard Factor	Organization	Inappropriate custom regulation	f.1	
				Organizational pressure (workload, workhour)	f.2	
				Inaccurate responsibility & duty	f.3	✓
				Aberrant communication	f.4	
				Improper duty handover	f.5	
				Inappropriate placement of human resources	f.6	
				Chilling effect of seafarers	f.7	
				Seafarers' interaction	f.8	
				Leadership problem (superior supervision)	f.9	
				Immoderate authoritarianism	f.10	
				Lack of authority	f.11	
				Inappropriate procedure, regulations, instructions	f.12	✓
				Education-training onboard	f.13	
				Staffing of seafarers (nationality, qualification)	f.14	
				Others	f.15	
			Technological factor	Ship design	g.1	
				Equipment & tool (utility, reliability)	g.2	
				Maintenance check-up	g.3	
				Cargo property	g.4	
				Cargo handling management	g.5	

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.044

				Draft (loadage, overload)	g.6	
				Kinds of ship certification	g.7	
				Others	g.8	
			Workplace factor	Lighting	h.1	
				Noise	h.2	
				Temperature, humidity	h.3	
				Vibration	h.4	
				Cleanliness	h.5	
				Atmosphere (stench, fumes, gases)	h.6	
				Ergonomic design of workplace	h.7	
				Work characteristics	h.8	
				Influence by others in workplace	h.9	
				Absence or misarrangement of equipment	h.10	
				Automation level of ship	h.11	
				Diet suitability	h.12	
				Others	h.13	
	Organizational Influences	Management / Supervision		Boarding inappropriate seafarers	i.1	
				Insufficient management of eligibility of seafarers	i.2	
				Education-training absence	i.3	
				Education-training deficiency	i.4	
				Inappropriate education-training contents	i.5	
				Inappropriate education-training procedure	i.6	
				Insufficient assessment or development of education-training	i.7	
				Mismanagement of equipment & supplies	i.8	
				Others	i.9	
		Operation		Operation tempo	j.1	
				Inappropriate operating system	j.2	
				Inappropriate ship operation plan	j.3	
				Absence of safety culture	j.4	✓

				Management environment (economic, political, legal, social condition, etc.)	j.5	
				Budget problem	j.6	
				Inappropriate reward and punishment system	j.7	
				Poor working condition (vacation, shift system)	j.8	
				Hiring policy	j.9	✓
				Accident emergency countermeasures	j.10	
				Others	j.11	
		Violations		Boarding unqualified seafarers	k.1	
				Onboard standards violation	k.2	
				Violate behavior connivance	k.3	
				Others	k.4	
	Unsafe Acts	Active Failures		Category	Code	
		unintentional acts	Slip	Skill-Based Errors (SBE), Momentary attention failure	l.1	
			Lapse	Skill-Based Errors (SBE), Momentary memory problem	m.1	
		intentional acts	Mistake	Knowledge-Based Errors (KBE)	n.1	
			Violation	Routine Violations (RV)	o.1	✓
				Exceptional Violations (EV)	o.2	✓

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.044

Table 3: Causation factors associated with the Maryia Moran accident

S/N	Code		Accident Causes	Data quality
1	a.3	VTS failures	The VTS watch stander noticed the Cheramie Bo Truc No 22's "course had changed abruptly," placing the vessels on a collision course. He reached out to the Cheramie Bo Truc No 22 once, on channel 1A (which vessels were required to monitor while transiting the area), with no answer.	5
2	a.5	Inappropriate navigation aid	After narrowly avoiding the jack-ups, automatic identification system (AIS) and VTS data showed the Cheramie Bo Truc No 22 crossed the channel at 0400 at a near right angle, then followed the east side of the channel.	
3	a.8	Mismanagement of waterway	The Maryia Moran/Texas was in the center of the channel, making 8 knots over ground against an ebb tide, according to the chief mate.	
4	b.2	International regulations & Codes	Inland Navigation Rules require either a port-to-port passage or communication either by radio or whistle signal for an agreed-upon alternate passage between two vessels.	
5	d.3	Alcohol, Drugs	The Cheramie Bo Truc No 22-captain used saliva swab test kits, and the mate's results indicated a blood alcohol concentration of at least 0.02 grams per deciliter (g/dL). The regulatory limit for commercial mariners is 0.04 g/dL.	
6	e.5	Estimate of the situation inability	The Maryia Moran/Texas pilot hailed the Cheramie Bo Truc No 22 on channel 13, to which the mate answered. During the radio call, believing a collision was imminent on the Cheramie Bo Truc No 22.	
7	e.6	Erroneous assumption, prediction, prejudice	Attempting to use the autopilot in a channel, nearly colliding with stationary jack-ups, weaving across the channel, ignoring the warnings from the on-watch AB and engineer in the wheelhouse, and suddenly turning in front of the ATB all indicate a degree of misjudgment, impairment, and/or incompetence.	
8	f.3	Inaccurate responsibility & duty	The Cheramie Bo Truc No 22 AB and engineer recognized the developing hazardous situation as the mate started the turn toward the ATB and again advised the mate to steer to port. The mate ignored their concern. They did not take further action despite the hazardous situation.	
9	f.12	Inappropriate procedure, regulations, instructions	The Cheramie Bo Truc No 22 AB and engineer stated they had to correct the mate's steering in the channel twice (before the turn in front of the ATB), but they did not summon the captain.	
10	j.4	Absence of safety culture	Although both vessels were aware of each other, no VHF radio passing arrangement or maneuvering signals were made. Contributing to the accident was a lack of early communication from both vessels.	
11	j.9	Hiring policy	The Cheramie Bo Truc No 22 was crewed with a master, mate, unlicensed engineer, and two able seamen (ABs).	
12	o.1	Routine Violations (RV)	L&M Botruc Rental's Alcohol, Firearms, and Controlled Substances Policy prohibited alcohol from being consumed or brought on company property.	
13	o.2	Exceptional Violations (EV)	The manual for the Cheramie Bo Truc No 22's autopilot specifically warned users not to use autopilot in a "harbor entrance or narrow channel." Despite this warning, the mate attempted to use the autopilot after getting under way on the accident voyage.	

After that, the authors classified the code table for latent factors of Levels 1 and 2 specified in the guideline for maritime accident investigation. After all the data were coded, the contributing factors were classified under the three levels of the HFACS-MA. For the next step, the factors in each category were subdivided into sub-categories depending on their attribute. This stage allowed the authors to confirm the contributory factors under each level of the HFACS-MA framework by the different types of accidents. After the classification was completed, the process of the relational analysis of contributing factors between each level was performed by accident type.

Encoding causal factors

Table 4 illustrates the frequency of causal factors of one accident investigation report as well as the percentage, which represents the frequency of occurrence to the total 9 contributory factors. The category of the highest proportion of HFACS-MA category is the pre-conditions for unsafe acts (69.2 %), followed by the organizational Influences (15.4 %) and the unsafe acts (15.4 %). The 15 subcategories of contributing variables assigned to each HFACS-MA category are then further categorized. At level 1 of pre-conditions for unsafe acts, outside factors show the highest ratio in the accident reports, accounting for (23 %). The physical environment in outside factors and rule regulation in personnel factors were the highest at (23 %) and (7.7 %), in sequence. Among level 2 of the organizational influences category, the factors related to the company's operation were higher than operation, with (15.4 %) and (0 %), in sequence. In level 3 of the category of the unsafe act, the proportion of violations accounted for (7.7 %), as mistakes (7.7 %). However, none of the reports referred to the causal factors involved in the unintentional acts of seafarers.

One accident report of collision have found 13 contributory factors. Figure 5 shows a diagram of the relationships in which the contributing factors identified at each level are affecting contributing factors in 3 levels, in terms of collision accidents. The accident reports indicated that the latent failure of the collision, was due to a strong current, an estimate of the situation's inability, and erroneous assumption, prediction, and prejudice due to the captain or pilot or the relief captain. The active failure of the collision accidents was caused by routine violations and exceptional violations.

Table 4: Distribution of casual factors of HFACS-MA category

Levels	Category	Sub-category	Frequency	Percentage
Level 1 <u>*(9)*</u>	Pre-conditions for unsafe acts (69.2 %)			
	Outside factors <u>*(4)*</u>	Physical environment	3	23 %
		Rule Regulation	1	7.7 %
	Personnel factors <u>*(3)*</u>	Cognitive Factor	0	0 %
		Physiological Factor	1	7.7 %

Table 4: Distribution of casual factors of HFACS-MA category (Cont'd.)

Levels	Category	Sub-category	Frequency	Percentage
Level 1 <u>*(9)*</u>	Pre-conditions for unsafe acts (69.2 %)			
	Personnel factors <u>*(3)*</u>	Personal Readiness	2	15.4 %
	Onboard factors <u>*(2)*</u>	Organization	2	15.4 %
		Technological Factor	0	0 %
		Workplace Factor	0	0 %
Level 2 <u>*(2)*</u>	Organizational Influences (15.4 %)			
		Management / Supervision	0	0 %
		Operation	2	15.4 %
		Violations	0	0 %
Level 3 <u>*(2)*</u>	Unsafe acts (15.4 %)			
	unintentional acts	Slip	0	0 %
		Lapse	0	0 %
	intentional acts <u>*(3)*</u>	Mistake	1	7.7 %
		Violation	1	7.7 %
Total			9	100.0%

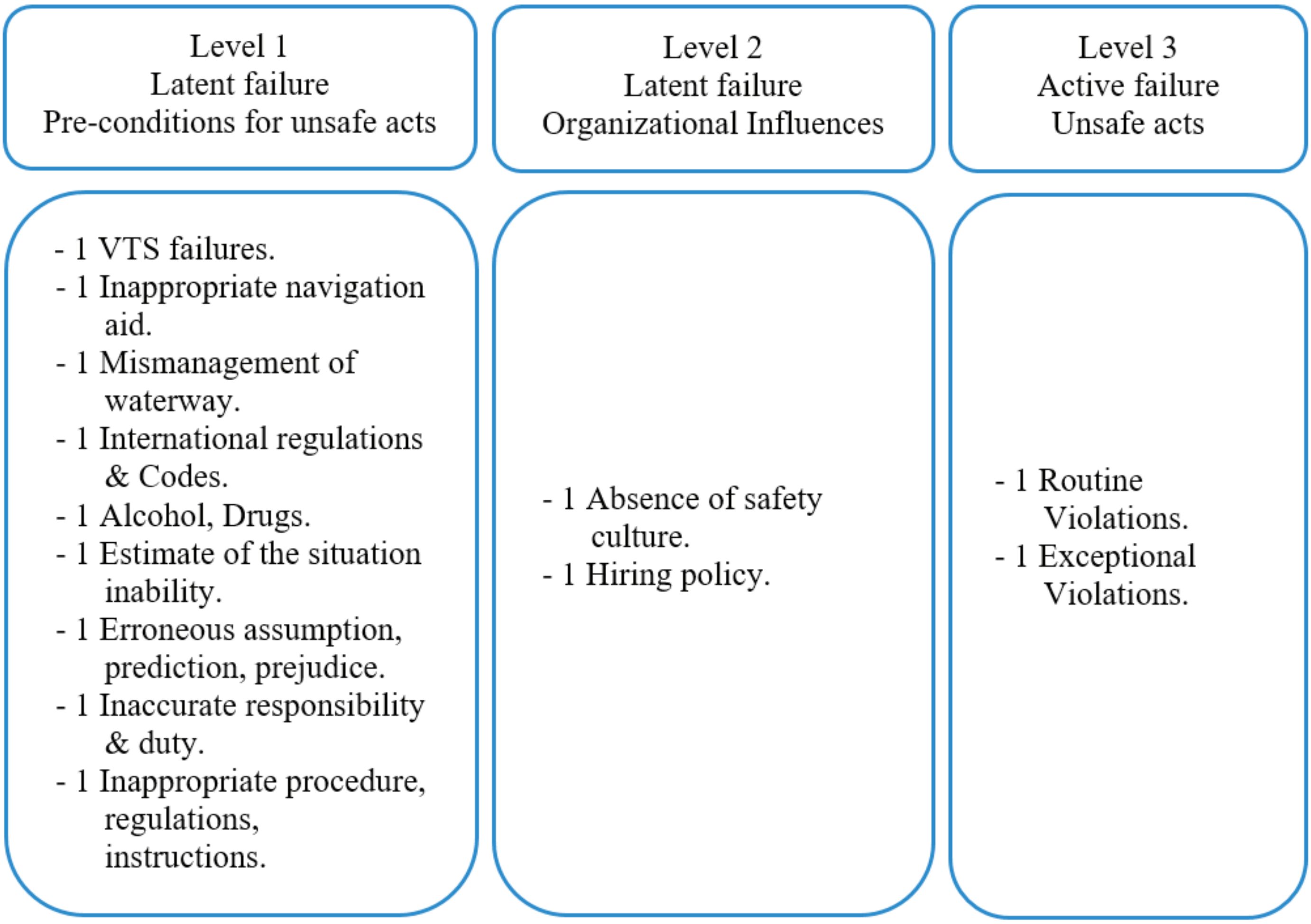


Figure 5: Relations of casual factors among levels

Effective intervention and reduction programs

This final step explored the specific pattern of the accidents and the contributing factors that need further inquest. The evaluation of investigative records assists in establishing the reason for the towing vessel accident pattern. Based on the relationships of contributing factors at each level by accident type, six patterns with active failure and latent failure have been discovered. Table 5 shows the ways to countermeasure the failure.

Table 5: The pattern of towing vessel accidents causes and countermeasure

Accident Type	Pattern #	Active Failure	Latent Failure	Implications	countermeasure
Collision	#1	Routine Violations (RV)	Boarding unqualified seafarers	Estimate of the situation inability	Commitment with the code of U.S. Federal Regulations
	#2	Exceptional Violations (EV)	Violation of the use of equipment	Unable to control the ship	Commitment with the international Standards by putting equipment operating instructions clearly on the equipment

Conclusion and Recommendations

One of the most difficult tasks accident analysts confront is to choose the appropriate, most effective technique to use. The current endeavor has assessed the potential of the HFACS-MA technique as means of analyzing maritime accidents and found it rather suitable for the following reasons: (a) Compared to other accident analysis methods, it has salient features and sound capabilities to extract the results and is easy to use in the analysis of maritime accidents, (b) It represents a reliable tool to analyze comprehensive accident investigation reports and to identify errors and adverse events underlying organizational systems, (c) It assists accident investigators in systematically identifying the active and latent organizational failures that lead to an accident, and (d) It can be used as a framework that reviews and analyses historical accidents.

The preceding arguments are supported by the results of earlier studies that compared a variety of accident investigation models and concluded that the HFACS-MA model is the best match for accident prevention and reduction strategies. The current work can be further augmented by investigating negative issues associated with the use of the HFACS-MA model, proposing suitable modifications to get around them and examining the reliability and accuracy of the modified model by comparing its results with those of other HFACS versions as well as with other competitive accident analysis models.

REFERENCES

Akyuz, E., Celik, M., Cebi, S., 2016. A phase of comprehensive research to determine marine-specific EPC values in human error assessment and reduction technique. Saf. Sci. 87, 63–75. https://doi.org/https://doi.org/10.1016/j.ssci.2016.03.013

Alexander, T.M., 2019. A case based human reliability assessment using HFACS for complex space operations. J. Sp. Saf. Eng. 6, 53–59. https://doi.org/10.1016/j.jsse.2019.01.001

Bai, Y., Jin, W.-L., 2016. Chapter 43 - Human Reliability Assessment, in: Bai, Y., Jin, W.-L.B.T.-M.S.D. (Second E. (Eds.), . Butterworth-Heinemann, Oxford, pp. 793–802. https://doi.org/https://doi.org/10.1016/B978-0-08-099997-5.00043-5

Calixto, E., 2016. Chapter 5 - Human Reliability Analysis, in: Calixto, E.B.T.-G. and O.R.E. (Second E. (Ed.), . Gulf Professional Publishing, Boston, pp. 471–552. https://doi.org/https://doi.org/10.1016/B978-0-12-805427-7.00005-1

Chauvin, C., Lardjane, S., Morel, G., Clostermann, J. P., & Langard, B. (2013). Human and organisational factors in maritime accidents: Analysis of collisions at sea using the HFACS. Accident Analysis & Prevention, 59, 26-37.

Chen, S.T., Wall, A., Davies, P., Yang, Z., Wang, J., Chou, Y.H., 2013. A Human and Organisational Factors (HOFs) analysis method for marine casualties using HFACS-Maritime Accidents (HFACS-MA). Saf. Sci. 60, 105–114. https://doi.org/10.1016/j.ssci.2013.06.009

Hollnagel, E., Goteman, Ö., 2004. The Functional Resonance Accident Model.

Hulme, A., Stanton, N.A., Walker, G.H., Waterson, P., Salmon, P.M., 2019. Accident analysis in practice: A review of Human Factors Analysis and Classification System (HFACS) applications in the peer reviewed academic literature. Proc. Hum. Factors Ergon. Soc. Annu. Meet. 63, 1849–1853. https://doi.org/10.1177/1071181319631086

Islam, R., Abbassi, R., Garaniya, V., Khan, F., 2017a. Development of a human reliability assessment technique for the maintenance procedures of marine and offshore operations. J. Loss Prev. Process Ind. 50, 416–428. https://doi.org/https://doi.org/10.1016/j.jlp.2017.10.015

Islam, R., Yu, H., Abbassi, R., Garaniya, V., Khan, F., 2017b. Development of a monograph for human error likelihood assessment in marine operations. Saf. Sci. 91, 33–39. https://doi.org/https://doi.org/10.1016/j.ssci.2016.07.008

Islam, R., Khan, F., Abbassi, R., Garaniya, V., 2018. Human error assessment during maintenance operations of marine systems – What are the effective environmental factors? Saf. Sci. 107, 85–98. https://doi.org/https://doi.org/10.1016/j.ssci.2018.04.011

Kim, H. T., Na, S., & Ha, W. H. (2011). A case study of marine accident investigation

and analysis with focus on human error. Journal of the Ergonomics Society of Korea, 30(1), 137-150.

Krulak, D. (2004). Human factors in maintenance: Impact on aircraft mishap frequency and severity. Aviation, Space and Environmental Medicine, 75, 429-432.

Lin, C., Xu, Q. and Huang, Y. (2021). Applications of FFTA-HFACS for Analyzing Human and Organization Factors in Electric Misoperation Accidents. Applied Sciences, 11(19), p.9008. doi:10.3390/app11199008.

Mazaheri, A., Montewka, J., Nisula, J. and Kujala, P. (2015). Usability of accident and incident reports for evidence-based risk modeling – A case study on ship grounding reports. Safety Science, 76, pp.202–214. doi:10.1016/j.ssci.2015.02.019.

National Transportation Safety Board [NTSB], 2020. Marine Accident Reports - Gulf of Mexico (USA) Marine Accident Reports - Gulf of Mexico (USA).

Nosov, P.S., Ben, A.P., Matejchuk, V.N., Safonov, M.S., 2019. IDENTIFICATION OF "HUMAN ERROR" NEGATIVE MANIFESTATION IN MARITIME TRANSPORT. Radio Electron. Comput. Sci. Control 0. https://doi.org/10.15588/1607-3274-2018-4-20

Patterson, J. and Shappell, S. (2010). Operator error and system deficiencies: Analysis of 508 mining incidents and accidents in Queensland, Australia using HFACS.Accident Analysis and Prevention, 42, 1379-1385.

Reinach, S. and Viale, A. (2006). Application of a human error framework to conduct train accident/incident investigations. Accident Analysis and Prevention, 38, 396-406.

Reason, J., 1990. The contribution of latent human failures to the breakdown of complex systems. Hum. Error Aviat. 484, 5–14. https://doi.org/10.4324/9781315092898-2

Salmon, P.M., Lenné, M.G., Stanton, N.A., Jenkins, D.P., Walker, G.H., 2010. Managing error on the open road: The contribution of human error models and methods. Saf. Sci. 48, 1225–1235. https://doi.org/https://doi.org/10.1016/j.ssci.2010.04.004

Sarıalioğlu, S., Uğurlu, Ö., Aydın, M., Vardar, B. and Wang, J. (2020). A hybrid model for human-factor analysis of engine-room fires on ships: HFACS-PV&FFTA. Ocean Engineering, 217, p.107992. doi:10.1016/j.oceaneng.2020.107992.

Scarborough, A. and Pounds, J. (2001). Retrospective human factors analysis of ATC

operational errors. In: Proceedings of 11th International Symposium on Aviation Psychology, Columbus, OH.

Schröder-Hinrichs, J., Baldauf, M., Ghirxi, K. (2011). Accident investigation reporting deficiencies related to organizational factors in machinery space fires and explosions. Accident Analysis and Prevention, 43, 1187-1196.

Shappell, Wiegmann, D.U.S., 2000. The Human Factors Analysis and Classification System-HFACS Office of Aviation Medicine The Human Factors Analysis and Classification System – HFACS through the National Technical Information.

Shappell, S. a, Wiegmann, D. a, 2003. A Human Error Analysis of General Aviation Controlled Flight Into Terrain Accidents Occurring Between 1990-1998. Final Rep. 1–25.

Shaw, C., 2021. Primary Causes of Maritime Accidents [WWW Document]. URL https://www.carabinshaw.com/primary-causes-of-maritime-accidents.html (accessed 9.19.21).

Soner, O., Asan, U., Celik, M. (2015). Use of the HFACS-FCM in fire prevention modelling on board ships. Safety Science, 77, 25-41.

Theophilus, S.C., Esenowo, V.N., Arewa, A.O., Ifelebuegu, A.O., Nnadi, E.O. and Mbanaso, F.U. (2017). Human factors analysis and classification system for the oil and gas industry (HFACS-OGI). Reliability Engineering & System Safety, 167, pp.168–176. doi:10.1016/j.ress.2017.05.036.

Uğurlu, Ö., Yıldız, S., Loughney, S., Wang, J., Kuntchulia, S. and Sharabidze, I. (2020). Analyzing Collision, Grounding, and Sinking Accidents Occurring in the Black Sea Utilizing HFACS and Bayesian Networks. Risk Analysis, 40(12), pp.2610–2638. doi:10.1111/risa.13568.

Underwood, Peter, and P.W., 2019. Accident analysis models and methods : guidance for safety professionals.

U.S. Department of Defense. (2005). Department of Defense Human Factors Analysis and Classification System Guide, Washington, DC.

Wang, X., Zhang, B., Zhao, X., Wang, L., Tong, R., 2020. Exploring the underlying causes of chinese eastern star, korean sewol, and thai phoenix ferry accidents by employing the hfacs-ma. Int. J. Environ. Res. Public Health 17, 1–19. https://doi.org/10.3390/ijerph17114114

Yang, J. and Kwon, Y. (2022). Human factor analysis and classification system for the oil, gas, and process industry. Process Safety Progress. doi:10.1002/prs.12359.

Zohorsky, P. (2020). Human Error in Commercial Fishing Vessel Accidents: An Investigation Using the Human Factors Analysis and Classification System. Engineering Management & Systems Engineering Theses & Dissertations. [online] doi:10.25777/sb7t-mr44.

MRT
ISSN 2812-5622

http://dx.doi.org/10.21622/MRT.2023.02.1.061

Evaluating Learning Management System and e-Learning Modules in Maritime Education

Emeliza T. Estimo [(1)] and John Erll N. Destacamento [(2)]

[(1),] Research and Development Center, [(2)] College of Maritime Education
John B. Lacson Colleges Foundation, Bacolod City, Philippines

Emails: emeliza.estimo@jblfmu.edu.ph, johnerll.destacamento@jblfmu.edu.ph

Received on: 07 February 2023 Accepted on: 02 March 2023 Published on: 05 April 2023

Abstract

Purpose: *Learning Management Systems (LMS) that enable educational institutions to manage all aspects of the digital learning process and getting feedback from actual users through an evaluation process is essential in determining how effective the system works, how convenient it is for the users, and what else needs to be done to improve it for optimum use. This descriptive-evaluative study aimed to determine the level of satisfaction of the instructors and the students with the Learning Management System (called the JeLMS) established by a higher institution in the Philippines as a platform for online instruction at the height of the COVID-19 pandemic. This study also aimed to determine the students' overall satisfaction with the learning modules uploaded to the JeLMS and to identify points that need improvement based on their experiences.*

Design/Methodology/Approach: *The level of satisfaction of the faculty and students with the JeLMS was measured based on the following components: Functionality, Accessibility, Technical Features, and Cognitive Presence utilizing the framework of Anstey, Lauren & Watson, and Gavan (2018). The level of students' satisfaction with the quality of modules was done based on the aspects of Content and Organization, Language, Format, Learning Activities, Learning Materials, Assessment Instruments, and References Used. Data were collected through an online survey with a sample size of 534 students and 63 instructors selected using convenience sampling. The numerical data gathered from the survey were analyzed using the mean, frequency count, and rank. Data collected through the open-ended questions were analyzed thematically to arrive at common responses.*

Findings: *The results revealed that the satisfaction of the instructors and the students with the JeLMS and the learning modules uploaded to it are at high levels. The data also revealed certain problems and difficulties and suggestions for improvement.*

Key-words:
Learning Management System, Online Teaching and Learning, Learning Modules, COVID-19, Maritime Education and Training

INTRODUCTION

The COVID-19 pandemic has caused a sudden shift in pedagogy. Face-to-face classes were halted, and educational institutions were drastically pushed to maximize their resources by converting their learning materials into digitized forms. With the extensive application of online learning as one of the approaches for blended instruction, much has been invested in purchasing subscriptions to online platforms and applications and creating institutional Learning Management Systems.

A learning management system (LMS) enables educational institutions to manage all aspects of the digital learning process. As a centralized online education hub, it provides educators with a system for creating and managing their lessons, assigning quizzes, and grading students. It is a software or tool for recording, tracking, and channelizing online course material, tests, and reports (Bashin & Hitesh, 2021). Moreover, it serves as a channel through which teachers and students can openly communicate (Ülker & Yılmaz, 2016). It is considered advantageous as it offers a centralized source of learning and provides schools to save all the learning content in one place instead of having it scattered at different locations (Conde et al., 2014).

After the first few months COVID-19 was declared a pandemic, a university in the Philippines created its own Learning Management System, referred to as the JeLMS, to be utilized in all its academic units. The JeLMS is an alleyway for online learning, specifically training and instructions accessible to the university. This learning technology is well-designed for 21st-century learners, providing easy access to the lessons and substantial knowledge anytime-anywhere with ease. The platform is *Moodle*-based, enabling teachers to create e-courses easily, add activities and assignments, and keep an eye on their students' progress. It also allows teachers and students to communicate and encourage collaboration in forums and discussions. The platform is multi-faceted and flexible, so there is no need to get confused when learning the way around for the first time. The online functionality of JeLMS provides educators and students with a more convenient way to deliver and access quality instructions apart from the traditional way or face-to-face teaching mode. It was designed to provide teachers and students with a centralized online education platform for managing lessons and administering various assessments such as quizzes and periodic examinations. Course shells containing learning modules for different courses were uploaded to the system. However, since it is a new system, it needs to be evaluated after its testing phase. According to Wang and Chen (2009), Learning Management Systems must be assessed using a principled approach. An evaluation of a 'change technology' is essential. When conducting the evaluation, it is important to engage the faculty and students on their feelings and attitudes towards the new platform.

This study aimed to determine the level of satisfaction of the instructors and the students with the JeLMS to determine how effective the system works based on certain parameters, how convenient it is for the users, and what else needs to be done to improve it for optimum use. This investigation also aimed to determine the students' level of satisfaction with the learning modules uploaded to the JeLMS and to identify the points that need to be improved based on their experiences.

THEORETICAL FRAMEWORK

The topic of this paper can be viewed in the context of Vygotsky's Social Development Theory, John Dewey's Theory of Learning, and Jean Piaget's (1975) Theory of Assimilation and Accommodation cited in Bormanaki and Khoshhal (2017) which describes teaching and learning as a complex interactive social phenomenon between teachers and students (Crawford, 1996 cited in Picciano, 2017).

Vygotsky's Social Development Theory allows us to view teaching and learning in a sociocultural context in which teachers and students interact in shared experiences. Tools and other mechanisms may be devised to facilitate interaction with one another. Taken in the context of the current learning environment, this implies adopting methods and strategies appropriate to the learners' needs during this pandemic. As the nature of the learning environment shifts according to existing realities, teachers and students are also expected to adapt to these changes by using learning tools to facilitate the delivery of instruction.

Moreover, Dewey's Theory of Learning saw learning as a series of practical social experiences in which learners learn by doing, collaborating, and reflecting with others. The use of reflective practice by both learner and teacher is a pedagogical cornerstone for interactive discussions that replace straight lecturing in face-to-face or online classes. Students must be exposed to a learning environment that simulates realistic experiences.

Dewey's theory is further strengthened by Piaget, who opined that learning as a process only makes sense in situations of change. Therefore, learning is partly knowing how to adapt to these changes. With the pandemic causing the inevitable shift in the mode of instruction from in-class to remote, both the teachers and the students are expected to manage and cope with the changes in the learning environment.

CONCEPTUAL FRAMEWORK

Several experts in evaluating LMSs and other eLearning systems, tools, and platforms offer insightful concepts on which the concept of this study was built. Kabassi et al. (2016), citing Singh (2010), opined that Information and Communication Technologies (ICTs) make learning more comprehensible and efficient. The same source claims that using ICT tools and systems facilitates better comprehension, helps set clear goals, and gives them self-paced learning and greater flexibility.

However, Conklin (2020) notes that evaluating a technology change, such as the JeLMS, is critical. When conducting an evaluation, the designers may want to engage the direct users of the system, such as the faculty and the students in this study, to gather their feelings and attitudes toward the new platform. The evaluation must consist of designing the survey instrument and deciding when the data collection should occur, how the data will be analyzed, and how the results will be used and communicated.

Anstey and Watson (2018) offer educators a framework with criteria and levels of achievement to assess the suitability of an e-learning tool for their learners' needs, learning outcomes, and classroom context. This rubric contains the following criteria: Functionality, Accessibility, Technical Features, and Cognitive Presence.

Functionality considers a tool›s operations or affordances and the quality or suitability of these functions to the intended purpose—that is, does the tool serve its intended purpose well? In the case of e-learning tools, the intended purpose is classroom use. Its sub-components include Scale (Can it accommodate the size and nature of the classroom environment?), Ease of Use (Is the tool intuitive and easy to use?), Technical Support / Help Availability (Does it offer timely technical support to help students regulate self-learning?), and Hypermediality (Does it provide multiple forms of media such as audio, video, and textual communication channels that support and encourage instructors and students to engage and interact with?)

Accessibility It is measured through the system's adherence to accessibility standards, user-focused participation, required equipment, and use cost. To be accessible, the system must be designed to address the needs of diverse users, their various literacies, and capabilities, thereby widening opportunities for participation in learning does not require equipment beyond what is typically available to instructors and students (computer with built-in speakers and microphone, internet connection), and does not impose any unreasonable financial obligation to the students.

As to *Technical Features*, the system must allow users to archive, save, or import and export content or activity data in various formats. It must have the capacity to support learning and provides opportunities for communication, interaction, and transfer of meaning between instructors and students. It should contain easy-to-use features that significantly improve an instructor's ability to be present with learners via active management, monitoring, engagement, and feedback. It should allow the instructors to monitor learners' performance on various responsive measures that can be accessed through a user-friendly dashboard.

Finally, *Cognitive Presence* requires the system to enhance engagement in targeted cognitive tasks that are used to be overly complex or challenging to manage and facilitate learners' exercise of higher-order thinking skills, and regularly receive formative feedback on learning (i.e., they can track their performance, monitor their improvement, test their knowledge).

On the students' level of satisfaction with the quality of learning modules uploaded to the JeLMS, the following components were considered: Content and Organization, Language, Format, Learning Activities, Learning Materials, Assessment Instruments, and References/Sources Used.

On *Content and Organization*, the learning modules must specify the topics and the learning outcomes and align with those provided in the course outline. Their contents must be systematically presented and easy to follow.

The *Language* used in the modules must be free from grammatical, mechanical, and spelling errors. It must be appropriate to the students' level of comprehension, and the instructions and discussions must be clear and easily understood.

As regards the *Format*, the modules in all courses must follow the same template in all parts. Mechanical standards for spacing, highlighting, capitalization, margining, and use of punctuation must be properly observed, and the illustrations must be legible and

properly labeled.
Furthermore, the *Learning Activities* should match the intended learning outcomes, be varied and interesting and engage students' active participation and use of higher-order thinking skills.

As to the *Learning Materials*, the modules must include interesting graphics such as diagrams, photos, charts, graphs, and other visual presentations. The lessons in the modules must encourage the use of online resources, such as links to related videos and literature. Also, the learning materials used in the modules should be carefully selected and relevant to the topics.

On the aspect of *Assessment*, the assessment instruments provided in the modules should match the intended learning outcomes. The items included in the assessments must be carefully prepared and free from errors. The instructions in the assessments must be clearly stated and easy to follow. Lastly, the types of assessment must engage students to think critically.

Regarding *References/Sources Used*, the discussions in the modules must be strengthened by a wide use of references/sources. The references/sources used in the modules must be substantial and up to date, and modules must use accessible online sources aside from textbooks and manuals.

The evaluation frameworks discussed above were considered in evaluating the JeLMS and the quality of the learning modules uploaded.

STATEMENT OF THE PROBLEM

This study aimed to evaluate the JeLMS as a learning management system and the learning modules that were uploaded to it to identify points that need to be improved based on the users' experiences.

Specifically, the following questions were raised in this investigation.

1. What is the level of satisfaction of the faculty with the JeLMS in terms of the following aspects?
   a. Functionality
   b. Accessibility
   c. Technical Features
   d. Cognitive Presence
2. What is the level of satisfaction of the students with the JeLMS in terms of the same aspects?
3. What problems and difficulties did the faculty and students experience using the JeLMS?
4. What suggestions do they have to improve the system?
5. What is the students' level of satisfaction with the quality of learning modules uploaded to the JeLMS in terms of the following aspects?
   a. Content and Organization
   b. Language
   c. Format
   d. Learning Activities
   e. Learning Materials (Graphics, Videos, and Related Articles)
   f. Assessment Instruments
   g. References Used
6. What suggestions do they have to improve the modules uploaded to the JeLMS?

METHODOLOGY

Descriptive-survey and descriptive-evaluative designs were employed to determine the level of satisfaction of the instructors and the students with the JeLMS, as well as the level of satisfaction with the learning modules uploaded to the system from the point of view of the students.

Data collection from a sample size comprising 534 students and 63 instructors started three months after the series of quarantines took place, preventing schools from holding face-to-face instruction. These respondents were selected using convenience sampling (Bashin, 2020) but reaching out to as many instructors and students as possible.

The instrument for measuring the respondents' satisfaction with the JeLMS was based on the parameters of Anstey and Watson (2018) in their instrument titled *"Rubric for eLearning Tool Evaluation,"* namely, Functionality, Accessibility, Technical Features, and Cognitive Presence. This instrument was designed in two ways: one from the instructors' point of view and the other from the students'. The same set of parameters was used.

A researcher-made survey instrument was used to determine the students' level of satisfaction with the quality of learning modules uploaded to the JeLMS. This instrument was presented to two experts in the field of Information Technology to validate its content in terms of its relevance in the context of the study. It was also presented to three field experts, including the Academic Deans of the college programs and the Principal of the Basic Education Department. The criteria of Good and Scates, as illustrated in Oducado (2020), were used for the face and content validation of the instrument. Corrections and suggestions were reflected on the instruments before they were posted online through Google Forms.

Since the face-to-face interview was not possible during this period, the link to the survey was sent to the target respondents, who were asked to accomplish it within two weeks. To reach out to as many respondents as possible, answering the survey was facilitated by the respective Deans and the Principal among their instructors in the department. For the students, the assistance of the faculty advisers was a big help.

Mean was used to determine the level of satisfaction of the faculty and students with the JeLMS and the learning modules. The level of satisfaction was rated and described using a five-point Likert scale as shown below:

5	Strongly Agree	Very High Level of Satisfaction
4	Agree	High Level of Satisfaction
3	Moderately Agree	Moderate Level of Satisfaction
2	Disagree	Low Level of Satisfaction
1	Strongly Disagree	Very Low Level of Satisfaction

To find out the specific problems and difficulties experienced by the faculty and students using the JeLMS, frequency count and rank were used. Data were counted based only on the responses of those who answered this part of the survey. Thematic analysis was used to analyze the suggestions given by both groups of respondents.

RESULTS AND DISCUSSION

Level of Satisfaction with the JeLMS

Most of the instructors and the students have expressed a high level of satisfaction with the University's Learning Management System (JeLMS) on all indicators of the criteria (Table 1), with the highest mean pointing to Technical Features (m = 3.68). This means that the system has highly satisfied the users in terms of the following features: it allows users to archive, save, or import and export content or activity data in a variety of formats; it can support learning and provides opportunities for communication, interaction, and transfer of meaning between instructors and students, it has easy-to-use features that would significantly improve an instructor's ability to be present with learners via active management, monitoring, engagement, and feedback, and it allows the instructor to monitor learners' performance on a variety of responsive measures that can be accessed through a user-friendly dashboard. Hogle (2019), in her article "Improve Learning Management System Courses with User Feedback" explains that soliciting learner feedback and asking the right questions can drive improvements in existing courses. It can also spark the creation of new learning resources. However, she also pointed out that learning managers can obtain meaningful survey results by seeking feedback on the content. One approach, according to her, is to ask learners to identify specific elements of the system that were most—or least—useful. Providing a text box where learners explain their responses can offer valuable information on improving a course or the system used in delivering the course.

Table 1: Level of Satisfaction with the JeLMS

Criteria	Instructors		Students	
	Mean	Interpretation	Mean	Interpretation
Functionality	3.65	High	3.57	High
Accessibility	3.63	High	3.58	High
Technical Features	3.82	High	3.68	High
Cognitive Presence	3.63	High	3.53	High
Total	3.68	High	3.59	High

Problems and Difficulties Experienced by the Instructors and the Students with the JeLMS

The overall numerical evaluation of the JeLMS has pointed to a high level of satisfaction on all indicators. However, data obtained from the open-ended questions in the survey instrument were able to capture first-hand feedback which the figures failed to reveal. This usually happens in surveys where the respondents would normally rate the items based on their general judgment; and, unless they are asked what the problem is, their numerical responses could not really provide a clear picture of the situation. So, in addition to the survey in Likert scale, this question was also asked: *"What problems and difficulties did you experience in using the JeLMS?"*

Tables 2 and 3 show that sixty-seven percent of the instructors and 71% of the students reported experiencing occasional problems in using the system, which was commonly experienced as system lagging/ error, difficulty logging back if the connection is lost, and some data being difficult to recover when the system is down. The rest of the issues mentioned had something to do with its features being difficult to follow, particularly when making quizzes and other types of assessments, and the complexity of the steps, that is, "many steps are required to get the task done," quoting one of the respondents.

Table 2: Problems and Difficulties Experienced by the Instructors in Using the JeLMS

Problems and Difficulties Experienced	f	Rank
Many steps are required to get the task done.	2	8
If the connection is lost, I cannot log back in.	7	2
Not user-friendly.	3	6.5
Some data cannot be recovered when the system is down.	6	3
Some quiz features, like the dropbox image, are difficult to follow.	5	4
System lagging/error/cannot be accessed/overload	28	1
Inaccurate system of enrolling students (e.g., some students have two or more accounts)	3	6.5
Limited/Unstable internet connectivity	4	5

Almost the same problems were noted from students' feedback, with system lagging/error ranked on top, followed by sudden errors when taking quizzes and exams. The third problem was not mainly about the JeLMS but internet connectivity issues. Other problems were the unavailability of notification to students if they missed performing an activity. A few have also expressed that the time allotted to take the assessments was insufficient. Moreover, there was a problem retrieving what had already been encoded if a sudden error in the system happened.

Table 3: Problems and Difficulties Experienced by the Students in Using the JeLMS

Problems and Difficulties Experienced	f	Rank
System lag/error/ cannot be opened/interrupted	162	1
Sudden error while/when taking quiz/exam	131	2
Connectivity issues	65	3
Feedback features are not available, e.g., It does not notify the student of what he has missed or what subject he still needs to answer.	22	4
There needs to be more time allotted for assessments.	10	6
Data retrieval is not possible anymore once a sudden system error is experienced.	20	5

Specifically for students with limited resources, the following problems are perennial: getting disconnected in the middle of their classes, experienced by 84 (16%); difficulty in understanding the lessons discussed by their teachers, expressed by 72 (13%); difficulty in understanding the instructions by 37 (7%); and internet load is not enough to use the video features of the application, expressed by 22 (4%) of the students (Figure 1). These challenges were found in the study of Chung et al. (2020), who noted that the biggest challenge for degree students is internet connectivity. For diploma students, it is difficult to understand the subject's content.

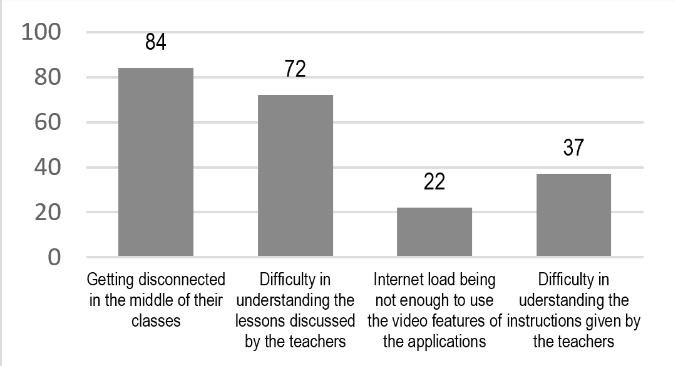


Figure 1. Challenges and Difficulties Experienced by Students with Limited Internet Resources

Suggestions of the Instructors and Students on the JeLMS

The instructors' suggestions centered on improving the system based on the problems encountered by the users, providing more hands-on tutorials on using the different features of the system focusing on the difficulties identified, improving the internet connectivity (better and faster bandwidth for a quicker and stabler connectivity), providing more user-friendly features, allowing alternative platforms for meeting the class, sending materials to students, and giving of assessments, rigorous monitoring of traffic flow and updating of the website from time to time to make it more efficient, providing a separate LMS per campus to avoid system overload, and assigning technical support staff to address problems right away/provide an immediate response to queries.

Teachers at this time of the pandemic are taking on all types of pressures, from ensuring that their students get the best education to cope with their technical difficulties in using online learning systems and devices. Gleaning on the comments expressed by the instructor-respondents, they need technical assistance as much as possible. They also need to be trained further on using the JeLMS and its features. With the multiple roles they are expected to perform as they implement blended learning, with online learning being one of the approaches, preparing, planning, and executing tasks expected out of them add much pressure, and the lack of time doubles it. For this, they need a Learning Management System that is easy to use and would not add more to their stress level. They need a good flexible teaching platform that can help them better contribute to quality education and the overall success rates of students (Huang et al., 2020).

There is also the challenge of how to keep the students engaged in the online class (Online Learning Challenges and Solutions, 2021) by using tools and multiple types of learning approaches such as videos, live classes, discussions, relevant articles, and other strategies and materials for better learning outcomes, but only if these tools would not cause a system overload. The instructors also expressed this concern. The same source has discussed the challenge of dealing with technical issues using LMSs. Many teachers struggle with technical issues that are unavoidable and cause stress. They become helpless if technical errors come in the middle of the live session or communication with students. Aside from providing technical support for solving problems that can interfere with the learning process, the article suggests upgrading computer systems with applications and software that can help effectively deliver learning with a high-speed internet connection.

Moreover, the students have expressed the need to set more extended time for taking online quizzes and exams, organizing the learning modules for specific sections to avoid mix-ups, the inclusion of saving features per page so that if a sudden error occurs, data/information already entered can still be retrieved, allowing students other alternative ways of taking quizzes or exams if they miss taking them on the specific time due to technical/connectivity problems, improving the memory database so it could accommodate a massive quantity of users to eliminate lagging in the website, simplifying and reducing the system's features to make it more user-friendly for teachers and students, and sending notifications directly to students' Gmail accounts if teachers have uploaded something that calls for urgent attention.

Students' Level of Satisfaction with the Quality of Learning Modules Uploaded to the JeLMS

Moving further, students have expressed high satisfaction with the quality of learning modules uploaded to the JeLMS. Table 4 shows that most respondents expressed high satisfaction with all indicators of each aspect. These aspects include Content and Organization, Language, Format, Learning Activities, Learning Materials (graphics, videos, and related articles), Assessment Instruments, and References Used.

Table 4: Students' Level of Satisfaction with the Quality of Modules Uploaded to the JeLMS

Aspects of the Modules	*Mean*	*SD*	*Interpretation*
Content & Organization	3.88	0.87	High
Language	3.76	0.87	High
Format	3.76	0.87	High
Learning Activities	3.74	0.88	High
Learning Materials	3.79	0.86	High
Assessment Instrument	3.75	0.83	High
References Used	3.83	0.80	High
Total	*3.79*	*0.88*	High

Students' Suggestions to Improve the Learning Modules

In another open-ended question, the students were asked, *"What suggestions do you have to further* *improve the learning modules uploaded to the JeLMS?"* For their ease and convenience, they have expressed the following suggestions:

1. Simplify the modules.
2. Set a maximum number of pages for each module (others are too crowded/too long for students to comprehend; some are simply copy-pasted from other sources without any attempt to simplify).
3. Align quizzes/exams with the learning objectives and contents of the modules discussed.
4. Provide students with PDF copies of the modules.
5. Instructors to provide their own video-recorded lectures or demos of the topics.
6. Make the modules more interesting.
7. Use the same template/format of modules in all subjects.
8. Organize and edit materials (modules, quizzes, exams) to remove grammatical or mechanical errors before uploading them.
9. Teachers to discuss the learning materials (modules, videos), not just send them.
10. Offer other relevant learning materials and references (links to videos, articles, etc.) to supplement the lessons.
11. Provide a manageable number of quizzes/activities.

CONCLUSION

Relative to the first and second research questions, the results revealed a high level of satisfaction of the instructors and the students with the JeLMS and the learning modules uploaded to it. However, the high level of satisfaction with the JeLMS and the learning modules does not negate the fact that the users had experienced occasional problems and difficulties in utilizing them.

On the third objective which is to identify the problems and difficulties experienced by the users, it was found that while the JeLMS and the modules uploaded to it had been helpful, their utilization needs to be improved because of some technical issues with the system, poor internet connectivity, and technical glitches during the actual use of these online tools and materials. Some of the learning modules already uploaded to the system may need to be taken down and reviewed further before being re-uploaded to the system.

Suggestions to improve the JeLMS (research question 4) expressed by the faculty centered more on improving the JeLMS based on the problems encountered by the users, providing more hands-on training to familiarize the instructors with its features, and assigning technical support staff to provide immediate assistance if technical glitches may arise, among others. Some of the students' suggestions include setting more time for taking online quizzes and exams, organizing the learning modules to avoid mix-ups, adding saving features per page to ensure retrieval of encoded contents in case of a system breakdown, and simplifying the system's features to make them more user-friendly.

On the fifth objective which is to determine the students' level of satisfaction with the quality of learning modules uploaded to the JeLMS, a high level of satisfaction was noted on all aspects. However, they expressed numerous suggestions, particularly on how to improve these learning modules in terms of content and organization and format.

Given the findings of this study, digital transformation should be part of the university's strategic plan in the next five years. After experiencing the pandemic, the world has slowly welcomed the idea of adopting the Hybrid and HyFlex learning environment which allow the use of multiple teaching modalities. In this digital era, the University needs to develop contingency plans that could provide the resources necessary to keep its operations going. It needs to set plans and strategies for better and more effective delivery of instruction as it welcomes the crucial role of technology and the inevitable conversion of learning materials into digital form. As García-Peñalvo et al. (2020) put it, a higher education institution should have a comprehensive plan with viable initiatives focused on people and empowered by technology. The use of technology is the medium for introducing improvements and needed change. The University's digital transformation means embracing the digital society in which we live, creating a more transparent place that promotes equality, inclusion, and participation, for the good of the school and for the benefit of the students that it serves.

REFERENCES

Anstey, L. and Watson, G., 2018. A rubric for evaluating e-learning tools in higher education. Educause Review, (September).

Bashin, H. (2020) Convenience Sampling | How to analyze a convenience sample? Available from: https://www.marketing91.com/convenience-sampling/ [Accessed 21st May 2022]

Bashin, H. (2021) Learning Management System (LMS)—Overview & Features. Available from: https://www.marketing91.com/learning-management-system/ [Accessed 21st May 2022]

Bormanaki, H.B. and Khoshhal, Y., 2017. The role of equilibration in piaget's theory of cognitive development and its implication for receptive skills: A theoretical study. Journal of Language Teaching and Research, 8(5). https://doi.org/10.17507/jltr.0805.22.

Chung, E., Subramaniam, G. and Dass, L.C., 2020. Online learning readiness among university students in Malaysia amidst Covid-19. Asian Journal of University Education, 16(2). https://doi.org/10.24191/AJUE.V16I2.10294.

Conklin, S. (2020). Evaluating LMS. Available from: https://edtechbooks.org/learning_management_systems/evaluating [Accessed 21st May 2022]

Conde, M.Á., García-Peñalvo, F.J., Rodríguez-Conde, M.J., Alier, M., Casany, M.J. and Piguillem, J., 2014. An evolving Learning Management System for new educational environments using 2.0 tools. Interactive Learning Environments, 22(2). https://doi.org/10.1080/10494820.2012.745433.

García-Peñalvo, F.J., Corell, A., Abella-García, V. and Grande-de-Prado, M., 2021. Recommendations for Mandatory Online Assessment in Higher Education During the COVID-19 Pandemic. In: Lecture Notes in Educational Technology. https://doi.org/10.1007/978-981-15-7869-4_6.

Hogle, P. (2021) Improve Learning Management System Courses With User Feedback. Available from: https://www.absorblms.com/blog/improve-learning-management-system-courses-with-user-feedback [Accessed 22nd May 2022]

Huang, R.H., Liu, D.J., Guo, J., Yang, J.F., Zhao, J.H., Wei, X.F., Knyazeva, S., Li, M., Zhuang, R.X., Looi, C.K. and Chang, T.W., 2020. Guidance on flexible learning during campus closures: Ensuring course quality of higher education in COVID-19 outbreak. Beijing: Smart Learning Institute of Beijing Normal University, (May).

Kabassi, K., Dragonas, I., Ntouzevits, A., Pomonis, T., Papastathopoulos, G. and Vozaitis, Y., 2016. Evaluating a learning management system for blended learning in Greek higher education. SpringerPlus, 5(1). https://doi.org/10.1186/s40064-016-1705-8.

Oducado, R.M., 2021. Survey Instrument Validation Rating Scale. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3789575.

Picciano, A.G., 2017. Theories and frameworks for online education: Seeking an integrated model. Online Learning Journal, https://doi.org/10.24059/olj.v21i3.1225.

Ülker, D. and Yılmaz, Y., 2016. Learning Management Systems and Comparison of Open Source Learning Management Systems and Proprietary Learning Management Systems. Journal of Systems Integration. https://doi.org/10.20470/jsi.v7i2.255.

Wang, Y. and Chen, N.S., 2009. Criteria for evaluating synchronous learning management systems: Arguments from the distance language classroom. Computer Assisted Language Learning, 22(1). https://doi.org/10.1080/09588220802613773.

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.070

Real Time Kinematic (RTK) Heave as a Replacement of Motion Reference Unit (MRU) Heave in Hydrographic Surveying Works

Mohamed Elmeligy[1], Saad Mesbah[2] and Mohamed Mohasseb[3]

[1]College of Maritime Transport and Technology, Arab Academy for Science, Technology and Maritime Transport, Abu-Qir, Alexandria, Egypt.
[2]Consultant to the Academy President for education affairs, Arab Academy for Science, Technology and Maritime Transport, Abu-Qir, Alexandria, Egypt.
[3]Egyptian Naval Hydrographic Dept., Naval Forces.

Emails: elmeligy57@aast.edu, saadmesbah@hotmail.com, mohamedmohasseb@live.com

Received on: 28 January 2023 Accepted on: 26 April 2023 Published on: 22 May 2023

Abstract

Purpose: *Heave is one of the major contributors to errors in water depth measurements. Motion Reference Unit (MRU) measures the heave signal with high-level accuracy as well as other ship motions. Unfortunately, MRU has been reported to have some of drawbacks such as heave drift error, influence of ship motion dynamic, in addition to its very expensive price. Real-Time Kinematic Global Positioning System (RTK GPS) uses dual frequency receiver and carrier phase differential technique under kinematic solution and provides very accurate position in all three components in real time. In addition, RTK GPS also calculates the low frequency changes in water level such as tidal oscillation.*

Design/Methodology/Approach: *This research is an attempt to investigate the possibility of using the RTK GPS data to deduce the heave signal from the GPS height (tides - heave) instead of heave from MRU to correct the water depth. Moreover, it aims to examine to what extent RTK heave can be used as a backup to satisfy the International Hydrographic Organization (IHO) survey order standards. A comparison between the extracted RTK heave and MRU heave signals revealed a good agreement with a strong direct correlation of 0.96. RTK heave as a replacement for MRU heave in hydrographic surveying was statistically validated using many methods of analysis such as test of the normality, paired samples t test, Wilcoxon signed ranks test, heave signals frequency adjustment, descriptive statistics for the two heave signals, descriptive statistics for each signal individually, correlation and trend, analysis between the two signals, scatter diagram and trend, standard deviation and uncertainty for soundings, characteristics of the difference between two signals and comparing the surfaces by Triangulation Irregular Network (TIN) Model.*

Findings: *The results of this analysis provided the possibility of using RTK heave as a replacement for MRU heave in hydrographic surveying. Therefore, RTK GPS is not only used to provide precise position or tidal oscillations but also, based on this study, it could be used to measure heave accurately to correct the depth satisfying IHO survey standards.*

Key-words:
Hypack -- Hydrographic Survey -- Motion Sensor - RTK GPS Heave - Height of Tide

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.070

INTRODUCTION

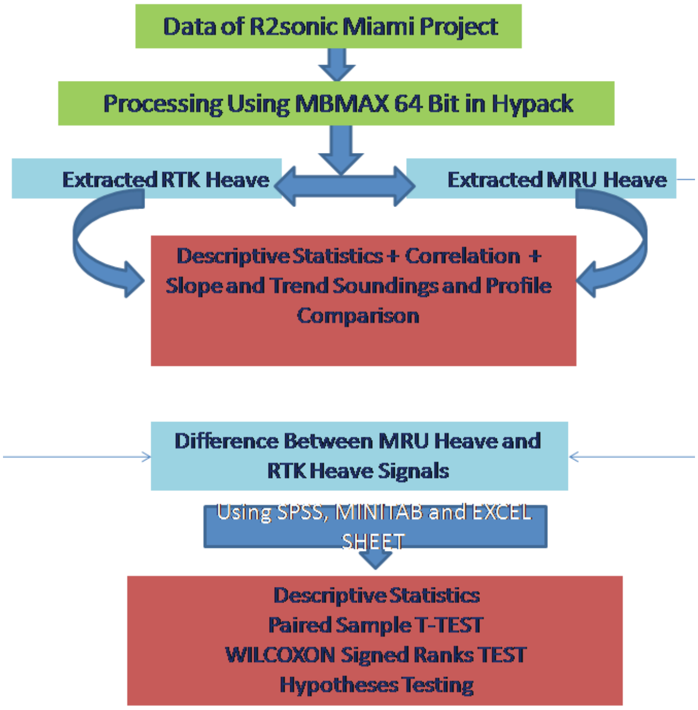


Fig. 1. Theoretical framework of research flow

Vessel at sea, is subjected to six different motions with six degrees of freedom, which are surge, sway, heave, roll, pitch and yaw, induced by the sea state. These motions are mainly due to oceanographic and atmospheric forcing (OMC international, 2005).

Heave, as a vertical displacement relative to a water level, is a major contributor to errors in water depth measurements, defined as an oscillation of rise and fall around a defined datum (mean sea level), (typically higher than 0.04 Hz) (Rapatz, 1991; Godhavn, 2000).

Many researchers have addressed movements of the ship, especially Heave Motion such as Grover (1954), Caldwell (1955), Tucker (1955), Rapatz (1991), Kielland et al. (1995), Chang et al. (2002), Wang et al. (2007), Blake (2007), and Rabah et al. (2010).

In 1954, Grover addressed the early heave sensor known as "Pressure Sensors". The pressure sensor was fixed to the side of the ship and provided a continuous measurement of the pressure of the water column above the sensor. As the ship moved up and down the water, pressure at the sensor head decreased or increased according to the simple formula:

{$P = \rho g h$} is used to extract the height h, where P is pressure, ρ is water density and g is acceleration due to gravity (Grover, 1954; Rapatz, 1991).

After that, in 1955, Caldwell discussed the second early heave sensor which is called "Electrostatic Strip". The electrostatic strip is used for measuring the conductivity of sea water to assist in measuring the height of the water along a metal strip attached to the side of the ship (Caldwell, 1955; Rapatz, 1991). The attempts to measure the vertical motion (heave) by different two earlier methods yielded a successful result before the world of GPS. However, there was an objection from Tucker in 1955 who investigated the previous techniques while offering direct measurement of the water height with respect to the ship's hull. However, there was no way of distinguishing whether the water level change is due to the motion of the ship such as rolling or due to changes in the sea surface as caused by waves, etc. These extraneous changes of the water level in direct contact with the hull cause significant measurement errors and limit the usefulness of hydrodynamic techniques to times when the sea surface is very calm.

After GPS usage, Rapatz, in 1991, tested a model for investigating and proving the initial suggestion about the capability of differential GPS to measure vessel heave. After that, developing the practical utilizing for this theory consisted of some practical steps such as testing the static data by usage, collecting data in the field and, finally, data processing and evaluating the results of processing. The technique used for determining heave from GPS measurements utilized the high precision with which the carrier phase signal can be measured to determine the relative movements of the GPS antenna from epoch to epoch. After determination of the motion, refining it into height changes from epoch to epoch and integration gave the height of motion over time. Appropriate datum selection and low frequency filtering to help in extracting only the heave signal not tide signal, combined with pitch and roll measurements allow the determination of vertical motion of any point on a vessel (Rapatz, 1991).

After Rapatz, another technique was conducted by Kielland et al. in 1995 who stated that a significant error source, which was encountered by hydrographers, is wave induced vertical motion of their survey vessel (heave). In heavy swells, uncorrected heave noise will degrade the accuracy of the surveyed soundings. Heave motion can be measured using inertial technology to be corrected to calm water conditions. Unfortunately, the high cost of inertial heave compensators has prohibited their widespread use. An algorithm was carried out and authorized by the Canadian hydrographic to use to determine heave corrections for a hydrographic survey vessel. The algorithm is simply a high pass filter acting on the unused DGPS vertical position record already being observed on the vessel. A low-cost pitch and roll inclinometer was used to correct for the lever arm effect between the GPS antenna and the sounder's transducer. The experiment indicated that decimeter heave compensation accuracy was obtained.

In 1995, Kielland used the GPS for measuring the heave but through an algorithm. After a few years, in 2002, Chang et al. discussed the results of the application of a vessel-based GPS system for hydrographic surveys, particularly for the collection of attitude-corrected bathymetric measurements. The kinematic solutions of the onboard GPS antennas can effectively determine and provide all parameters of attitude, including roll, pitch and heave, for the reductions of bathymetric measurements to the vertical. The accuracy of measurement can be significantly improved. The attitude correction, based on the kinematic GPS solutions from a multiple antenna configuration, has successfully shown its important role in bathymetric data reductions.

In an attempt to overcome some problems of using motion sensor Blake, in 2007, developed a heave algorithm for use with low-cost GPS receivers. This algorithm was to overcome some of the problems and limitations associated with the use of inertial sensors for the measurement of heave in three areas:

- Cost
- Stability
- Usability

This has been achieved through the development of a highly accurate velocity estimation algorithm using stand-alone low-cost GPS receivers and the algorithm has been extensively tested in both a simulated and a real-world marine environment (Blake, 2007).

With the advanced development in GPS, it was a necessary to develop the heave algorithm to adapt with the new types of GPS receivers so, Rabah et al. (2010) developed GPS heave algorithm that can be used with all types of GPS receivers, single or dual receivers; processed in Post processing mode or in Real Time Kinematic mode. The GPS heave values computed from 1 Hz GPS recorded data was found to be inadequate for the measurement of the frequency of heave motion experienced by the vessel during the trial. The results of the sea trial showed the ability of developed heave algorithm to measure heave to the accuracy required for at least the IHO survey order. The RTK GPS high update rate showed an increased level of performance over the heave solutions using 1 Hz data.

SIGNIFICANCE OF THE RESEARCH

It is of importance to look for an alternative approach for using the most recent technology for extracting heave to overcome the above-mentioned drawbacks associated with MRU heave signals, especially in hydrographic surveying operations. Thus, the research question for this study is mainly to answer the following: "to what extent can hydrographers depend on RTK GPS heave to correct water depth soundings" as an alternative way of MRU heave or as a good backup method. Also through this analysis, some hypotheses will be experimented and will answer whether applying heave from RTK GPS is efficient and whether it abided by the IHO standards or not, so the research will be validated by the following hypothesis:

The difference between MRU heave and RTK heave signals was assumed to follow approximately the normal probability distribution due to the large samples size. Therefore, parametric statistics will be used to test the significance, whether the mean of MRU heave equals the mean of RTK heave, or whether they have a significant difference.

T-Test for paired samples (RTK heave, MRU heave) will be utilized for this case considering:

- Significance level was taken 5 %
- Hypotheses testing formulation will be as follows:
- Null hypothesis (H_0) and alternative hypothesis (H_1)

H_0: $\mu_1 = \mu_2$ or $\mu_1 - \mu_2 =$ Zero

And H_1: $\mu_1 \neq \mu_2$

Using analysis software package, T-TEST for the research data of (RTK heave, MRU heave) with a confidence level 95 %.

MATERIAL AND METHODS

Material

Data of Multibeam Echo-Sounder (MBES) hydrographic survey was made available by HYPACK Company (USA) as shown in Figure 2. That was conducted in LUMUS ISLAND TB, Miami, USA. Data contained 3 MBES lines with total length of 2 km. Having a minimum depth of 3 feet (0.91 cm) and the maximum depth reached 70 feet (21.336 m).

- The MBES angle limit was setting out to 60 degrees.
- The Applanix MRU (POS MV) was used for both positioning and heave.
- The Sonic 2024 MBES was used for sounding. The grid used was state plane NAD_83 with

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.070

ellipsoid WGS 84 in one FL-0901FLORIDA EAST.

- Collecting data and processing using HYPACK software.

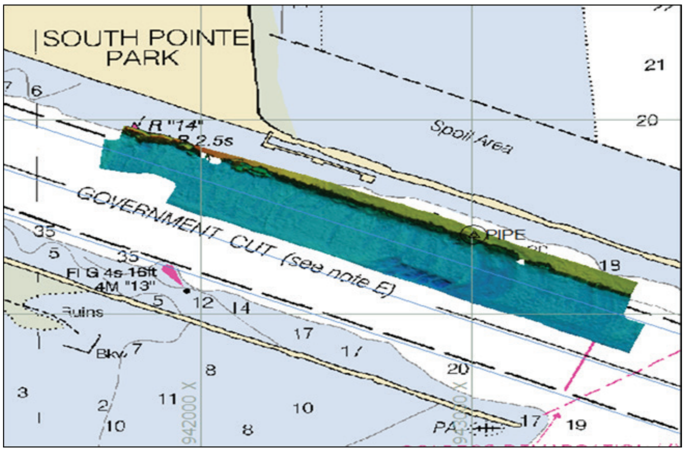


Fig. 2: R2Sonic Miami snippets survey project (HYPACK Software)

The survey data were conducted using heave from two different sources (MRU and RTK GPS) at the same time to compare between the two signals. The RTK GPS height usually contains two superimposed frequencies: one is low frequency changes (tides) and the other is high frequency changes referred to as (heave).

Methods of Analysis

Method of calculating RTK GPS height

Figure 3 shows a survey boat using RTK GPS to measure and determine the current water level correction (RTK GPS Tide). In this example, the pre-determined reference ellipsoid (a) is 100m above the chart datum which is a given and fixed value for each part of the earth.

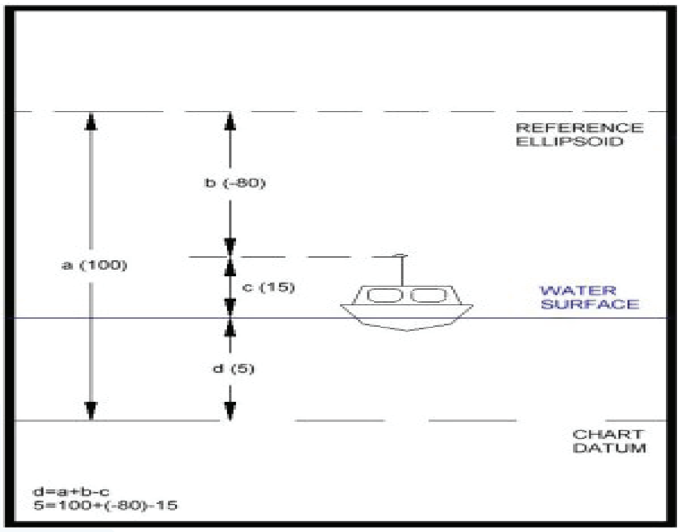


Fig. 3. HYPACK method for obtaining real time water levels (HYPACK user manual, 2015).

d = a + b – c.. (1)

d= (100) + (-80) - 15 = 5m

Where (d) is the height of water surface above the chart datum (RTK GPS Tide) which is required to be measured.

(a) is the height of the reference ellipsoid above the chart datum.

(b) is the height of the GPS antenna relative to the reference ellipsoid (This is automatically measured by RTK GPS).

(c) Is the height of RTK GPS antenna above the static water line (This is measured manually from the antenna to the sea level).

When HYPACK is configured correctly, it computes this value at each RTK GPS update and saves the position and the tide correction to the raw data file. The sign of value (d) is negative by HYPACK to be consistent with the normal tide correction values.

When the raw data file from the survey program is read into the multibeam editor, each sounding will have an RTK tide correction, based on the method shown above (HYPACK, 2013c).

Methods of analysis for both of signals (RTK GPS heave and MRU heave)

Analysis and comparison have to be made first, between the two simultaneous heave signals: (RTK GPS) and (MRU). The second comparison was conducted after applying heave correction to the created soundings surfaces and profiles to validate the results.

For each signal of heave whether from RTK or MRU or from the difference between them statistical analysis was conducted, and correlation analysis were obtained using statistical programs:

1- SPSS,
2- Minitab program, and
3- MBMAX 64-bit module in HYPACK software.

The methods of analysis were conducted as follows:

1- Heave Signals Frequency Adjustment,
2- Descriptive Statistics for the Two Heave Signals,
3- Descriptive Statistics for Each Signal Individually,
4- Correlation and Trend Analysis Between the Two Signals (Hr, Hm),
5- Scatter Diagram and Trend,
6- Standard Deviation and Uncertainty for Soundings,

7- Characteristics of the Difference between Two Signals,
8- Test of the Normality Paired Samples T Test,
9- Wilcoxon Signed Ranks Test,
10- Comparing the Surfaces by TIN Model,
11- Hypotheses Testing, and
12- Limitation of RTK GPS.

RESULTS AND DISCUSSION

The heave is a major contributor to the uncertainty in depth measurements due to the effect of the wind and waves on the free water surface. Motion Reference Unit (MRU) is responsible for measuring the heave, but it has some drawbacks, problems and errors as reported by several studies, such as Böder (2008), which were mentioned in the introduction.

RTK GPS measures and calculates the Heave in addition to the Tide. This can be done using MBMAX 64bit module in HYBACK software package. It is possible to decide on selecting the heave either from MRU or RTK using MBMAX 64bit to apply it during data processing.

The Main Results of the Analysis

Heave Signals Frequency Adjustment

An independent comparison could be done but there is a problem that both the initial H_m and H_r are not at the same time tag because the sampling frequency of MRU is greater than the sampling frequency of RTK. RTK heave is delayed than MRU heave due to GPS processing time. For these reasons, both heave signals were found to have similar amplitude but with a time shift between both of them, although both signals have equal length of record but different in samples number as shown in Figure 4.

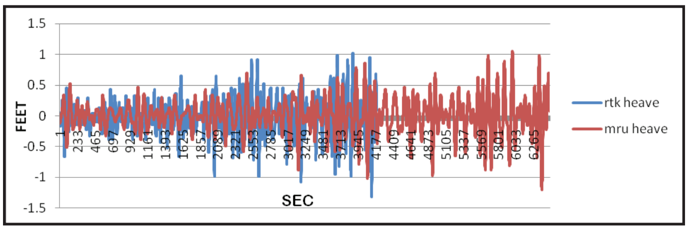


Fig. 4. Time series segment of MRU heave and RTK heave for line 1, demonstrating shifting in time (length of record is 4.4 minutes)

By using Visual Basics software this problem was figured out by using time alignment between both heave signals: RTK and MRU. After that, the two heave signals for MRU (H_m) and RTK (H_r) was adjusted to have the same time tag as shown in Figure 5.

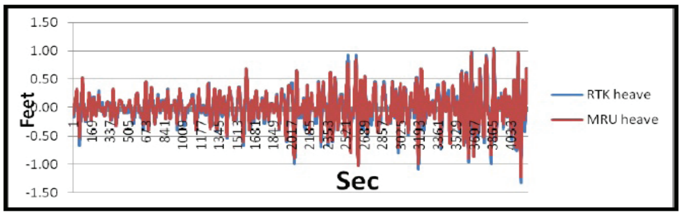


Fig. 5. Heave for MRU and RTK having the same time tag for line 1

Descriptive statistics of the two heave signals

Table 1: Processing Summary for RTK and MRU Data Points

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
RTK	9618	100.0%	0	.0%	9618	100.0%
MRU	9618	100.0%	0	.0%	9618	100.0%
RTK-MRU	9618	100.0%	0	.0%	9618	100.0%

To conduct a comparison between RTK heave signals and MRU heave signal, it was necessary to understand the attitude of signals itself through descriptive analysis of each signal individually.

Descriptive statistics was conducted using SPSS program and the results showed that the number of validated samples to be tested was 9618 values and under confidence level 95%, the mean for MRU heave was -.0005 ft while the mean for RTK heave was -.0163 ft.as shown in Table 1.

The median for RTK heave or MRU heave was .000 for both signals which means that the middle of all values after arrangement is zero level for the heave which is the sea level. Thus, confirming that the rise and fall oscillations of both heave signals are around zero value (sea level).

Standard deviation for MRU heave was .30 ft and for RTK was .31 ft. It was deduced from these values that the standard deviations for both data are almost the same despite the fact that they are measured by two different equipment at the same position and the same time. Also descriptive analysis indicated that the measured heave values using MRU were varying between 1.48 ft (45.1 cm) and -1.57 ft (-47.9 cm) and the measured heave using RTK was varying between 1.45 ft (44.2 cm) and -1.61ft (-49.1 cm) as shown in Table 2 and Figure 6.

ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.070

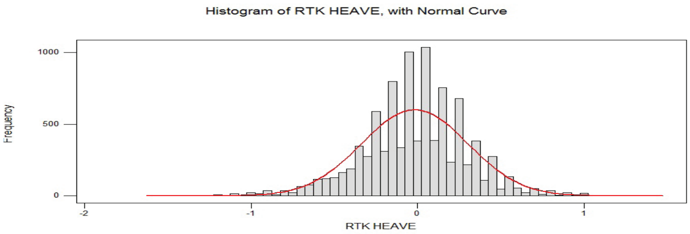


Fig. 6. Histogram of RTK with normal curve

Table 2: Descriptive Statistics for RTK Heave

	Overall project		Statistic	Std. Error
RTK	Mean		-.0163	.00325
	95% Confidence Interval for Mean	Lower Bound	-.0227	
		Upper Bound	-.0099	
	5% Trimmed Mean		-.0127	
	Median		.0000	
	Variance		.102	
	Std. Deviation		.31887	
	Minimum		-1.61	
	Maximum		1.45	
	Range		3.06	
	Interquartile Range		.36	
	Skewness		-.199	.025
	Kurtosis		1.664	.050

Table 3 and Figure 7 showed the minimum values for RTK and MRU to be (-1.61, -1.57) and the maximum values to be (1.45, 1.48). These values seem to oscillate around zero where the values for each signal of RTK and MRU fall between -1.61 ft and 1.48 ft. This has been confirmed also by the median value of both signals when it becomes zero. Descriptive statistics also showed that the mean for RTK heave is -.0163 ft with standard error .00325 ft and the mean for MRU heave is -.0005 ft with standard error .00307 ft.

Table 3: Descriptive Statistics for MRU Heave

			Statis-tic(ft)	Std. Error
MRU	Mean		-.0005	.00307
	95% Confidence Interval for Mean	Lower Bound	-.0065	
		Upper Bound	.0055	
	5% Trimmed Mean		.0026	
	Median		.0000	
	Variance		.091	
	Std. Deviation		.30125	
	Minimum		-1.57	
	Maximum		1.48	
	Range		3.05	
	Interquartile Range		.32	
	Skewness		-.180	.025
	Kurtosis		2.123	.050

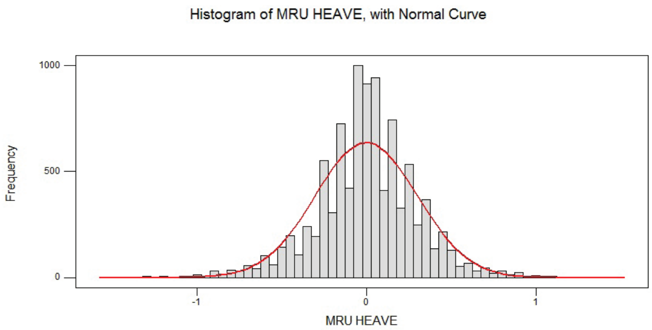


Fig. 7. Histogram of MRU with normal curve

Skewness is a measure of symmetry, or more precisely, to test the lack of symmetry. A distribution for a data set is symmetric if it looks like a mirror; i.e. the same to the left and right of the center line. So, based on both the skewness of RTK heave -.199 with standard error 0.025 and the skewness of MRU heave -.180 with the same standard error 0.025, it is clear to notice that both data have a negative skewness slightly to the left with the same standard error.

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.070

One of the most commonly used measures is standard deviation. This value gives information on how the data values are deviating from the mean of the data set, using the following formula:

$$s.d = \frac{\sqrt{\Sigma(x-\bar{x})2}}{\sqrt{n-1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where: Σ = sum of,
X = individual values and $\bar{x}$ = mean of the values,
n = number of data points

Large standard deviation indicates that the data points are dispersed far from the mean and a small standard deviation indicates that they are clustered closely around the mean. The standard deviation of the RTK heave was 0.31ft and the MRU heave was 0.30 ft which revealed that both MRU heave and RTK heave dispersed around the mean almost with the same standard deviation.

Correlation Analysis

The correlation coefficient between MRU heave and RTK heave for overall the 3 lines using SPSS analysis program gave 0.96. This correlation coefficient value indicated a strong and direct proportional relationship between the two considered signals.

Both of RTK heave and MRU heave data were plotted on a scatter diagram to see the rate of the change between MRU heave and RTK heave. If the slope of the linear regression equation between MRU heave and RTK heave shows almost 45˚ line or close (i.e., slope is equal or close to 1.0), it indicates the great association between both signals. The slope is defined as the ratio of the vertical change between two points (the rise), to the horizontal change between the same two points (the run) and it comes from the following formulas:

$$\text{Slope } = \frac{\text{opposit}}{\text{adjacent}} = \frac{Y2-Y1}{X2-X1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The regression equation is Y = 1.018 X, showing a trend passing through origin and almost equals to 1.0. The explained variance R^2 is 0.92 i.e., 92% as shown in Figure 8.

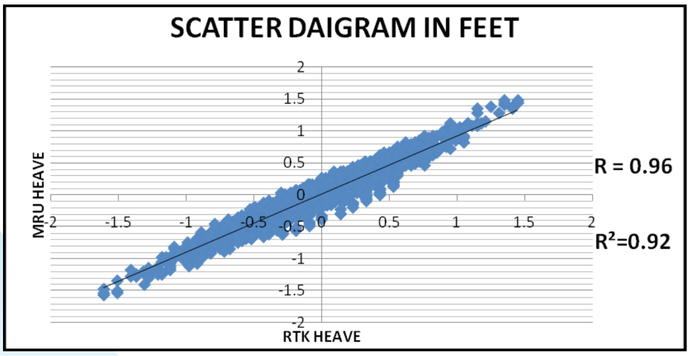


Fig. 8. Trend and correlation coefficient between RTK heave and MRU heave values for overall project lines

Scatter Diagram and Trend

A scatter diagram is plotted to check linearity between RTK and MRU heave which demonstrated a strong correlation (96%) for the overall signals and direct proportional between them. The linear equation for the analysis between RTK heave and MRU heave signals is Y = 1.018x with no intercept. If the slope (1.018) is close to (1), then the changes in Y = changes in X, as the regression line passes through the origin (0,0) as shown in Figure (8) and in this case almost Y X because of the high similarity.

The index of determination is R2= 0.9253 known also as the explained variance so, the r= $\sqrt{0.9253}$ = 0.96. Close to one indicating high similarity between them.

Standard Deviation and Uncertainty for Soundings

Standard deviation is a measure of dispersion of a set of data around its mean. The calculated standard deviation for the difference between soundings surface applied MRU heave (s1) and soundings surface which applied RTK heave (s2) is 0.18 ft (5.5 cm), which means the uncertainty for the difference between the two soundings surfaces 2 = 2 x 5.5 =11 cm with confidence level 95 %. According to equation 4,

Uncertainty in depth = $\pm\sqrt{a^2 + (b \times d)^2}$..................(4)

Uncertainty in depth = $\pm\sqrt{(0.25)^2 + (0.0075 \times 13.72)^2}$ = 27 cm.

The uncertainty of the differences between two soundings surfaces i.e., basically between the two heave signals for RTK and MRU fall was found to within the limit of Total Vertical Uncertainty (TVU) for the overall project which was estimated as 27 cm with confidence level 95 % following the IHO special order standards.

Characteristics of the Difference between Both Signals

The differences between MRU heave signals and RTK heave signals are conducted to obtain the descriptive measures between the difference between RTK GPS Heave and MRU Heave using SPSS and MINITAB analysis programs as shown in Table 4.

ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.070

			Statis-tic(ft)	Std. Error
RTK-MRU	Mean		-.0158	.00089
	95% Confidence Interval for Mean	Lower Bound	-.0175	
		Upper Bound	-.0141	
	5% Trimmed Mean		-.0170	
	Median		-.0100	
	Variance		.008	
	Std. Deviation		.08735	
	Minimum		-.33	
	Maximum		.44	
	Range		.77	
	Interquartile Range		.10	
	Skewness		.371	.025
	Kurtosis		1.566	. 050

Table 4: Descriptive Statistics for the Difference between MRU Heave and RTK Heave Signals

Based on confidence level 95 %, the mean of the difference between MRU heave and RTK heave is -.0158 ft (-0.5 cm) and the standard deviation for the differences is .087 ft which means that all the differences fall between (0.0158 + 2 x 0.087) = 0.19 ft and (0.0158 - 2 x 0.087) _0.16 ft with a confidence level 95%.

Test of the Normality

In order to test the hypotheses, the normality test, known as Kolmogorov-Smirnov-Lilliefors test was conducted to detect which tests will be used whether parametric or non-parametric tests in analyzing the signals of difference. According to the test, as shown in Figure 9, normality is not achieved (since sig < 0.05) for the overall data sets whether for RTK or MRU. Normality is considered one of the conditions required for conducting parametric tests such as T-Test. However, based on central limit theory (CLT) and due to a large sample size (n=9618), the researchers will be able to use T-Test as a proximately test or to use the non-parametric tests such as Wilcoxon Signed Ranks Test.

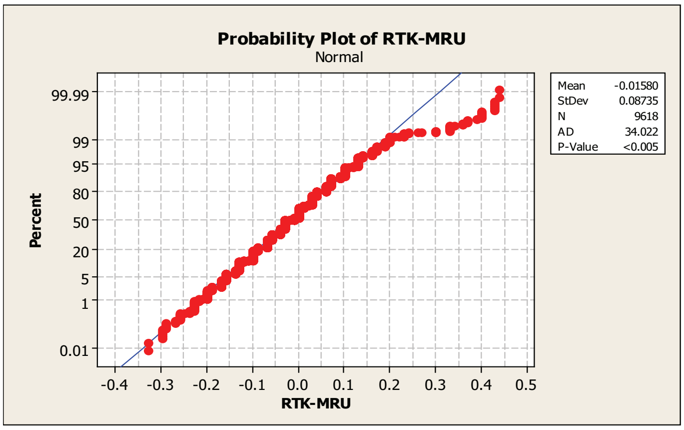


Fig. 9. Testing the Normality

Paired Sample T-Test

Parametric statistics could be used to test the significance, whether the mean of MRU heave equals the mean of RTK heave or whether they have a significant difference, T-Test for paired samples (Hr, Hm) are utilized for this case considering:

- Significance level is taken 5 %
- Hypotheses Testing formulation will be as follows:
- Null hypothesis (H_0) and alternative hypothesis (H_1)

H_0: $\mu_1 = \mu_2$ or $\mu_1 - \mu_2 =$ Zero

And H_1: $\mu_1 \neq \mu_2$

Paired samples T-Test displayed P-value (sig) which is .000 that is less than significance level (p-value <.05) , which means that the mean difference -.0158 is a significant difference. Therefore, null hypothesis H_0 is rejected that assumed μ_1=μ_2, , that is to say; there is a significant difference between the two signals with a confidence level 95%. The analysis rejects the null hypothesis which assumed that there is no significant difference between MRU heave and RTK heave and cannot reject the H_1 which assumed that there is a significant difference between RTK heave and MRU heave and the mean of this difference was -.0158 ft (0.5 cm). The mean of difference falls between -.01755 ft and -.01406 ft as displayed in Tables 5-8 with confidence level 95 %. This difference is demonstrated in tables 5 and 6.

Table 5: Paired Samples Statistics

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	RTK	-.0163	9618	.31887	.00325
	MRU	-.0005	9618	.30125	.00307

Table 6: Paired Samples T-test

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1 RTK - MRU	-.01580	.08735	.00089	-.01755	-.01406	-17.741	9617	.000

Wilcoxon Signed Ranks Test

Another test which deals with the samples as ranks not as values to calculate the asymptotic significance based on significance level .05 to check the hypothesis testing as shown in Table 7.

Table 7: Wilcoxon Ranks

Ranks

		N	Mean Rank	Sum of Ranks
MRU - RTK	Negative Ranks	3474a	3969.66	13790598.50
	Positive Ranks	5055b	4467.97	22585586.50
	Ties	1089c		
	Total	9618		

a. MRU < RTK
b. MRU > RTK
c. MRU = RTK

The positive ranks of (MRU-RTK) heave in Table 7 is larger than the negative ones, that was proven earlier by comparing the two means of signals. Both signals are tied (equal) for 1089 out of 9618 showing

MRU = RTK for a ratio 11%

Comparing the Surfaces by TIN Model

The final method of comparing the soundings is carried out by volume calculation technique through TIN model in HYPACK software by loading two xyz files and creating two surfaces one of them is MRU surface *Sm* and other one is RTK surface *Sr* by TIN MODEL (Triangulation Irregular Network) which merges the two models to determine where they overlap with each other and to generate statistics on the differences between them as shown in Figure 10.

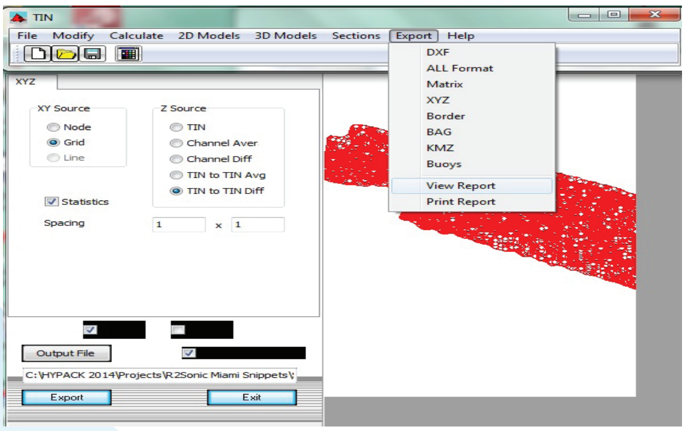


Fig. 10. Export XYZ Data in TIN MODEL

The mean difference between soundings data used MRU heave and the soundings data used RTK heave and the standard deviation for the differences were calculated as follows:

Arithmetic means for differences ($\bar{x}1 - \bar{x}2$) was: 0.00

Standard deviation for the difference (s1-s2) was: 0.18 feet (5.5 cm)

The mean and standard deviation were calculated for the differences between two processed surfaces of soundings using (TIN to TIN) module in HYPACK software. The mean showed no difference between both surfaces while the standard deviation was 5.5 cm. The standard deviation for this difference between two surfaces of 5.5 cm has to be checked if it is within the limit of uncertainty of the project.

According to the minimum standard for hydrographic survey (IHO SP44, 2008), the maximum allowable TVU for the special order is calculated based on the IHO standard equation:

Uncertainty in depth = $\pm\sqrt{a^2 + (b \times d)^2}$ .... (5)

Where the term (a) denotes the constant error limit and the term (b x d) denotes the depth dependent error limits, given as (a) = 0.25 m, (b) = 0.0075 m and (d) =13.72 m. The measurement of heave and tide, along with other less significant errors, are considered to form part of (a) (Imahori et al., 2003; IHO standards, 1998). So, the maximum allowable TVU for the project based on the equation 5 is:

Uncertainty in depth = $\pm\sqrt{(0.25)^2 + (0.0075 \times 13.72)^2}$ = 27cm.

The standard deviation for the difference between the two surfaces is 1 = 5.5 cm and the uncertainty for the difference between two surfaces is 2 = 2 x 5.5= 11 cm using 95% confidence level compared with the limit of the uncertainty in depth for the project TVU (27 cm according to IHO standard for the special order). That is to say, that the calculated uncertainty for the project is within the permissible uncertainty by IHO standards.

Hypotheses Testing

The mean difference between MRU heave and RTK heave was tested using paired samples T-Test and Wilcoxon signed ranks Test using SPSS and MINI TAB programs. The hypotheses testing results were deduced from both tests as follows:

From Table 5-7, the mean difference between RTK heave and MRU heave was -0.0158 ft (.48 cm) which is less than 5 mm and P-value was 0.000 with confidence level 95%.

Because the P-value <.05 , so null hypothesis H0 which assumed that there is no significant difference between MRU heave and RTK heave was rejected and cannot reject H1 which assumed that there is a significant difference between the mean of MRU heave and the mean of RTK heave.

Based on statistics analysis, this significant difference is -0.0158 ft (0.48 cm) just only 4 mm with confidence level 95% which means both heave signals are not perfectly the same due to the difference of equipment to measure heave (GPS OR MRU). However, according to the IHO standard and the maximum allowable TVU in equation (4), the uncertainty in depth was calculated to be 27 cm compared with the difference between RTK heave and MRU heave which did not exceed 0.5 cm, i.e., still within the limit of uncertainty of the special-order project, which is 1% from the maximum value of the heave (-1.61 ft (49 cm)). According to confidence level 95 %, 0.5 cm is not considered significant for the overall research.

Therefore, all the above revealed the possibility of using:

- RTK heave as a replacement of MRU heave in hydrographic survey or as
- An alternative source for getting heave as a backup system for getting heave as long as, the differences do not exceed the maximum allowable total vertical uncertainty.

LIMITATION OF USAGE OF RTK HEAVE

The First Problem

Despite the benefits of using RTK heave as a replacement of MRU heave or heave compensator, this replacement may face one drawback because of the possibility of having RTK outage because of the radio link. However, hereafter some of suggested solutions to avoid the RTK outage:

The First Solution

Using Post Processing Solution (PPS) when collecting RTK data to overcome the RTK outage. In case of using the RTK heave and MRU heave together as a double check or as a backup. A GPS outage occurs when fewer than four valid satellite measurements are available at each update. The longer the outage time, the less accurate navigation solution is obtained. In this case, it is possible to take the advantages of the INS system as self-content equipment, especially the heave signal measurement (vertical component) to bridge the GPS height gaps during the hydrographic survey operation and taking advantages of both systems characterizations by spectrally fusing both signals to have a single signal with all vessel's dynamics included (El-Assal, 2009).

The Second Problem

In this research the RTK GPS provides the high frequency movement (heave) but does not provide the other degree of freedom (movement of ship) which is (roll, pitch, yaw, sway, and surge) and all six degree of freedom is very important for Multi-Beam Echo Sounder (MBES) work.

The Second Solution

RTK GPS heave is completely suitable for single beam echo sounder survey and as a backup for MRU heave in MBES survey.

CONCLUSION

Heave is a major contributor to the uncertainty in depth measurements because of the wind and waves on the free water surface. MRU measures heave, but it has some drawbacks, problems and errors as reported by several studies such as heave drifts error. MRU was influenced by vibration and the magnetic field beside it is very expensive (Böder, 2008). Nowadays, RTK GPS is not only used in positioning (x, y and z) with centimeter accuracy nor for getting tide in real time related to the ellipsoid, but also it can be used for measuring and calculating heave signals.

Descriptive statistics, correlation, testing the normality, paired samples t-test and Wilcoxon signed ranks tests to compare RTK heave signals with MRU heave signals were done to investigate the possibility of using RTK heave instead of MRU heave and the results are:

- Based on statistical analysis, the difference between RTK heave and MRU heave has a difference which is -0.0158 ft (less than 0.5 cm) with confidence level 95%. The small difference between both heave signals can be referred to the different equipment measuring heave (RTK GPS and MRU), their difference in accuracy and sampling frequency in addition to their different techniques for measurements. However, according to the IHO standard and the maximum allowable TVU in equation 2, the uncertainty in depth was calculated 27 cm for average depth of 13.72 m compared with the uncertainty for the difference between RTK and MRU heave signals which still lies within the limit of uncertainty as specified by IHO special order for the project.

- The difference between RTK heave and MRU heave did not exceed 5 mm (i.e. about 1% from the maximum value of the heave (-1.61 ft (49 cm)). The calculations were based on confidence level 95 %.

- Using RTK heave is easy to apply and install on any rubber boat or small boat in all hydrographic surveying conditions. No consideration for magnetic and vibration problems if RTK GPS heave utilizes MBMAX 64bit module HYPACK software package.

- Therefore, all the above revealed the practical possibility of using RTK heave as a replacement of MRU heave in hydrographic survey that works as an alternative source for getting heave as a backup system for getting heave and as long as the differences do not exceed the maximum allowable total vertical uncertainty.

Acknowledgments (All sources of funding of the study must be disclosed)

We would like to thank Mr. / Pat Sanders and HYPACK Company for sponsoring and supporting this research by free license of the software for three years and we appreciate that one of the researchers was the first hydrographer to use the MBMAX 64 bit module and took part in its improvement while testing it. The researchers would also like to thank the ARAB ACADEMY for SCINCE, TECHNOLOGY and MARITIME TRANSPORT (AASTMT) for the fund.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

REFERENCES

S. Blake, C. Hill, T. Moore, C. Hide, and D. Park, "A heave compensation algorithm based on low cost GPS receivers," *Journal of Navigation*, vol. 61, no. 2, 2008, doi: 10.1017/S0373463307004651.

C. C. Chang, H. W. Lee, and I. F. Tsui, "Preliminary Test of Tide-Independent Bathymetric Measurement Based on GPS," *Geomatics Research Australasis*, vol. 76, 2002.

J. M. Godhavn, "High quality heave measurements based on GPS RTK and accelerometer technology," in *Oceans Conference Record (IEEE)*, 2000. doi: 10.1109/oceans.2000.881277.

IHO, *Manual on Hydrography. Publication M-13*. 2005.

I. H. O. IHO, "STANDARDS FOR HYDROGRAPHIC SURVEYS - Special Publication No. 44," *International Hydrographic Bureau*, 2008.

P. Kielland and J. Hagglund, "Using DGPS to measure the heave motion of hydrographic survey vessels," in *Proceedings of the Annual Meeting - Institute of Navigation*, 1995.

A. A. Gasm Elseid, A. Osman Hamza, and A. Fragoon, "DEVELOPING A REAL TIME ALGORITHM FOR DIAGNOSING GLAUCOMA," *ICTACT Journal on Image and Video Processing*, vol. 9, no. 2, 2018, doi: 10.21917/ijivp.2018.0269.

Böder, "Investigation of Attitude Sensors for Hydrographic Applications," 2008.

J. M. Caldwell, "The Step Resistance Wave Gauge."Proceedings of the First Conference on Coastal Engineering Instruments," California, 1955.

A. N. , A. E.-R. and S. M. A. 5- El-Assal, "On spectral fusion of GPS and heave data in support of Multibeam hydrographic surveying," Cape Town, South Africa, 2009.

Grover, "Observations on Ship Motions at Sea."Proceedings of the First Conference on Ships and Waves.," Hoboken, New Jersey, Oct. 1954, pp. 351–363.

Marine Services Department, "INDYNAMIC UNDER KEEL CLEARANCE," pp. 4–4, 2005.

P. J. V. 13- Rapatz, "Vessel Heave Determination Using the Global Positioning System. M.Sc.E," University of New Brunswick, New Brunswick, 1991.

Egyptian Shipyard Partial Lean Manufacturing Implementation

Mahmoud H. Kheireldin [(1)], Ibrahim S. Seediek [(2)] and Mohamed M. Elgouhary [(3)]

[(1)]Maritime Postgraduate Studies Institute, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt.
[(2)]College of Maritime Transport and Technology, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt.
[(3)]Borg El Arab Technological University - Alexandria, Egypt

Emails: M.Kheirel15039@student.aast.edu, isibrahim@aast.edu, mohamed.elgouhary@alexu.edu.eg

Received on: 26 March 2023 Accepted on: 01 May 2023 Published on: 06 June 2023

Abstract

Purpose: *This work tries to explain the notion of lean manufacturing as an engineering management strategy that can be used by Egyptian shipyards to assist them to compete in the global shipbuilding market.*

Design/Methodology/Approach: *Lean manufacturing uses tools like just-in-time, one-piece flow, and takt time, to improve product cycle times and quality by getting rid of waste in the manufacturing process. These tools are the foundation for eliminating waste in the shipbuilding industry. To help Egyptian shipyards to get a decision regarding how to respond to lean shipbuilding, this work gave a thorough overview of the potential applications of Lean Manufacturing Principles. It additionally improved the presentation of lean manufacturing in a manner suitable for Egyptian culture that is based mainly on the professionality of the workers not on robots, thus assisting the Egyptian shipbuilding sector to be closer to the principles of lean manufacturing.*

Findings: *By applying lean manufacturing tools in a block assembly line at the Egyptian shipyard, the greatest value of waste has been recognized. The shipbuilding cycle time for a 125-ton block assembly has been reduced from 60 days to 30 days as the workshops were capable to deliver two blocks in 60 days instead of 120 days, and the block production lead time was reduced to 50% of the original, reduction in the production lead time of block per man-hours to become 7100 instead of 9499 man-hours.*

Key-words:
Lean Thinking, Process Flow, Lean shipbuilding, Group Technology, just in Time.

INTRODUCTION

According to The Global and United States Shipbuilding Market Report & Forecast 2022–2028, the market will generate USD 61,628 million by 2025, up from USD 43,371 million in 2019, with a CAGR of 4.8% over the forecast period. The market is primarily driven by rising investments in marine infrastructure, rising trade volume, and rising demand for new ships and vessels. The market for bulk shipbuilding projects, which made up 34% of the total shipbuilding industry in 2019, is projected to grow to USD 61,628 million by 2025 from USD 43,371 million in 2019. Passenger ship building projects, purchased at a 36% rate, are projected to rise at a 4% annual pace to USD 80,700 million in 2025 from USD 51,400 million in 2019. Construction projects for cargo ships made up 34% of all projects, and by 2025, they are projected to reach USD 70,600 million, up from USD 51,400 million in 2019.

The phrase "lean manufacturing" first appeared in the 1990s, following the publication of the book "The Machine That Changed the World: The Story of Lean Production" (Womack et al., 1991). The movement of manufacturing concepts from professional worker-based production through mass production to lean production is continued in this book. Although lean manufacturing has its roots in the automotive sector and the Toyota Production System, other production lines are now using it. Lean manufacturing aims to decrease waste, boost efficiency and production, add value, lower costs, and boost competitiveness. Achieving consumer satisfaction is the main goal of lean shipbuilding.

Lean manufacturing, which was first developed inside the Toyota production system, is becoming more and more popular among manufacturers across all industries. It is not done by adding new methods to the way that products are made, but rather by altering the way that production is thought of. Although switching to lean shipbuilding could be challenging, the outcomes urge shipyards to try it. The fact that ships are build-to-order projects makes using lean manufacturing principles in the shipbuilding sector particularly challenging. Probably not all of Toyota's lean tool application techniques will apply to the shipbuilding industry, but the philosophy and principles can be applied with some adjustments. It is possible to observe a lot of the same principles used in the Toyota production system at work in shipyards by looking at models of world-class shipbuilding, for instance, Japanese shipyards use largely standardized modular designs with a steady flow of basic and intermediate parts, materials are precisely sequenced and moved through the shipyard utilizing the Just-in-Time principle. Instead of being examined, quality is built-in at the production station. Processes are timed and standardized using takt time. Instead of being transported into the stockyard months in advance, steel plates are brought in as needed. The main issue is that Egyptian shipyards have not yet entered the global market, preferring to supply the domestic commercial and military markets. Despite advancements in the field of standard and standardized production directed by intermediate products generated by the Egyptian shipbuilding industry, its overall integration level is still below the world-class level, nevertheless. Additionally, most Egyptian shipyards still employ the conventional intensive production management technique. The competitive advantage declines as labor expenses rise.

Egyptian shipyards must adapt their manufacturing processes and rely on lean manufacturing philosophies and practices because of steps taken to increase their competitiveness. The Toyota production system, the underlying lean concepts, and the best applications of the lean methodologies, according to the author, will serve as a platform for modernizing the production processes used in Egyptian shipyards.

This paper provides a framework for using the lean shipbuilding process ideas. within the assumption that the ship is built to be producible according to lean principles. The lean shipbuilding model will describe the lean manufacturing philosophy in the shipbuilding industry. Additionally, some outstanding shipbuilding examples will be provided.

Shipbuilders aim to increase productivity, cut labor costs, and shorten the production cycle if they want to remain in business and become more competitive (Liker, 2004). Utilizing lean manufacturing as an engineering management strategy, shipyards will have a competitive advantage. Eliminating waste is one of the objectives of this lean thinking, which can improve customer satisfaction and turn waste into value.

Traditional versus Lean Shipbuilding

Push vs. Pull

Lean shipbuilding is an engineering management approach that seeks to reduce waste and non-value-added operations throughout the shipbuilding process to improve output and quality, lower prices, and adhere to lead or delivery times.

Traditional shipbuilding uses the push technique to create numerous identical ship parts in a single run. Similar ship parts are produced one by one until the desired quantity is reached according to a precise schedule. This technique, which has a high degree of anticipation, may result in either overproduction or underproduction. Process items are moved back and forth between workstations during production. Parts and subassemblies stay idle during delays, where they can be lost or destroyed, this not only uses capital but also takes up space.

Lean shipbuilding uses the pull technique. No part is produced in a pull technique unless the customer demands it. The customer in this case could be anyone from the assembly welder to the owner of the vessel. The system is very sensitive and flexible to the needs of the consumer because this procedure is demand oriented. As soon as a part is finished, it is used, preventing downtime between workstations. There is no value added to the part by the downtime between workstations. Because the part is enhanced at each stage, the true value is added at the workstation. It becomes more useful to the customer with each development.

Delivery periods for raw materials are another distinction between push and pull techniques. During a push cycle, the material is ordered and delivered well in advance of the scheduled date. Large stocks of materials that may not be needed for some time result from this. Once more, unused materials result in increased expenses for both the land needed to keep them and the materials themselves, which are not regained until the materials are used. but during the pull cycle, smaller orders and deliveries are often made. A pull cycle can take delivery of small lots many times during the day, whereas a push cycle might take delivery of huge quantities of material once a week or once a month. Smaller lot sizes are ensured, as a result, as well as the storage spaces.

Batch and Queue vs. Continuous Flow

Large batch sizes are another type of waste that is present in conventional shipbuilding. A batch is a collection of parts that are created sequentially up to a predetermined number, at which point they are moved to the following station. The term for this is batch and queue flow, batch refers to the volume of a part produced, and queue refers to the parts' waiting period until they are required. The method determines the different batch sizes. Each part must wait until all other parts in its batch are finished before it can be released and sent as a batch to the next station. The part wastes time by being stored in a bin after being transferred to the following station until it is needed for manufacturing. The lead times for freshly ordered products are also lengthened by this batch method. Before the production line can be altered to accommodate new orders, a fixed number of batches must first be produced. This increases the time needed to implement a change order in addition to increasing the time needed to deliver a product to the client.

In lean shipbuilding continuous flow is used. Waiting time is eliminated by moving each part to the next station as it is created. Additionally, it enables the shipyard to deliver the appropriate part in the appropriate quantity at the appropriate time in response to customer demand. Since parts are only produced when needed, the manufacturing process can be modified to satisfy client demand.

By reducing the number of Defects through product inspection by the workforce at each station and reducing the damage that may happen while the product is waiting to be used, continuous flow also contributes to improving the quality of the finished product. The next operator can instantly see any flaw that can develop during continuous flow from the preceding process. After that, the process is stopped until the issue can be resolved, avoiding damaged parts from leaving the shop and raising overall quality.

One-piece / Continuous Flow

One-piece flow entails establishing assembly techniques for the creation of subassemblies, units, and part families that go through the same set of processes. Between 1965 and 1995, Japanese shipbuilders who adopted such lean techniques saw a 150 percent boost in productivity.

Hull divisions are first defined by planners, who then break them down into pieces or blocks, which are then further broken down into sub-blocks or subassemblies, and so on. The zoning procedures are finished by defining zones that can be produced in a single piece. One-piece construction is made easier along the manufacturing line by intricate detail design. Comprehensive subassembly integration for one-piece flow requires master scheduling execution.

Lean Shipbuilding Overview

Philosophy of Lean Shipbuilding

Because it utilizes less of everything than the mass production method, this system is known as the "lean manufacturing system." To build a new ship in half the time, lean manufacturing uses half the labor force in the facility, half the manufacturing area, half the tool investment, and half the engineering hours. Toyota's Production System is based on 14 principles under four sections, all beginning with the letter P. (Philosophy) Each organization must have a long-term philosophy. (Process) The right steps will produce the right outcomes. (People) By improving their work, they must bring value to the organization. (Problem-Solving) Regular problem-solving results in structured learning. Eliminating the Eight Waste Elements has become the core of lean shipbuilding.

Fig. 1. The 14 principles / 4P's model / lean shipbuilding

Lean Shipbuilding Five Principles

As per Figure 2, Lean shipbuilding's five principles are:

Fig. 2. Lean shipbuilding's five principles

I- Identify value to identify customer needs from Operations. This can be done using value management.
II- Map the value flow, processes required to define the Product as value flow, so mapping will help in Understanding.
III- Create a process flow to avoid or reduce batch and Queue, if possible.
IV-Establishing pull system, producing when and what Customer's needs.
V-Seek for perfection and continuous improvement.

Proceed to Lean Shipbuilding

When lean shipbuilding is used, the shipyard becomes a lean enterprise. According to Liker and Lamb (2002), shipyard management should do the following:

i- Construct the system, learn by doing, then train in an 80:20 rule (80% of outcomes comes from 20% of causes, to prioritize the 20% of factors that will produce the best results).
ii- Map the pilot value stream to demonstrate the resilience of the system and provide a benchmark example.
iii- Map the future-state value stream.
v-Teach in a kaizen (continuous improvement) workshop and implement quick adjustments.
vi-Sort value stream sample data to improve clarity.
vii-Making lean transformation imperative is necessary since it is not a voluntary process.
viii-Select lean leaders, hire a lean specialist, and engage the professionals.

Definition of Waste in Lean Shipbuilding

Numerous manufacturing processes present the possibility of waste issues impacting worker productivity, product quality, costs, and production time (Fitriadi et al, 2021). Waste in lean shipbuilding is anything that increases the time and expense required to build the ship but does not improve its value in the eyes of the customer. Value-added activities make the product a desirable item for the customer. Figure 1 shows simplified steps required to sub-assemble the ship hull steel plates. Only activities displayed in dark green add value. The light green dotted activities do not add value from the customer's point of view.

Since the value-added time makes up a small portion of the overall time limit, it is evident from Figure.1 that the overall benefit of cutting cycle time value-added activities is only up to a small portion of the time total. The efficiency of value-added activities may be attacked, as may be anticipated from mass productive thinking. One may, for instance, shorten the cycle time required to cut steel.

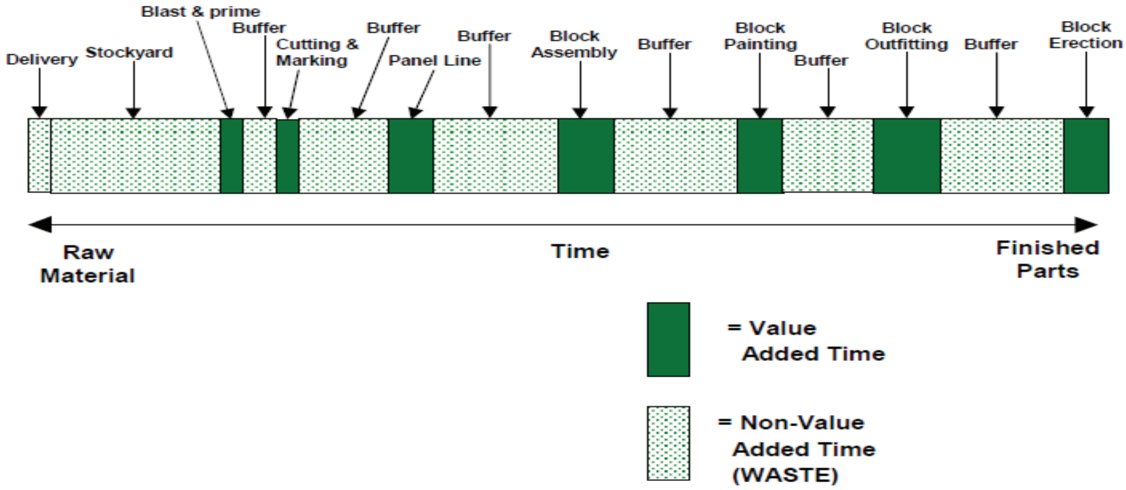


Fig. 3. Shipbuilding value-added / non-value-added activities

Value- added activities are activities that, in the owner's perspective, provide added value to a ship. This includes steel processing into subassembly and grand block assembly.

Non-value-added activities are activities that, from the owner's perspective, do not add value to the ship, for example moving sections from one station to another. Those activities include waste and must be minimized or eliminated.

Activities that do not add value to block assembly. But it needs to be done because if not done it will cause the supply process to be disrupted. Those activities include waste that is difficult to eliminate. For example, inspection activities, or waiting for machines.

Utilizing the Just-in-Time Method

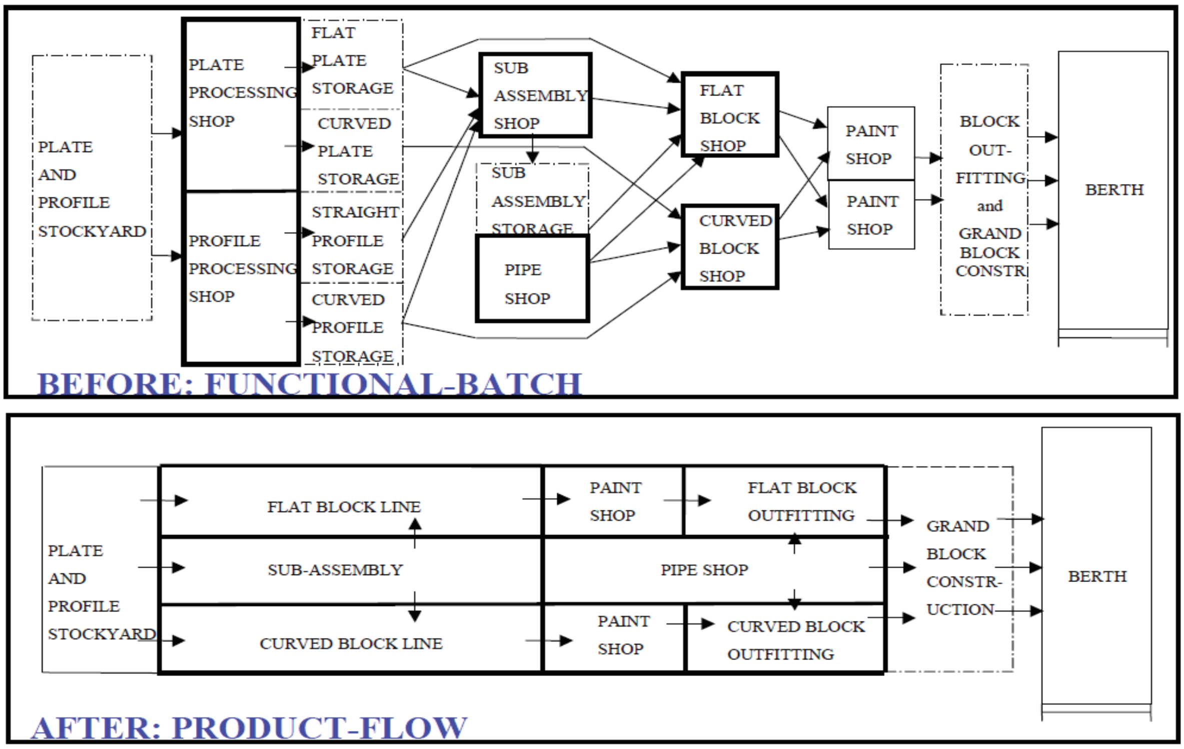


Fig. 4. Just-in-time in shipbuilding (Liker, 2002)

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.081

By obtaining the proper number of raw materials and creating the proper quantity of goods at the proper location and time, the just-in-time manufacturing principle helps to eliminate waste (Phogat, 2013). A one-piece flow is perfect for an on-demand production system (Kolich et al., 2012). Although this method is primarily used for mass production, elite shipyards, particularly Japanese yards, have adapted it. Therefore, a one-piece flow, as seen at the bottom of Figure 1, is the best solution from the perspective of lean manufacturing. In this situation, one can work with one plate and one stiffener at a time and cut only the material he/she needs to pass it on, finish cutting, pass it on, complete the subassembly, pass it on, and assemble the block. An expanded view of the shipbuilding process is shown in Figure 1. Egyptian shipyards have often been arranged according to their functions. For instance, all buildings, whether curved or flat, are created in a single workshop, and both straight and curved profiles are created in different workshops. Panels and profiles are used to create large quantities, which are subsequently put into storage. After that, they are moved to the sub-assembly for sorting. Every component must go through the same paint shop, which frequently turns into a bottleneck. A typical configuration in Lean Shipyards is depicted in the bottom portion of Figure 1. The yard is set up according to the "product line" in this instance.

In this scenario, flat blocks go through one set of operations, and curved blocks go through another set of operations, making up a manufacturing line rather than separate vessels. For instance, all flat panels are cut in straight profile process lanes before being delivered in tiny batches to the flat block line for assembly. One paint shop is designated for flat blocks, and the other is designated for curved blocks, as shown in Figure 1. After being prepared in separate locations, flat and curved blocks are then brought together to form a huge block assembly.

Use of Takt Time Technique

Takt time, a pacing mechanism used in lean shipbuilding operations, is introduced to help control the production flow. Takt time is primarily defined by the "Customer Demand Rate."

The ability to give shorter lead times to clients and enhance the usage of the shipyard, which results in increased revenue, is one of the major advantages of continuous-flow manufacturing. Depending on the size and complexity of the ship, Takt time might differ significantly from ship to ship. Similarly, each portion of a ship, which is made up of numerous distinctive components, may have a varied Takt time. It makes more sense to think of the ship as a collection of smaller pieces when considering Takt's period.

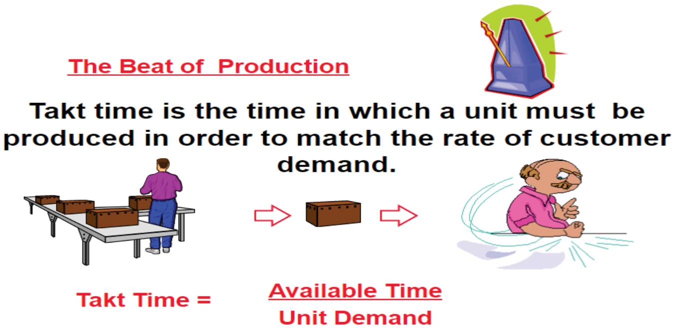


Fig. 5. TAKT TIME (Liker, 2002)

Utilize the Group Technology Approach.

A concept known as "Group Technology" is founded on the idea that related products should be handled similarly. Group Technology shortens the lead time for production, work-in-process, labor, tooling, rework, scrap material, setup, delivery, and documentation (Shahin, and Janatyan, 2010). The conceptual model for Group Technology is divided into four parts:

i- processes: product groups, classification, design conformity, group production, group technology management, and the automated factory system.
ii- Intermediate variables: determining the part family, standardizing the process plan, group scheduling, group tooling setup, reducing the number of materials purchased, using computer-aided design and manufacturing, and using CNC machines.
iii- Production wastes: operating power, inventory, movement, complexity, waiting, needless process, and defect.
iv- Objectives: The major goal is to lower waste and expenses to increase production.

Employing a Simulation Model

The expense of finding optimal solutions and the risk associated with making poor decisions in the real world can both be significantly lowered by using a virtual shipbuilding environment (Krause et.al, 2004). The procedures are as follows:

i- Setting goals as simulations can be used for multiple goals, increasing productivity, assisting in new investments, reducing inventory, material flow analysis, manpower sizing, and continuous improvement of production.
ii- Collecting the appropriate data.
iii- Building the model and establishing the logic and procedures to represent the real system.

iv- Validating the form to check that the model is already working as a real system.
v- Running the simulation and collecting the results, if one must, change some parameters and see how the model behaves, otherwise, he/she will fall then back to step (iii).
vi- Analyzing the results to aid decision-making.
vii- extracting Final documentation with a detailed description of what needs to be done.

European Shipyard Using Lean Manufacturing (Kolich et al., 2012)

The actual lean manufacturing implementation requires the transformation of traditional panel lines and built-up panel lines which still exist in many European shipyards. Combination of lean principles results in time savings and in man/hour reduction, which directly brings significant savings to the shipyard (Kolich, 2011). Table 1 below shows the activities of the traditional block assembly lines that exist in most European shipyards.

Table 1: Activities of the Block Assembly Workstations (Kolich et al., 2012)

station	description	Takt time (hours)	Coefficient	Takt time x Coeff. Man/hours
1	Forming a panel by joining and welding steel plates	4	4 seams x 2 workers x 4 panels = 32	128
2	Turn over the panel to weld it on the other side	4	4 panels x 2 workers = 8	32
3	Marking the plate for longitudinal stiffeners	4	4 panels x 2 workers = 8	32
4	Fitting and welding of longitudinals	4	4 panels x 2 workers = 8	32
5	Quality control and transportation to the built-up panel line	4	4 panels x 1 workers = 4	16
6	leveling with heat	8	2 built-up panels x 2 workers =4	32
7	Labeling, laying, and tack-welding of transverses	8	2 built-up panels x 12 workers = 24	192
8	Welding of transverses and cleaning the weld	8	2 built-up panels x 12 workers = 24	192
9	Grinding and preliminary outfitting	8	2 built-up panels x 10 workers = 20	160
10	Final block assembly before erection on the slipway	16	11 workers	176
Total man/hours for complete double-bottom block assembly				1000

Lean manufacturing when implemented properly lead to a decrease in both duration time and man-hours as well as in a decrease of necessary space in the shipyard. However, pieces of equipment are recommended to be installed in a block assembly line, Figure 6 shows the workstations:

i- At lean workstation 2, install a high-grade fitting machine to do fitting up to four longitudinals simultaneously,
ii- At workstation 3, install four automatic welding machines on the girder to weld longitudinals on both sides simultaneously,
iii- At workstation 4, install three machines of one side automatic Flux-Copper Backing,
iv-At lean workstation 5, install Push-type insert equipment to push transverses,
v-At lean workstation 6, install four portable welding robots, suspended from two girders.

By conducting the elimination of the non-added value activities, where the transverses have cut-outs that require additional work for the fitting and welding of lugs. So, when lean is applied, the panel-

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2023.02.1.081

block assembly line eliminated the need for lugs, as specified in Figure 7.

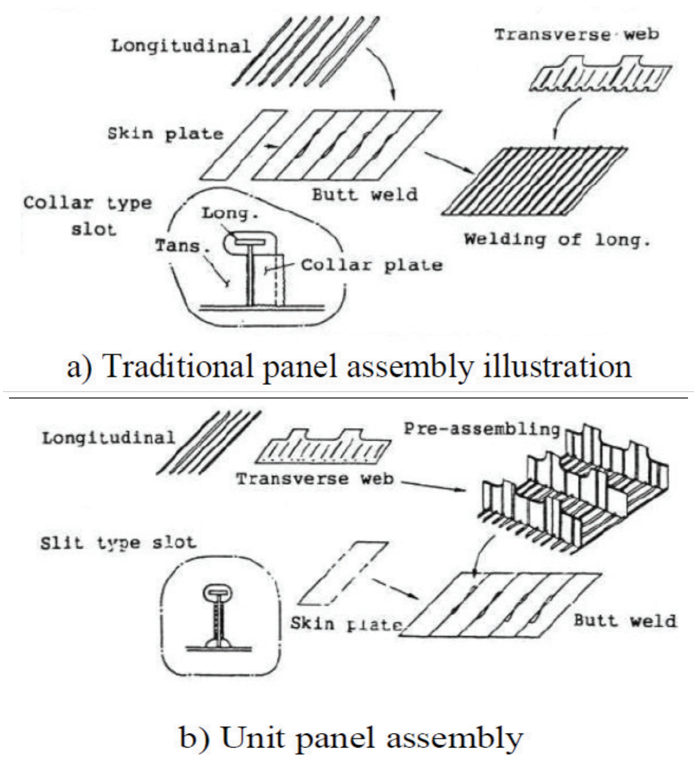


Fig. 7. The traditional vs. lean panel line (Kolić, 2011)

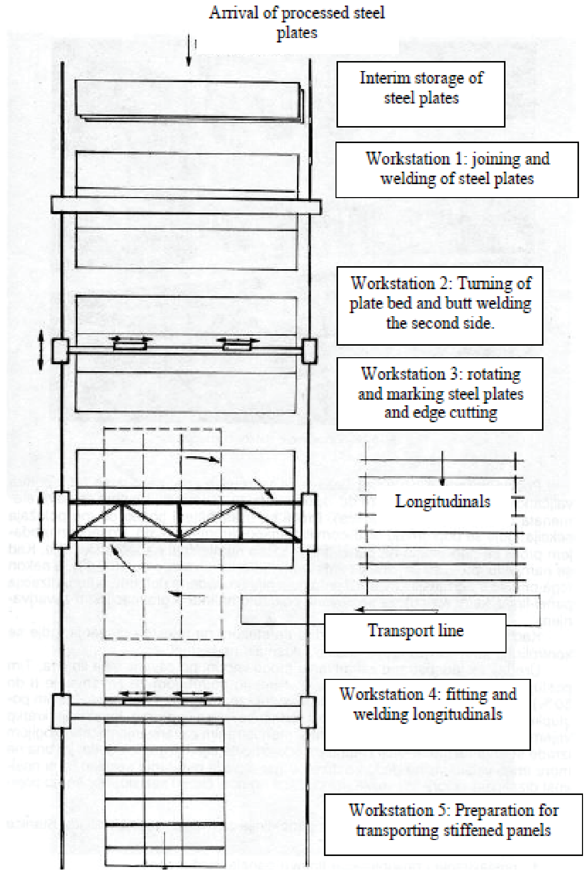


Fig. 6. Panel line workstations (Kolić, 2011)

Table 2 below shows the activities of the lean block assembly workstations.

Table 2. Activities of the Lean Block Assembly Workstations (Kolich et al., 2012)

station	description	Takt time (hours)	Coefficient	Takt time x Coeff. Man/hours
1	Unit plate trimming along the edges	1	5-unit plates x 4 panels x 2workers = 40	40
2	Turn over the panel to weld it on the other side	1	5-unit plates x 4 panels x 2workers = 40	40
3	Marking the plate for longitudinal stiffeners	1	5-unit plates x 4 panels x 2workers = 40	40
4	Fitting and welding oflongitudinals	1	4 one-sided seams x 4 panels x2 work-ers = 32	32
5	Quality control and transportation to the built-uppanel line	4	2 built-up panels x 20 workers = 40	160
6	leveling with heat	4	2 built-up panels x 5 workers = 10	40
7	Labeling, laying, and tackwelding of transverses	4	12 workers	48
Total man/hours for complete double-bottom block assembly				400

Egyptian Shipyard Under Study to Adapt to Lean Shipbuilding

The Egyptian shipyard under study is a medium to big size shipyard. It produces a variety of vessels, including river barges, tankers, ro-ro ships, and medium-sized warships. Additionally, it has the capacity to produce 35 boats every year. Two slipways, one with a 300-ton lifting capacity overhead gantry crane, are used to launch ships. According to the capacity of the cranes at the workshops and the capacity of the carriers, the erection blocks are planned to be close to 125 tons. Although this shipyard has decent production facilities that meet the needs of the productive product mix program, it is necessary to be improved to increase competitiveness. The best workshop to apply the lean method as a pilot form within the shipyard is Assembly & Welding Shop and Block assembly shop. A lot of waste has been recognized in this workshop.

Cutting and Welding Facilities at Egyptian Shipyard (Krishnan, 2012)

i- Metal Processing Shop, where automated Plate Cutting Machines, shearing machines, Hydraulic Presses, and rollers capable to do Marking, Cutting, and Forming metals (steel, stainless steel, and aluminum), are attached to the Metal Processing shop a stockyard for Plates and Sections.

ii- Unit Assembly & Welding Shop consists of four lanes; the first is for assembly and welding of the flat section, and the second is for the assembly and automatic submerged arc welding at the entrance of the lane. Third is where small sections /units of stiffened floors and girders, built-up web frames, and deck beams are assembled and welded using mainly semi-automatic CO_2. Last is where the slightly curved and framed sections /units are assembled and welded using mainly semi-automatic CO_2. It is normal that all the units/sections be inspected by the QC staff attending permanently the workshop and any NDT is to be applied to all built sections prior to being transported to the block assembly workshop.

iii- Block Assembly and Welding Shop, where Blocks up to 125 tons are assembled out of the subsections and sections supplied by the unit assembly and welding shop using the various types of processes of welding on the flat stand or curved stand depending on the specified block, quality took place for approval then transported using transporters to Blast and Painting Shop and then to the slipway.

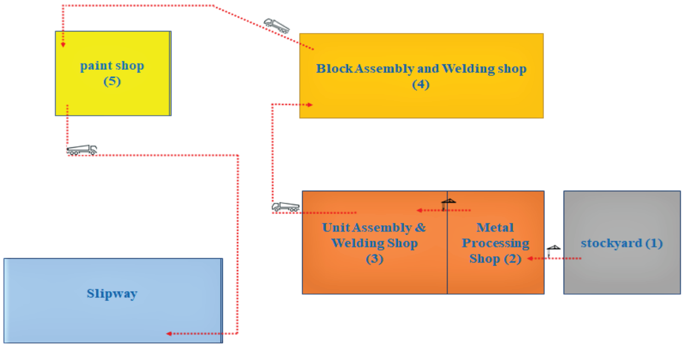


Fig. 8. Shipyard production system before lean implementation

Egyptian Shipyard Production System

The shipyard production system did not cope with the lean concept. In the past times, the steel plates were pushed from the stockyard (1) to the Metal Processing Shop (2) to be cut and marked according to the shop drawings. Then pushed to the Unit Assembly & Welding Shop (3) to get an assembly of micro panels and panels up to the small section, then the small sections are loaded onto the transporters and taken to the Block Assembly & Welding shop (4), then the blocks are loaded onto the transporters to the paint shop (5) then pushed to the slipway to assemble all blocks together on keel laid at the slipway (see Figure 2) below.

Egyptian Shipyard Production Line Wastes

Table 3: Observed Wastes at an Egyptian Shipyard

According to Toyota classification	Observation
Waiting	Wasted time because of the lack of operating procedures and searching for raw materials.
Over-processing	Lack of standardized work. Lack of logical sequence of tasks. Lack of tasks organization.
Unnecessary motion	Unnecessary movements between stations and searching for components.
Defects	Long Stiffeners were cut and deformed during transportation to the next station due to a lack of organization and coordination.
Inventory	Out of stock of some parts and exceed of other parts due to lack of organization.

Transportation	Unnecessary transportation of sections to be assembled at the next workshop.
Overproduction	Cutting More panel profiles before it is required
misallocated personnel	Non-utilized workers or assigned for a job not fitted with their talents.

MEHODOLOGY

Change Process Sequence of the Block Assembly Line (Kolich et al., 2017), (Oliveira 2018) The target was to enter the stages of lean manufacturing without any additional financial burdens on the management achieving a clear result that encourages moving forward toward the implementation of lean manufacturing. It was by searching for the greatest value of waste in production processes and finding that there was a transportation process that did not add value to the final product, which is the transfer from the Unit Assembly & Welding Shop (3) to the Block Assembly & Welding shop (4). This step was canceled, and part of the Unit Assembly & Welding Shop (3) was re-equipped to become an additional Block Assembly and Welding shop (*4) with Shop (4), also equip the Block Assembly and Welding Shop (4) to perform as the processes of the Unit Assembly & Welding Shop (3) to be (*3).

The new sequence of production became; the steel plates are pushed from the stockyard (1) to the Metal Processing Shop (2) to be cut and marked according to the shop drawings. Then pushed to the Unit Assembly & Welding Shops (3) & (*3) to be assembled into small sections, then the small sections are assembled to form the block, in the Block Assembly Shops (4) & (*4), The blocks are then loaded onto a transporter to the Blast & Painting Shop (5), then pushed to the slipway to assemble all blocks together (see Figure.3 below).

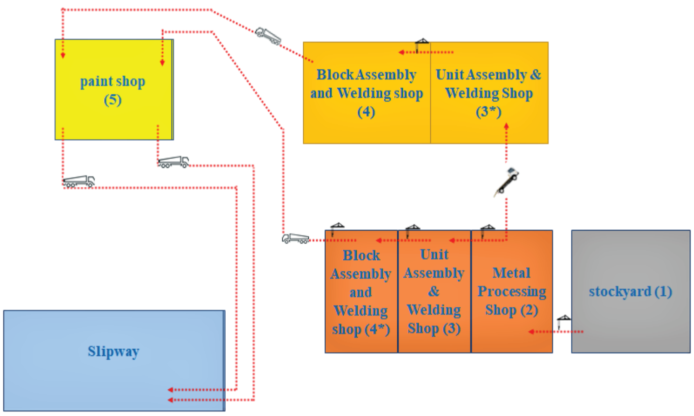


Fig. 9. Shipyard production system after lean implementation

RESULTS AND DISCUSSION

Using a lean shipbuilding system presented in this work to eliminate wastes, in this situation it came from transportation, which has an impact on ship production cycle time and delivery time.

Also, there is a hidden waste no one inside the shipyard notice which is misallocated manpower and misassigned areas. As Unit Assembly & Welding Shop was split into shop (3) & shop (*4) (doing the role of Block Assembly Shop), and the Block Assembly Shop is split also into shop (4) & shop (*3) (doing the role of Unit Assembly & Welding Shop), with surprising that both workshops are working perfectly at the same time with no additional manpower needed. Table 3 shows the comparison of the shipyard's production situation before and after the implementation of lean shipbuilding.

The traditional system for the Egyptian shipyard was designed to produce block assembly weighing 125 tons each using 12 m (length) x 3 m (width) steel plates with a thickness of 8 mm - the weight of the plate is about 2.2 tons, which means that the block uses 56.8 steel plates. Processing for only one plate takes 140 man-hours, and 7952 man-hours to produce one block assembly. i.e., there are about 1547 man/hours out of 9499 man/hours not assigned to work.

When partially implementing the lean tools in the Egyptian Shipyard, the shipyard has now two block assembly lines that are capable to deliver two blocks in 60 days instead of 120 days as in the traditional system.

Block production man-hour was reduced from 140 man-hours to 125 man-hours by canceling transportation activity from workshop (3) to workshop (4).

Production cycle takes 7100 man/hour to produce one block i.e., there are about 2399 man/hours out of 9499 man/hours not assigned to work. This is what gave the Egyptian shipyard the privilege of establishing a new block assembly line to be in parallel.

Table 4: The Comparison of the Shipyard's Production Situation Presented by the Egyptian Shipyard

Trade	Max capacity Monthly Man/Hour	Traditional	Lean implementation	
		Block assembly line Man/Hour	Block Assembly 1 Man/hour	Block Assembly 2 Man/hour
Metal Processing Shop				
Metal Processing Shop: Production Capacity Per Month: 210 Tons, The Number of Hours (40) Based on The Use of Steel Plate 12 Meters X 3 Meters with a Thickness of 8 mm - Weight of the plate is 2.2 Tons. The total capacity monthly is 3818 Man/hour.				
Cutting & Marking	2290	20	15	15
Grinding	764	10	10	10
Steel Forming	764	10	10	10
Total	3818	40	35	35
Unit Assembly & Welding Shop				
Unit Assembly & Welding Shop: Production Capacity Per Month: 130 Tons, The Number of Hours (50) Based on The Use of Steel Plate 12 Meters X 3 Meters with a Thickness of 8 mm - Weight of the plate is 2.2 Tons. The total capacity monthly is 2954 Man/hours.				
Assembly & Welding	1181	20	15	15
Final Welding	1477	25	20	20
Additional Marking	148	2.5	2.5	2.5
Straightening	148	2.5	2.5	2.5
Total	2954	50	40	40
Block Assembly and Welding shop				
Block Assembly & Welding Shop: Production Capacity Per Month: 120 Tons, The Number of Hours (50) Based on The Use of Steel Plate 12 Meters X 3 Meters with a Thickness of 8 mm - Weight of the plate is 2.2 Tons. The total capacity monthly is 2727 Man/hour.				
Assembly & Welding	1090	20	20	20
Final Welding	1365	25	25	25
Additional Marking	136	2.5	2.5	2.5
Straightening	136	2.5	2.5	2.5
Total	2727	50	50	50
Total Line Man/hours		140	125	125
Total Man/hours	9499	7952	7100	7100

CONCLUSIONS

The Egyptian Shipbuilding industry needs changes to become competitive in the international shipbuilding market. Lean manufacturing as an Engineering Management approach when implemented properly at the Egyptian shipyard will do the best arrangement of the shipbuilding processes. Lean shipbuilding is characterized by low cost, small investment, and great benefits compared with automation. That is what encouraged Egyptian shipyards to try to transform to lean to benefit from the decrease in both duration time and man/hours as well as in a decrease of necessary space in the shipyard. lean shipbuilding that has been introduced in this work integrates lean some shipbuilding tools, such as just-in-time, takt time, and continuous flow operation. Also, identify the added and non-add value activities in the production process and recognize most of the wastes. The production efficiency of the Egyptian shipyard block assembly line was partially improved, the production balance was improved and identified, and personnel and time waste were reduced distinctly by using the lean shipbuilding introduced partially in this work. The shipbuilding cycle time for a 125-ton block assembly has been reduced from 60 days to 30 days as the shops became capable to deliver two blocks in the same 60 days instead of 120 days, and the block production lead time was reduced to 50% of the original, 25% reduction in the man/hour needed for block production.

Egyptian shipyard was able to open the 2nd block assembly line with no need for hiring more workers. According to cultural differences, this work is limited to Egyptian shipbuilding projects and Egyptian shipyards.

Now, the Egyptian shipyard has the available tool to step-by-step implement lean production and overcome the shortcomings of the traditional system that only focuses on plan scheduling and monitoring of the production process. although what has been achieved in reducing the production time by implementing lean shipbuilding in the Egyptian shipyard, but comparing to the European model, there are still many procedures required to be implemented to reach a competitive delivery time and competitive product price.

FUTURE WORKS

Logistics analysis, time analysis, cost analysis, and activity analysis in the lean shipbuilding system will be investigated (Leal et al., 2017). Moreover, the Egyptian shipbuilding operation process will be further optimized using discrete event simulation, while shell, outfitting, coating integration operation methods, and the layout of logistics facilities will be continuously improved to increase the production efficiency of shipbuilding and enhance the competitiveness of small and medium-sized shipyards.

REFERENCES

Cantarelli, C.C. *et al.* (2018) 'Cost Overruns in Large-Scale Transport Infrastructure Projects', *Automation in Construction*, 2(1).

Fitriadi, F. and Ayob, A.F.M. (2022) 'Identifying the Shipyard Waste: An Application of the Lean Manufacturing Approach', *International Journal of Global Optimization and Its Application*, 1(2). Available at: https://doi.org/10.56225/ijgoia.v1i2.19.

Kolić, D. (2011) 'Methodology for improving flow to achieve lean manufacturing in shipbuilding', *Faculty of Engineering*, Phd of Des.

Kolić, D., Fafandjel, N. and Zamarin, A. (2012) 'Lean manufacturing methodology for shipyards', *Brodogradnja*, 63(1).

Kolich, D., Storch, R.L. and Fafandjel, N. (2017) 'Lean methodology to transform shipbuilding panel assembly', *Journal of Ship Production and Design*, 33(4). Available at: https://doi.org/10.5957/JSPD.160028.

Krause, M. *et al.* (2004) 'Discrete event simulation: An efficient tool to assist shipyard investment and production planning', *Journal of Ship Production*, 20(3). Available at: https://doi.org/10.5957/jsp.2004.20.3.176.

Krishnan, S.N. (2012) 'A Scientific Approach to Measure Shipbuilding Productivity', *Maritime Affairs:Journal of the National Maritime Foundation of India*, 8(1). Available at: https://doi.org/10.1080/09733159.2012.690565.

Leal, m, & G.J.M. (2017) 'hull's manufacturing cost structure. Brodogradnja / Shipbuilding', pp. 1–24.

Liker, J.K. (2004) *The Toyota Way (2nd Edition): 14 Management Principles From the World's Greatest Manufacturer*, *McGraw-Hill*.

Liker, J.K. and Lamb, T. (2002) 'What is lean ship construction and repair?', *Journal of Ship Production*, 18(3). Available at: https://doi.org/10.5957/jsp.2002.18.3.121.

Phogat, S. (2013) 'an Introduction To Applicability of Lean in Shipbuilding', *International Journal of Latest Research in Science and Technology*, 2(5).

The Global and United States Shipbuilding Market Report & Forecast (2022).

Womack, J.P., Jones, D.T. and Roos, D. (1992) 'The machine that changed the world', *Business Horizons*, 35(3). Available at: https://doi.org/10.1016/0007-6813(92)90074-J.

مركز الأكاديمية للنشر
ACADEMY Publishing Center

MRT
Maritime Research & Technology Journal

Volume 2 - Issue 1 - June 2023 - ISSN 2812-5614

http://apc.aast.edu/ojs/index.php/MRT