IAMUS Proceedings & Conference book

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The International Association of Maritime Universities (IAMU) Student Session

Proceedings & Conference Book

Adjunct professor Minna Keinänen-Toivola
IAMUS 23 Program Editor

"A publication of the International Association of Maritime Universities"

Preface

The 23nd Annual General Assembly (AGA 23) is the annual meeting of the International Association of Maritime Universities (IAMU). The IAMU Student session (IAMUS), held annually as part of the AGA, brings together students and official representatives of IAMU member universities from all over the world to discuss, exchange, and share recent progress and future trends in maritime sector within the scope of IAMU.

The 23nd AGA and IAMUS are hosted by Satakunta University of Applied Sciences, in the cities of Helsinki and Rauma, Finland.

23rd AGA and IAMUS 23 is the best platform to enable students from around the globe to meet each other "face-to-face" and disseminate the latest research advancements in the fields of topics deal with Breakthrough Technologies for Seafaring and MET, Managing Maritime Safety and Security, Environmental Sustainability in Seafaring and Education of Global Maritime Professionals.

The theme of the AGA23 IAMUS is "Quality of the Education of Global Maritime Professionals".
The IAMUS Conference book contains abstracts of papers presented at the technical session. This year IAMUS has received high-level abstract submissions from a variety of different countries and IAMU universities.

We hope your experience with AGA 23 and IAMUS is a fruitful and long-lasting one. With your support and participation, the student session will continue its success for a long time.

Finally, we would like to thank the organizing committee, the members of the program committees, and reviewers. They have all collaborated to execute a world-class scientific conference appropriate to the respected work of the International Association of Maritime Universities and all member universities.

Adjunct professor Minna Keinänen-Toivola
IAMUS 23 Program Editor

Theme

IAMUS Main Theme:
Challenges of future competences

Sub-themes:
Breakthrough Technologies for Seafaring and MET
Managing Maritime Safety and Security
Environmental Sustainability in Seafaring

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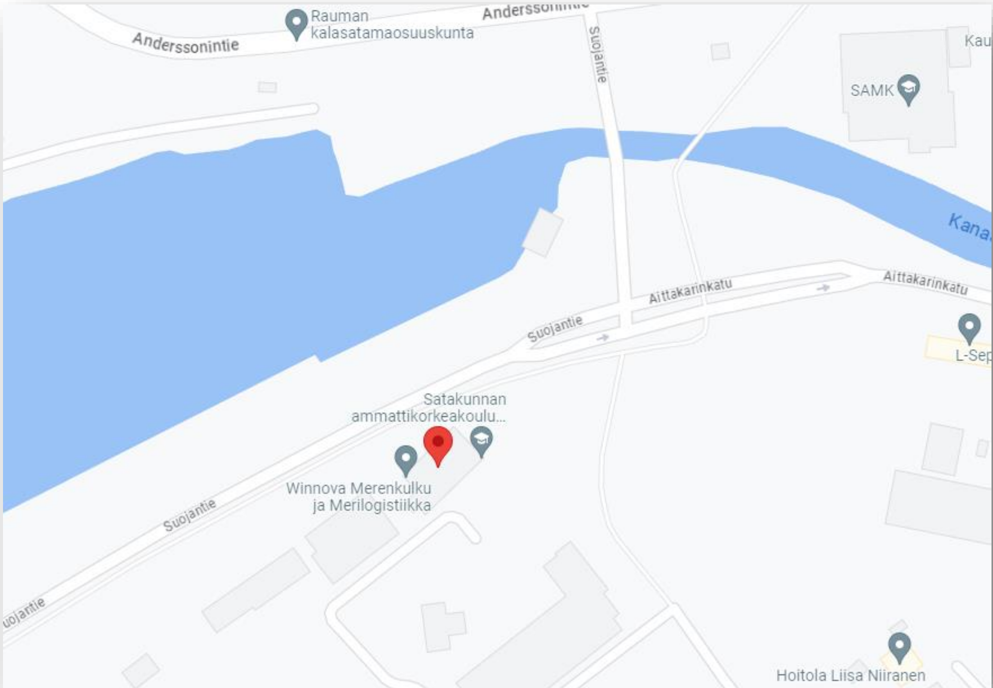
Venue

The IAMUS Conference takes place in Rauma at the Merimäki building
Suojantie 2, Rauma, Finland



Program overview October 19, 2023 / Technical Sessions

Time	Activity	Location
9.00-9:30	**Opening ceremony**	Merimäki Auditorium,
Chair: Mrs. Lesya Demydenko Satakunta University of Applied Sciences		
Co-Chair: Ms. Elviira Tuomi Satakunta University of Applied Sciences		
Session 1		
9:30-10:00	Sung-Jae Jeong, Seung-Hun Jung, Tae-Yang Song: **Suggesting a New Norm in Education for MASS Operators**	Merimäki Auditorium MA122
10:00-10:30	Zhen Tian, Yihang Zhou: **Thermo-economic analysis on OCCS of LNG dual-fuel vessels based on the EEDI framework**	
10:30-11:00	Zhen Tian, Junjie Zhou: **A Zero Energy Increment Onboard Carbon Capture System for LNG-fueled Ship**	
Coffee Break		
Session 2		
11:30-12:00	Tianhui Zhu, Hongxiang Ren, Fuquan Xu, Jiawen Sun: **Visualization and Simulation of Ocean Scenes with Physically-Based models in Marine Simulators**	Merimäki Auditorium MA122
12:00-12:30	Amit Sharma, Charlott Sellberg: **Towards Practicable Learning Analytics for Maritime Education and Training**	
12:30-13:00	Martin Nikolla, Ljubomir Pozder, Goran Vizentin, Goran Vukelić: **Enviromentally Sustainable Technology for Building Composite Boat Equipment**	
Lunch		
Session 3		
14:00-14:30	Val Arvin G. Bucais, Patrick P. Delgado, Wilfred Louie L. Espino, Neil Joshua V. Esquillo, Airah Faith G. Hortillas, Henrickmike G. Jadan, John Peter A. Laguardia, Keyneil Cuill J. Mancilla, Louie James G. Robles, Jobelie D. Villanueva: **Preparedness for Apprenticeship Among Maritime Students**	Merimäki Auditorium MA122
14:30-15:00	Mota, Artemisa & Lodhi, Rahul: **Paving the Way for the Introduction of Code for Autonomous Vessels: Critical Review of Regulatory Framework for Safety of Navigation**	
15:00-15:30	Haruki Itakura, Htoo Nay Wunna, Motoaki Moritaa, and Shinichi Motodaa: **Band Bending Mechanism in Dye-Sensitized Solar Cells Using Ruthenium and Indoline Dyes**	
15:30-16:00	Freya Jobson, Sara Lundmark: **Running miles and running lines, can seafarers do both while being happy?**	
Ending words		
Closing the conference		

IAMUS 2023 Instructions

For any further help regarding guidance, please contact iamus23@samk.fi.

Oral Presentation Guidelines

- Oral presentation slots have 30 minutes (20 min presentation, 10 min questions).
- Session Chairs will strictly demand time to allow members of the audience to switch sessions between presentations.
- All session rooms are equipped with LED Screens, a computer (MS Windows, MS PowerPoint, and Adobe Acrobat), microphone, remote control, and laser pointer. To avoid software compatibility problems, please embed all fonts in your PPTX file and bring a backup PDF file of your presentation.
- Preferable: send final presentation in PPTX or PDF format to iamus23@samk.fi by Friday 13th of October.
- Another option, bring your presentation on a USB storage device and report to the Session Chair indicated in IAMUS Program 15 minutes before the start of the Session.
- Online presentation is not possible, neither a recorded presentation
- Each session has Session Discussion, all presenters have to participate also this part of the program as they have to be ready to answer questions.

Poster Presentation Guidelines

- Posters will be presented during the Poster Sessions indicated in the IAMUS Program. Presenters should be standing next to the poster during the Poster Sessions to answer any question.
- Poster should be made in size A0 (height 841 mm x length 1189 mm). Please use large fonts (24 or above), avoid using dense text, tell the story in graphics, diagrams, and pictures as much as possible. Poster main ideas should be spelled out in the introduction and conclusions sections. The main point of the work should be crystal clear from spending only a few moments reading these sections.
- For any help regarding this matter please contact iamus23@samk.fi.

Name Badge

All attendees must wear the name badge at all times to gain admission to IAMUC.

Mobile Phone

As a courtesy to our presenters and other attendees, please turn off your mobile phones during the sessions.

Abstracts overview

1	Sung-Jae Jeong, Seung-Hun Jung, Tae-Yang Song: **Suggesting a New Norm in Education for MASS Operators**
2	Zhen Tian, Yihang Zhou: **Thermo-economic analysis on OCCS of LNG dual-fuel vessels based on the EEDI framework**
3	Zhen Tian, Junjie Zhou: **A Zero Energy Increment Onboard Carbon Capture System for LNG-fueled Ship**
4	Tianhui Zhu, Hongxiang Ren, Fuquan Xu, Jiawen Sun: **Visualization and Simulation of Ocean Scenes with Physically-Based models in Marine Simulators**
5	Amit Sharma, Charlott Sellberg: **Towards Practicable Learning Analytics for Maritime Education and Training**
6	Martin Nikolla, Ljubomir Pozder, Goran Vizentin, Goran Vukelić: **Enviromentally Sustainable Technology for Building Composite Boat Equipment**
7	Val Arvin G. Bucais, Patrick P. Delgado, Wilfred Louie L. Espino, Neil Joshua V. Esquillo, Airah Faith G. Hortillas, Henrickmike G. Jadan, John Peter A. Laguardia, Keyneil Cuill J. Mancilla, Louie James G. Robles, Jobelie D. Villanueva: **Preparedness for Apprenticeship Among Maritime Students**
8	Mota, Artemisa & Lodhi, Rahul: **Paving the Way for the Introduction of Code for Autonomous Vessels: Critical Review of Regulatory Framework for Safety of Navigation**
9	Haruki Itakura, Htoo Nay Wunna, Motoaki Moritaa, and Shinichi Motodaa: **Band Bending Mechanism in Dye-Sensitized Solar Cells Using Ruthenium and Indoline Dyes**
10	Freya Jobson, Sara Lundmark: **Running miles and running lines, can seafarers do both while being happy?**

Abstracts
Student Session

Suggesting a New Norm in Education for MASS Operators

Sung-Jae Jeong[a], Seung-Hun Jung[a], Tae-Yang Song[a]
[a]Korea Maritime and Ocean University, Busan, 49112, Republic of Korea

Keywords: MASS, Maritime Education and Training, STCW, Vocational Ethics, Security Ethics

The main purpose of this study is to propose the necessity and content addition of vocational ethics, security ethics, and Artificial Intelligence(AI) operating education for Maritime Autonomous Surface Ships(MASS) operators into International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers(STCW), based on the analysis of recent domestic and international trends related to each field. As AI may make wrong judgments, operators are required to make corrections according to the situation.[1]. Recently, it has been pointed out in other fields that the lack of professional ethics of computer and security experts is serious as insiders who are in charge of security work are involved in crimes after being tempted to cybercrimes.[2] Also, there is clear evidence that the absence of structured security awareness training for employees across the supply chain is a major source of vulnerabilities.[3] Therefore, by reflecting on the International Maritime Organization(IMO)'s categorization of MASS, the International Ship and Port Facility Security(ISPS) Code, the error factors of AI, the emergence of telecommuting after the pandemic, we should try to establish a standard education system for MASS remote operators and integrate it into the future STCW code. Therefore, it is necessary to discuss the reasons this new curriculum should be accepted in the maritime industry.

In this paper, this study will examine “Remote Operator” for degrees 2 and 3 MASS and discuss the required education of "Remote Operator". The need for the establishment of vocational ethics, security ethics, AI operation, and a new norm of education will be presented. As an example of the structure of these educations, we will examine accidents related to AI and analyze the contents of security ethics education for operators developed in other fields utilizing remote workplaces. Also, by interviewing associated industry experts, we can understand the risks of unqualified personnel at work. Through this method, necessary education can be recognized and applied appropriately in the STCW.

Through this study, we expect to be able to identify the realities of the maritime industry and propose complementary points to the emerging problems from implementing AI. Thus, creating a new paradigm of education that can contribute to the educational development of future MASS operators.

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[2] Tae-Hee Kim.(2017) Situation Analysis and Education Plan of Security Ethics for Training College Students Majoring in Information Security. Korea Contents Association Journal, 17(4), 596-605.

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Table 1. Summary of knowledge classification of practitioners on marine autonomous surface vessel (Shanghai Maritime University2018), Research on the Impacts of Marine Autonomous Surface Ship on the Seafarer's Career and MET, Technical Report.)

Knowledge Classification	
Ability	Leadership & communication
	Obedience & execution
	Psychological stress resistance
Knowledge	Traditional nautical knowledge
	Network communication knowledge
	Automatic control knowledge
	Data mining knowledge
	Artificial intelligence knowledge
Technology	Autonomous navigation
	Fault diagnosis
	Remote control
● Autonomy Level ✓ Vessel with process automation & decision support ✓ Remote-control vessels with crew onboard ✓ Remote-control vessels without crew ✓ Full autonomous vessels	

Table 2.

Competencies Autonomous Ships seafarers
Yeong-woo, Jeon, et al(2020) "A study on the necessity and method of fostering the next generation of marine experts", p.173

Stage	Degree of autonomy	Seafarers' competency	Ship control entity
1	Partial automation and decision support ship	Current decommissioning Competencies under the STCW Convention	Seafarer
2	Seafarers boarding + Remote control	Technical competency, Teamwork, Technical awareness, Communication, Language ability	Seafarer e-farer
3	Seafarers unboarded + Remote control	Technology awareness, Technology competency, Computer utilization & Information processing, Environment/Sustainability Awareness/Interest	e-farer
4	Autonomous Ships	Technology awareness, Technology competency, Computer utilization & Information processing, Environment/Sustainability Awareness/Interest	e-farer

Acknowledgements

This research was supported by Korea Maritime and Ocean University's Development Project Research Fund, 2023

Thermo-economic analysis on OCCS of LNG dual-fuel vessels based on the EEDI framework

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Shanghai Maritime University, Shanghai, 201306, China
Keywords: EEDI; OCCS; LNG dual-fuel vessels; thermo-economic analysis.

In order to fully control carbon emissions, the IMO recently stated that from 1 April 2022, the Energy Efficiency Design Index (EEDI) Stage 3 requirements have been strengthened in line with the amendments to MARPOL Annex VI adopted in 2020, which brings forward the effective date from 2025 to 2022 for ship types including gas carriers, cargo ships and LNG carriers. IMO has set Required EEDI for different types and sizes of ships. In order to meet the Required EEDI, the difference in CO_2 emissions between the Required EEDI and the Attained EEDI of the reference vessel needs to be calculated, and the gap is filled by the onboard carbon capture system (OCCS).

In this paper, an OCCS for a LNG-fuelled Kamsarmax vessel is proposed and optimized. The OCCS enriches the CO_2 in the flue gas emitted from the main engine by means of an alcohol-amine solution. The waste heat from the flue gas and the cold energy released during the LNG regasification process are used for the solution regeneration and CO_2 liquification. Moreover, the EEDI calculation method equipped with OCCS is also improved, and the correlation between CO_2 absorption, energy efficiency and economic efficiency in the system will be analysed.

The OCCS model based on the integrated use of cold and waste heat energy was constructed through Aspen HYSYS. The effects of flue gas mass flow rate, solvent mass flow rate and lean solvent temperature at the inlet of the absorber tower on CO_2 capture, energy efficiency, specific heat consumption, environment and economic efficiency were analysed. The environmental aspect was studied in terms of the carbon footprint of the system, while the economic aspect was studied in terms of the Payback Period (PBP) of the system.

This work belongs to the sub theme:

• Environmental Sustainability in Seafaring

Acknowledgements
The authors would like to thank the financial support from the IAMU Research Project for Young Academic Staff in FY2022

Visualization and Simulation of Ocean Scenes with Physically-Based Models inMarine Simulators

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Navigation School of Dalian Maritime University,Dalian, 116026, P.R. China

Keywords: Physically Based Simulation; Marine Simulator; Position Based Fluid; Maritime Education;

Abstract: A physically based marine scene simulation method is proposed to enhance the realism of the marine simulator visual system and improve the immersion and training quality of seafarers participating in marine simulator maneuvering training. A position-based dynamical framework is used to construct a fluid particle system model and impose velocity dispersion constraints. The results show that the position-based fluid particle hybrid model can effectively simulate the roll and break of waves on the complex sea surface. Furthermore, the particle system of the obtained velocity field can simulate the wave surface realistically to a certain extent, which can effectively improve the realism of the navigational simulator scenery system and thus improve the quality of seafarer training.

The theme categories: Education of Global Maritime Professionals

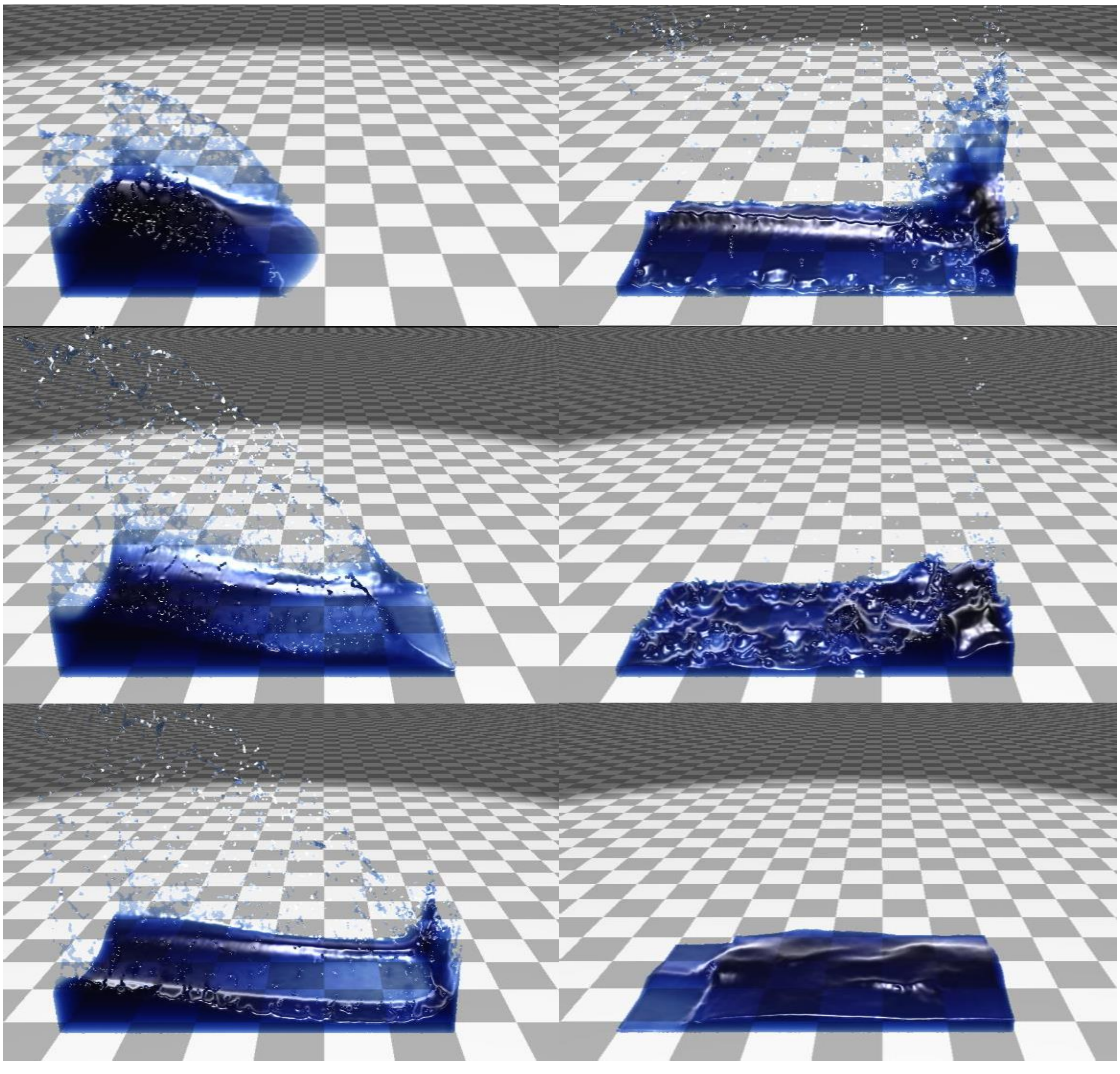

Fig. 1 Physically Based Fluid Model

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Does Location Matter: How Implementing International Experiences Increases Cultural Awareness for Global Maritime Professionals

Liam Howell, Kylie Maher, Keven Paul

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Keywords: Cultural Awareness, International Experiences, Global Maritime Professionals, Collaboration, Maritime Education and Training

Theme: Education of Global Maritime Professionals

The maritime industry is a global coalition. Educating and training future generations of maritime professionals in a diverse, multicultural world is vital for the sustainability of this sector. This has been recognized by the IAMU in their Global Maritime Professionals (GMP) Body of Knowledge (BoK) report (2019). In a survey of hundreds of key maritime stakeholders, cultural/diversity awareness and sensitivity (or cultural awareness) was identified as one of the 28 competencies needed for future global maritime professionals. With most students in Maritime Education and Training (MET) feeling they lacked the essential skills and knowledge necessary for cross-cultural learning and interaction, Massachusetts Maritime Academy implemented the idea of experiential learning and international collaboration as a suggested "express route" to developing cross-cultural adaptability. This program sends students to foreign countries to learn from maritime professionals while gaining cultural awareness. This learning experience has been shown to enhance cultural understanding. Examples include Sea term on the training ship traveling to the Caribbean, a trip to Asia for direct cultural exposure, or online consulting experiences with global maritime organizations. Before students participate in these opportunities, they assess their own cultural competence using the Cultural Quotient instrument. These are scored based upon how aware they initially are to different aspects of other cultures. The CQ assesses cultural competence in four dimensions: drive, knowledge, strategy, and action. An analysis was conducted of the Academy's four short international programs in 2017 (Singapore/Malaysia, South Africa, Norway, and UK) and found that growth in student cultural awareness and the cultural difference in the host destination were found be strongly correlated (r=0.664). Although a small sample size, our team will participate in further research to create a detailed regression analysis of all 25 international programs from the last seven years. As part of students' experiential learning grades, they must also complete the Cultural Quotient when they return to the United States. These final scores display the broadening of the participants' cultural awareness. Considering the maritime industry is a global market, cultural awareness and cross-cultural education proves to be a necessary learning tool for the growth and success of future professionals. This research can be used to provide virtual opportunities to students in maritime universities who cannot travel to other countries, which can still offer them the cross-cultural educational experiences. With the help of digitalization, online learning, and social media, collaboration with maritime professionals has been easier than ever before. The analysis will quantify the benefits of such experiences and can be used as a rationale to similar programs for global maritime professionals at other MET institutions. This paper will present our personal experiences, data analysis, and support our hypothesis of how cultural differences of countries will increase the overall cultural awareness of the traveling students. Our research and data will prove that implementing these cultural opportunities will be vital in the education, advancement, and success of the future wave of maritime students.

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Enviromentally Sustainable Technology for Building Composite Boat Equipment

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Keywords: sustainability, composites, natural fibers

This paper demonstrates the process of building the seat of a composite boat powered by solar energy for the Monaco Energy Boat Challenge. Composite materials reinforced with natural fibres wereused for the construction, which represents a modern sustainable concept in the construction of vessels.The use of composite materials can offer advanced construction solutions in modern marine industry, which can contribute to increased strength, reduced weight and improved corrosion resistance. With theincrease in global environmental awareness, various adaptation to regulations and environmental agendas in the maritime industry, there is an expanding need and desire to use "green" products and materials for the construction of vessels, ships, equipment, and other parts of maritime constructions that will be a segment of sustainable technologies in maritime industry.

Natural fibres, used instead of traditional artificial ones in composite materials, are renewable, easily accessible, low cost, absorb carbon dioxide and release oxygen during growth, and enable additional employment in the textile and agricultural industry. Fibres of this type are safer to handle andproduce. Natural fibres commonly used for reinforced composites (NFRC, natural fibre-reinforced composites) are most frequently cotton, sisal, coconut fibres, jute, hemp, flax, banana, basalt, etc. Theyare classified in the literature as "green" composites due to their degradable and sustainable properties of easy disposal without harm to the environment [1].

Further work and development of such technologies and the use of "green" materials is exceptionally important due to the development of new technologies in shipbuilding, testing the shortcomings of these types of composites in the marine environment, and introducing young students to the concepts of sustainable technologies. It is also improving the expansion of environmental awareness among students who, through their future work in practice, can greatly influence the preservation of biodiversity on Earth.

Figure 1. Natural fiber composite seat built by students for competition boat.

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Acknowledgements

This work has been fully supported by University of Rijeka under the projects uniri-technic-18-200 “Failure analysis of materials in marine environment” and “Marine Composite Material Recycling and Re-use”.

Paving the Way for the Introduction of Code for Autonomous Vessels: Critical Review of Regulatory Framework for Safety of Navigation

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Keywords: MASS (Maritime Autonomous Surface Ship) Code, SOLAS (Safety of Life at Sea), Safety of Navigation, Maritime Safety

Shipping is entering the era of autonomy. Trials of autonomous vessels by NYK (Nippon Yusen Kabushiki Kaisha) Group in Sep 2019 (Nippon Yusen Kaisha Line, 2019) and IMO's thrust on development of a goal-based instrument for autonomous vessels to be introduced by 2024 (IMO, 2022a) are indicative of the same. One of the issues which was highlighted by a report of the Legal Committee, on the Regulatory Scoping Exercise (RSE) commissioned by International Maritime Organisation was, the need to clarify, who, if anyone will satisfy the role of master onboard the ship (IMO, 2021). This paper will examine the regulations which governs Safety of Navigation {SOLAS (Safety of Life at Sea), Chapter V} in light of the report submitted by the Legal Committee on completion of RSE about the need of human presence onboard. MASS as a whole, will have effect on almost every sphere of maritime industry, starting from construction of the ship to port facilities for accommodating fully autonomous vessels. As per RSE, requirement exists for either major amendments to the existing conventions or introduction of a MASS Code as a supplement to IMO instruments (IMO, 2022b). Safety of navigation, when clubbed with external factors like rough weather conditions and SAR to state few, which till now is being looked after by the human presence onboard, is one of the issues which needs further deliberations. The research will systematically analysis each regulation in SOLAS Chapter V requiring human presence onboard and how it will be affected by introduction of unmanned vessels. The methodology which will be used is desk-based review of various literature and IMO docs. Finding the requirement for a full revision of future change of SOLAS Chapter V will be the main objective. The key concern is whether part 4 of the draft MASS Code would address issues like regulation 5.7 which talks of the necessity for the Master or ship's crew to monitor and report the weather when in vicinity of a cyclone (SOLAS, 1974). Also, Reg 14, 16, 24, 26 and many others will be examined. The paper will focus on coming out with recommendations for amendments to the regulations for Safety of Navigation towards inclusion of MASS with regards to human aspect of the Chapter V of SOLAS.

Referemces

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Band Bending Mechanism in Dye-Sensitized Solar Cells Using Ruthenium and Indoline Dyes

Haruki Itakura[a], Htoo Nay Wunn[a], Motoaki Morita[a], and Shinichi Motoda[a]

[a]Tokyo University of Marine Science and Technology, Tokyo, 135-8533, Japan

Keywords: Dye-Sensitized Solar Cell, Band Bending, Renewable Energy

I. Introduction

Among various power generation systems using renewable energy sources, solar power generation is relatively efficient and is also used on large vessels such as car carriers. There are several types of solar cells, but silicon-based solar cells are currently the most widely used. Although silicon- based solar cells are relatively efficient, they are expensive to produce and their rigidity limits the locations where they can be installed.

A dye-sensitized solar cell(DSSC) has the advantage of flexibility and higher conversion efficiency, so it can compensate for the shortcomings of silicon-based systems and allows a wider range of solar cells to be used. The DSSC system is made of three layers consisting of a dyed semiconductor layer, an electrolyte layer, and a counter electrode. In our laboratory, assuming the use of DSSC in the actual marine environment, seawater is used as the electrolyte and copper oxides are used as the counter eylectrode. Figure 1 shows a dyed semiconductor layer (dye sensitized TiO_2 layer) receiving energy from the sunlight to excite electrons. The electron energies of TiO_2 and the dye form an electronic band, the valence band and the conduction band, with a band gap between them. The band gap represents the minimum energy required for electrons to be excited and move into the conduction band, and DSSC uses solar energy. When sunlight hits the dye, the energy excites electrons in the dye to move into the conduction band and flow along the band bend of the dye and TiO_2 to the electrode. This band bend is very important for DSSC because of the tendency of electrons to move to lower energy levels.

II. Experimental method and results, discussion

In this experiment, ruthenium (N719) and indoline (D131) are used as dyes. Hydroxyapatite (HAp) is also used as a co-catalyst. Changes in electrode potential for each dye combination are measured. Figure 2 shows the experimental results. And Figure 3 shows band bending mechanism.

III. Conclusion

This paper argues that mixing ruthenium and indoline dyes results in improved performance as electrodes. The final paper will include discussion of band bending

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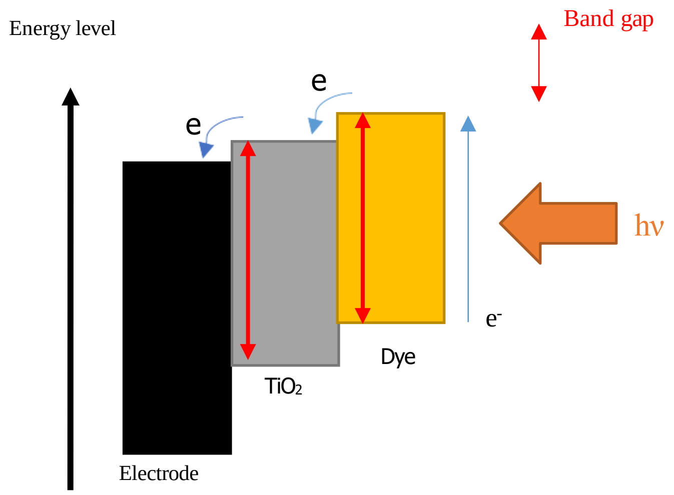

Figure1. Dyed semiconductor layer and band gap

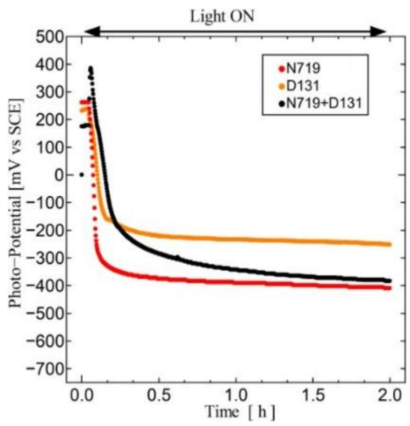

Figure2. Photopotential properties when applied different dyes to TiO_2

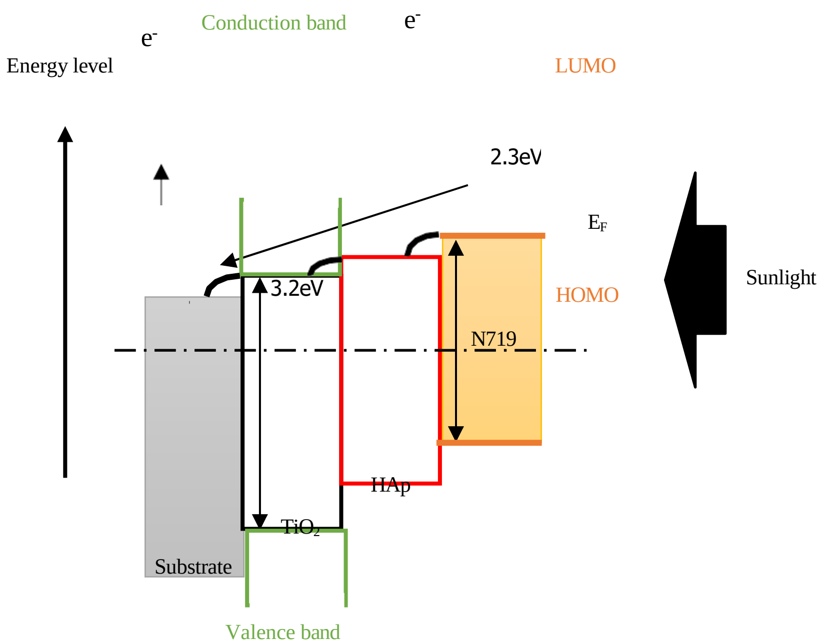

Figure3. Band construction and its bending mechanism

Running miles and running lines, can seafarers do both while being happy?

A survey-based study researching the possibility and opportunities for physical activity, and an active lifestyle's effect on seafarers' well-being.

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Keywords: Well-being, physical activity, shift work, seafarers.

Shipping is regarded as a high-risk occupation indicating elevated risks of fatality, accidents, an increased risk of cancer and cardio- vascular diseases together with impaired mental health and wellbeing[1]. The work is also characterized by stressors related to the workload and environment and diseases related to an unhealthy lifestyle [2]. The last few years have seen a major shift in focus towards well- being in general society which have made waves in the maritime sector. This have given rise to importantquestions about how seafarer's well-being and how it can be improved.

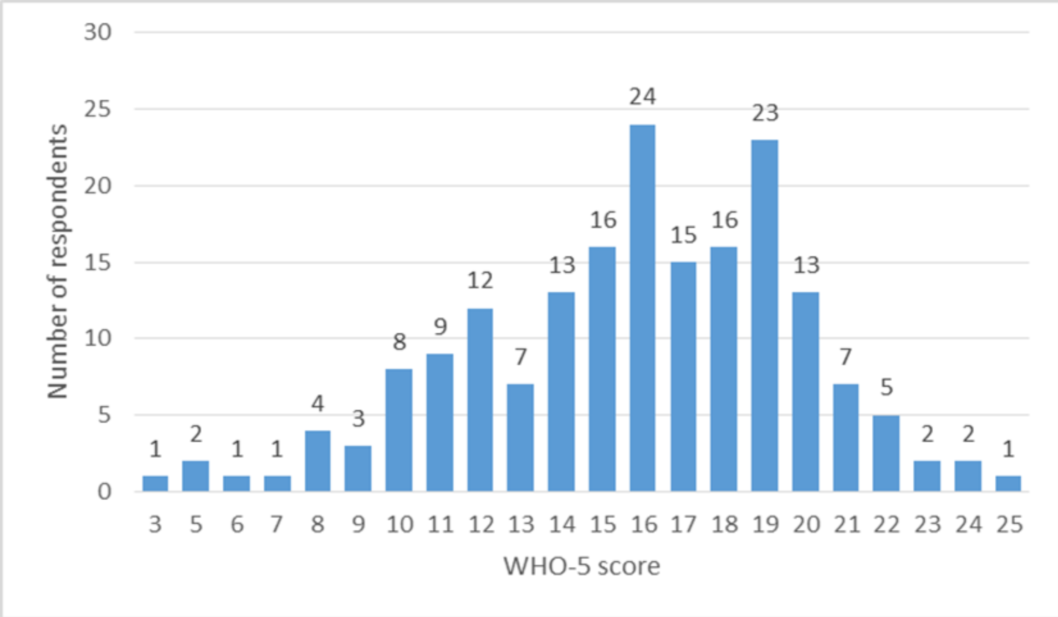
Seafarers commonly spend half or more of their life at their workplace, a workplace that controls theirsleep, social connections and their access to physical activity [3]. It is well known today that physical activity can have a positive impact on areas in life that affect well-being [4]. But does physical activity impact seafarer's well-being when they live in anything but a comfortable environment?

The study aimed to answer three questions; what opportunities are there onboard for the crew to perform physical activity, how are these opportunities for physical activities utilised by the crew and howare the crews' perceived well-being affected by physical activities onboard. The study used a questionnaire sent out via email to 20 Swedish shipping companies to distribute onboard their Swedish-flagged ships over flagged ships over 3000 GT, back came answers from 187 seafarers. To measure the perceived wellbeing of the respondents WHO-5 was used, a score below 13 indicated poor well-being [5].

The result showed that there were good opportunities to exercise onboard and that most of the seafarersutilised the space and equipment available. No connection between exercising and increased perceived well-being could be found in this study, but the study showed another interesting result. As seen in figure1, a significant amount (22%) of seafarers indicated having poor wellbeing. These groups of respondentswere mainly those who worked 12/12 shifts, those in the accommodation and catering department and engineers.

Although no connection could be found between exercise and improved wellbeing there were seafarerswith poorer well-being. Even though exercise might be a good way to improve wellbeing the work environment at sea is highly complex and comparing only exercise and well-being does not give the fullpicture. Some other factors, such as a harsh working environment and long hours, might affect the well- being of seafarers more than whether they get exercise. Establishing that some seafarers have poor well-being is the first step towards the development of a future onboard workplace environment that is safer, more efficient and healthier than it is today.

WHO-5 scores



Comment: A histogram showing the number of respondents and where their WHO-5scores are on a scale 0-25. Bellow 13 is considered poor wellbeing.

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A Four-Stage Super DEA Model for Shipping Connectivity Efficiency

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Abstract: Developing a globally-connected transportation network and enhancing maritime connectivity are essential for facilitating global trade. This study employs the entropy weight method, four-stage super-efficiency DEA model, competitive situation matrix, and K-means clustering analysis to comprehensively assess maritime connectivity efficiency among 44 countries along the Belt and Road Initiative from 2010 to 2021. Findings reveal: (1) Overall efficiency is increasing, with Japan, Singapore, and Qatar consistently leading. (2) Efficiency varies spatially, with East and Southeast Asia showing higher efficiency, and this disparity lessening with environmental considerations. (3) Total factor productivity improves due to technology, though composite and pure technical efficiency need attention. (4) The competitive matrix categorizes countries into four types, highlighting Malaysia's progress and underscoring the need for scale efficiency improvements. This study's insights illuminate the Belt and Road maritime network, constructing a global maritime network and enhancing connectivity along the route. Its contributions align with scientific standards and have implications for enhancing global trade and cooperation.

Keywords: The 21st Century Maritime Silk Road; Shipping connectivity efficiency; Four-stage DEA; Super SBM

1. Introduction

In 2023, the "Belt and Road" initiative reaches its 10th anniversary, with China having established maritime links to over 100 countries and regions. The maritime routes encompass all coastal areas along the Belt and Road, boasting an increasingly robust service network and leading global maritime connectivity. Creating a global transportation network to enhance maritime connectivity has been pivotal for global trade facilitation (Huang TC, et al. 2020). Yet, evolving trade dynamics place higher demands on the maritime sector. As a vital hub bridging domestic and international markets, the maritime industry is central to the 21st-century Maritime Silk Road, facilitating exchanges in trade, technology, talent, capital, and information among nations. Thus, efficient maritime connectivity profoundly influences regional strategies, trade facilitation, and shared development. Key evaluation indicators include maritime reliability, port competitiveness, transport resource utilization efficiency, and overall maritime performance (Saravanan V, et al. 2020). Our aim is to assess maritime interconnectivity efficiency, reflecting the ongoing significance of the Belt and Road initiative in bolstering global connectivity and advancing cooperation in maritime trade and logistics.

Currently, research on the shipping industry under the Belt and Road Initiative primarily focuses on ports and trade. Studies on port efficiency indicate that trade and market factors can impact the connectivity patterns of maritime transportation corridors among China, South Korea, Japan, and Russia (Tianming G, et al. 2021). Trade flows play a crucial role in driving the connectivity of maritime networks (Zuzanna KS. 2020), while European port efficiency is influenced by export credit agency regulations (Lopez B, et al. 2019). Low technological efficiency affects the total factor productivity of container ports in Argentina (Beatriz LB, et al. 2019), and port productivity is key to port competitiveness and market potential (Suárez A, et al. 2016). However, there is a lack of research in calculating maritime connectivity efficiency. Therefore, the scarcity of research on maritime connectivity efficiency prompts us to investigate the Belt and Road maritime network's characteristics and quantify dynamic transport efficiency. We aim to answer key questions: How significant are efficiency differences among countries? Which nations excel or need improvement? What factors affect efficiency changes? Enhancing maritime connectivity efficiency is pivotal for trade and cooperation. This study's insights offer strategies to optimize connectivity, fostering trade and cooperation in the Belt and Road initiative, with policy implications.

Regarding trade markets, the Maritime Silk Road policy is found to contribute to time and cost savings in maritime transportation, energy consumption reduction, and the promotion of sustainable development in the maritime environment and regional trade (Mou NX, et al. 2018). Investment in international ports holds significant implications for resource flow management and port competitiveness (Guo JK, et al. 2020). Research on shipping markets in developing countries focuses on productivity and efficiency evolution and drivers (Peng P, et al. 2018), and the efficiency score of container ports serves as a measure of competition in the shipping market at local, regional, and global levels (Oliveira G, et al. 2015). To comprehensively understand the characteristics and change mechanisms of the shipping network between China and Belt and Road countries, this study aims to analyze dynamic changes by measuring shipping connectivity efficiency, eliminating environmental interference, and employing a systematic quantitative approach. In terms of evaluation methods, Data Envelopment Analysis (DEA) is considered suitable for analyzing production and efficiency in the shipping industry (Cullinane K, et al. 2006). The four-stage DEA model, employing Tobit regression instead of SFA regression, ensures consistent parameter estimates (Fried HO, et al. 2002). The Super-SBM model addresses the limitation of the traditional SBM model by allowing for efficiencies greater than 1, enabling the evaluation and ranking of decision-making units that achieve DEA effectiveness (Tone K. 2002).

In conclusion, we utilize the four-stage DEA model to calculate maritime connectivity efficiency among countries along the Belt and Road initiative. This study holds significant value in elucidating the structural characteristics of the Belt and Road maritime network, constructing a global maritime network, and accelerating maritime transportation development in countries along the route. The theoretical significance lies in the application of the four-stage DEA model, allowing a comprehensive understanding of the efficiency performance in the maritime sector of Belt and Road countries, providing an economic foundation for similar research. The practical significance lies in the identification of countries or regions with low efficiency, providing reliable insights for policy formulation to accelerate the transformation and upgrading of the maritime industry and enhance overall competitiveness. This research contributes to the advancement of maritime transport efficiency, fostering economic cooperation and development among nations along the Belt and Road.

2. Methodology

The 21st Century Maritime Silk Road spans across East Asia, Southeast Asia, West Asia, South Asia, Africa, and Europe. Due to data limitations, this study comprehensively considers the characteristics of transit regions, port and shipping transportation networks, and economic variables, focusing on 44 countries as research subjects. Three indicators, namely Shipping Performance (SP), Port Infrastructure Quality (WEF), sourced from the WDI database, and Liner Shipping Bilateral Connectivity Index (LSBCI), sourced from the UNCTAD database, are chosen to assess maritime efficiency inputs. Shipping performance is assessed based on six criteria: tracking ability, competitiveness of international freight prices, logistics service quality, timeliness of goods delivery, customs clearance efficiency, and infrastructure quality related to trade and transport. These criteria aim to gauge the level of shipping performance development among countries along the Maritime Silk Road. Two output indicators, Port Throughput (TRADE) sourced from various countries' port authorities' websites, and Bilateral Trade Volume (CT) sourced from the UN Comtrade database, are selected. When employing the DEA model to measure shipping connectivity efficiency, it is essential to consider the influence of exogenous factors. Factors influencing maritime efficiency include urbanization level(URBAN), free cash flow (FCF), labor force level (LABOR), per capita GDP (PGDP), and environmental indicators such as carbon dioxide emissions(CO2). Data for these factors are sourced from the WDI database.

3. Result

3.1. Stage 1

The findings reveal that Japan, Singapore, Qatar, and Iraq consistently maintain shipping connectivity efficiency values above 1 for a span of more than three years, affirming the robustness of the DEA approach. Among these, Japan displays the highest average efficiency over the 12-year timeframe, with a mean value of 0.95. Notably, Algeria, Djibouti, Indonesia, South Korea, Libya, Madagascar, Malaysia, the Philippines, Tunisia, and Vietnam achieve frontier efficiency in various years, underscoring their pronounced strengths in efficient port resource allocation, shipping connectivity efficiency, and trade interactions with China. In contrast, Denmark, Bahrain, and Portugal consistently exhibit lower efficiency levels, potentially attributed to a higher prevalence of inefficient ports, greater distances from China, and inadequate port infrastructure. It is imperative to initiate prompt measures to bolster their port facilities and navigational capabilities.

3.2. Stage 2

Table 1 presents the outcomes of significance tests performed on the five environmental variables. Notably, per capita GDP exhibits a highly significant negative correlation at the 1% level. This indicates that higher per capita GDP corresponds to increased demand and expansion within the shipping market, fostering amplified production within the bilateral shipping sector. As a result, shipping resources are optimally utilized. Similarly, CO_2 emissions also reveal a significant negative correlation at the 1% level. Escalating CO_2 emissions drive governmental efforts towards achieving eco-friendly and low-carbon objectives. These endeavors involve reducing reliance on carbon-emitting transportation modes like railways and roads, promoting the adoption of clean energy sources, and curtailing emissions. Consequently, an overall enhancement in shipping connectivity efficiency is realized. In the context of urbanization, its elevation stimulates the growth of domestic and international markets, thereby fortifying liner shipping connectivity between the host countries and China. However, it is important to acknowledge that rapid urbanization necessitates heightened investments in inland transportation infrastructure. Notably, the amelioration of urban transportation networks may not directly translate into enhanced shipping facility quality and logistics efficiency.

Table 1. Tobit regression results

	SP	WEF	LSBCI
URBAN	0.132***	0.156***	-0.081***
	(6.68)	(12.74)	(-7.99)
FCF	-0.079	0.024	-0.073**
	(-0.79)	(0.45)	(-2.35)
PGDP	-0.225***	-0.926***	-0.116**
	(-4.54)	(-8.27)	(-2.24)
POP	0.131**	-0.739***	0.039
	(2.28)	(-3.73)	(0.68)
CO2	-0.363***	-0.159***	-0.175***
	(-7.59)	(-3.88)	(-3.14)
cons	0.233***	0.239***	0.242***
	(5.68)	(6.92)	(21.17)
sigma	0.180***	0.157***	0.154***
	(35.77)	(29.53)	(32.24)
Prob > F	0.0000	0.0000	0.0000
Observations	528	528	528

Note: level of significance: *10%, **5%, ***1%. Source: Compiled by the authors.

3.3. Stage 3

The Tobit model's fitted values were utilized for input variable readjustment. The adjusted inputs and original outputs were then inputted into the Super SBM model, yielding shipping connectivity efficiency values for each DMU in the fourth stage, excluding environmental factors.

3.4. Stage 4

From an average perspective, Japan consistently maintains the highest shipping connectivity efficiency value in the fourth stage, with an average of 0.93, owing to its influential Yokohama port and strategic China-Japan shipping route. China's varied vessel deployment and geographical proximity also contribute to their strong connectivity. Qatar closely follows with an efficiency of 0.82, attributed to major ports for oil and industrial exports and a robust trade partnership with China. This underscores the significance of shipping connectivity between these nations.

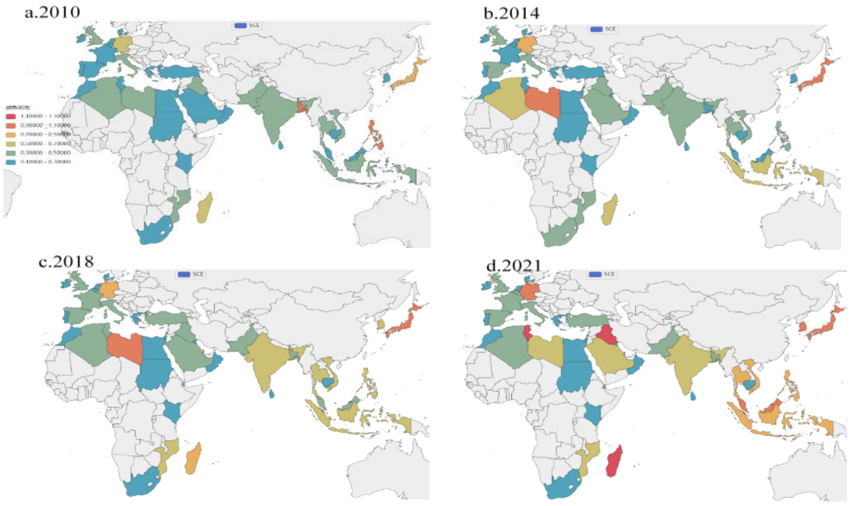

Figure 1. World Shipping connectivity efficiency Map (2010, 2014, 2018, 2021).

Source: Compiled by the authors.

Regional disparities are evident in the shipping network between Belt and Road countries and China. East Asian and Southeast Asian nations consistently exhibit higher shipping connectivity efficiency in both the first and fourth stages, while South Asian, West Asian, and African counterparts achieve moderate efficiency levels. In comparison, European countries and China showcase the lowest shipping connectivity efficiency. In the fourth stage, efficiency values improved for 33 nations, with Libya displaying the most significant advancement of 0.08. Conversely, 11 countries, including Indonesia, witnessed efficiency declines, with the maximum decrease of 0.24 outweighing the magnitudes of improvements.

Table 2. Comparison of shipping connectivity efficiency in the first and fourth stages

Country	Stage 1 mean	Stage 1 rank	Stage 4 mean	Stage 4 rank	Country	Stage 1 mean	Stage 1 rank	Stage 4 mean	Stage 4 rank
Japan	0.953	1	0.934	1	Belgium	0.239	30	0.261	30
Korea, Rep.	0.44	17	0.397	16	Denmark	0.115	44	0.128	44
Eastern Asia	0.6965		0.6655		France	0.267	27	0.28	27
Brunei Darussalam	0.197	38	0.189	41	Germany	0.731	6	0.739	5
Cambodia	0.222	31	0.302	26	Greece	0.182	40	0.2	37
Indonesia	0.798	3	0.558	7	Ireland	0.211	35	0.192	40
Malaysia	0.392	18	0.392	19	Italy	0.368	20	0.395	18
Philippines	0.611	9	0.638	6	Netherlands	0.221	32	0.239	31
Singapore	0.797	4	0.807	3	Portugal	0.145	42	0.159	42
Thailand	0.513	12	0.526	8	Spain	0.309	24	0.337	24
Vietnam	0.688	7	0.523	10	United Kingdom	0.356	21	0.365	22
Southeast Asia	0.5273		0.4919		Europe	0.2858		0.2995	
Bangladesh	0.338	22	0.386	21	Algeria	0.536	11	0.495	12
India	0.628	8	0.49	14	Tunisia	0.444	16	0.386	20
Pakistan	0.334	23	0.348	23	Egypt, Arab Rep.	0.245	29	0.262	29
Sri Lanka	0.221	33	0.231	32	Kenya	0.18	41	0.199	38
Southern Asia	0.3803		0.3638		Libya	0.446	15	0.526	9
Bahrain	0.123	43	0.133	43	Morocco	0.188	39	0.199	39
Iraq	0.565	10	0.413	15	Madagascar	0.738	5	0.764	4
Israel	0.199	37	0.217	36	Mozambique	0.47	13	0.495	13
Kuwait	0.247	28	0.226	33	Sudan	0.215	34	0.224	34
Oman	0.206	36	0.223	35	Djibouti	0.452	14	0.496	11
Qatar	0.818	2	0.821	2	South Africa	0.268	26	0.276	28
Turkiye	0.298	25	0.311	25	Africa	0.3802		0.3929	
Saudi Arabia	0.389	19	0.397	17					
Western Asia	0.3556		0.3426						

Source: Compiled by the authors.

Table 2 shows consistent rankings between the first and fourth phases, with Japan consistently leading followed by Qatar. Yearly changes align with the overall trend, reflecting fluctuations and enhancements in shipping connectivity efficiency among the Maritime Silk Road countries and China. These findings highlight limitations of the conventional DEA model and emphasize the robustness of the four-stage DEA model.

3.5 Malmquist Index

3.5.1. Decomposition term

Due to the limited dynamic analysis of the four-stage DEA model, this study investigates the dynamic changes and determinants of shipping connectivity efficiency. Regional analysis reveals that East and Southeast Asian countries exhibit a positive trend with total factor productivity and its decomposition components exceeding 1, indicating improving shipping connectivity efficiency. However, overall technical efficiency has declined to varying degrees, primarily due to neglecting pure technical efficiency. At the national level, 38 countries (86.4% of the total sample) achieved a Malmquist index greater than 1, indicating improved shipping connectivity efficiency over the 12-year period. From 2010 to 2021, the total factor productivity index reached 1.04, indicating a slight growth trend in shipping connectivity efficiency along the route. Attention should be given to enhancing pure technical efficiency.

3.5.2. Competitive position matrix

A shipping competition matrix is constructed to evaluate competitiveness based on comprehensive technical efficiency and technological progress. Median values of comprehensive technological efficiency (0.986) and technological progress (1.061) from 2010 to 2021 serve as reference points. Belt and Road countries are categorized into four groups: remarkable results, growth potential, accumulation, and slow development.

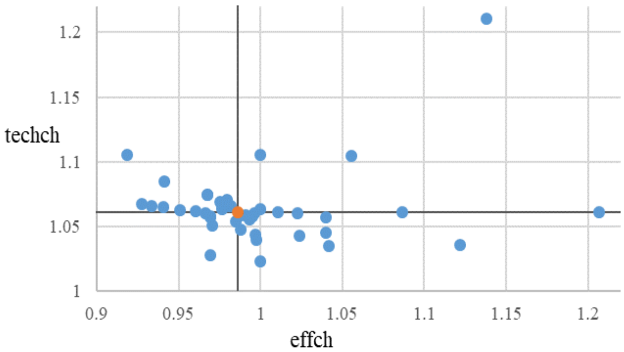

Figure 2. Shipping competitive position matrix

Source: Compiled by the authors**.**

3.5.3. K-means Cluster analysis

To further analyze shipping connectivity efficiency, cluster analysis is performed on adjusted pure technical efficiency and scale efficiency. The first group exhibited scale efficiency with pure technical efficiency below 1. The second group demonstrated relatively high efficiency, while the third group showed lower efficiency. The fourth group displayed technical efficiency with pure technical efficiency above 1. South Korea, Malaysia, and Tunisia stood out for their high scale efficiency and pure technical efficiency, indicating economies of scale and superior technical efficiency in their shipping markets, forming a "double high" scenario. On the other hand, Bahrain and 18 other countries exhibited lower pure technical efficiency and scale efficiency, suggesting the need for improved port and shipping management, technological advancements, and scaling up of the shipping market to enhance overall production efficiency.

Table 3. Comprehensive technical efficiency decomposition cluster analysis

	Initial clustering				Final clustering			
Group	1	2	3	4	1	2	3	4
ptc	0.93	1.16	0.93	1.04	0.95	1.15	0.97	1.01
stc	1.09	1.04	1.00	1.00	1.07	1.02	1.00	0.99

Source: Compiled by the authors.

4. Summary

This study reveals that maritime efficiency exhibited a fluctuating growth trend over the study period, with a notable decline in 2020 due to the pandemic impact, followed by a substantial rebound in 2021 due to global maritime trade recovery. Notably, urbanization level, physical capital, labor force, per capita GDP, and CO2 emissions had significant positive effects on shipping connectivity efficiency. Spatially, disparities in shipping connectivity efficiency were pronounced, with higher efficiency in East Asian and Southeast Asian countries, intermediate levels in South Asian, West Asian, and African nations, and the lowest efficiency observed in European countries. After accounting for environmental effects, regional disparities diminished. From 2010 to 2021, maritime total factor productivity increased by an average of 4.1%, predominantly driven by technological advancements. East Asian and Southeast Asian countries exhibited positive trends in total factor productivity. The competitive matrix classification identified various country types, highlighting Malaysia's remarkable progress and Italy's comparatively lower development level. Scale efficiency and pure technical efficiency emerged as crucial influencers of overall technical efficiency, with 41 countries falling short of entering the relatively efficient group. In conclusion, our findings, derived from a comprehensive evaluation using a four-stage DEA model, shed light on influencing factors and spatial disparities in shipping connectivity efficiency. These insights hold significant implications for fostering maritime development between China and the nations along the Maritime Silk Road.

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Thermo-economic analysis of LNG dual-fuel vessels based on the EEDI framework

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Abstract: An onboard carbon capture and storage (OCCS) system based on the integrated utilization of heat and cold energy for LNG-fuel carrier was proposed in this study to meet the requirements of energy efficiency design index (EEDI) phase 3. The process is composed of CO_2 absorption, CO_2 separation and CO_2 liquefaction. Based on Aspen HYSYS software, the thermodynamic performance of the system was analysed. These include the effect of mass flow rate of exhaust gas and lean liquor, lean liquor temperature at inlet of absorber regenerative heat on specific heat consumption, energy efficiency and exergy efficiency, which will provide the basis for subsequent economic and environmental analysis. In conclusion, when the exhaust gas mass flow rate is greater than 10000 kg/h and the lean liquor mass flow rate is greater than 13000 kg/h, the OCCS system meets the EEDI stage 3 requirements. When the exhaust gas mass flow rate reaches 20000kg/h, lean liquor mass flow rate reaches 16000kg/h, the system is in the best condition.

Keywords: EEDI; OCCS; LNG dual-fuel vessels; thermo-economic analysis.

1.Introduction

More than ninety percent of global trade relies on navigation, which leads to it accounts for 3% of global carbon dioxide emissions and 5% of global SO_x emissions (Jeong J et al. , 2018). As the COVID-19 pandemic fades, the shipping industry is set for a more prosperous future, the first is the reduction of greenhouse gases. To this end, the International Maritime Organization (IMO) has developed a strategy to reduce greenhouse gas emissions from international shipping, thus the definition of EEDI (Energy Efficiency Design Index) was born. The IMO requires the shipping industry to cut carbon emissions by 40% from 2008 levels by the end of 2030 (Sou W et al. , 2022), which means each ship has to reduce carbon emissions by 70%.

The percent of newbuilding with LNG capacity was to 5% in 2015, rising to 13% in 2018 (Balcombe P et al. , 2021). As a result, many options have been proposed. (Jeong J et al. , 2018) A liquefied natural gas -liquid hydrogen hybrid propulsion system was studied. (Lee S et al. , 2021) A new method for estimating the energy efficiency design index was studied, which was integrated with the OCCS. (Mehrpooya M et al. , 2017) studied a new air separation process based on cold energy recovery from LNG, combined with coal gasification, supercritical CO_2 power cycles and cryogenic CO_2 capture.

Most of the carbon reduction methods focus on carbon capture by alcoholic amine or membrane separation and the utilization of LNG cold energy. They have an one-sided emphasis on using a single method or energy, and this paper will introduce an Onboard Carbon Capture System (OCCS) on the basis of integrated use of LNG cold energy and alcohol amine method. Even fewer analyses combine the former two in tandem with EEDI. This system belongs to post-combustion capture. To facilitate storage and transport, the captured carbon dioxide needs to be liquefied. For LNG fuel ships, LNG is stored at a low temperature of -162℃ (Kanbur BB et al. , 2017). Before entering the main engine, the high-quality cold energy released by regasification is about 830kJ/kg. This means that the energy can be used to liquefy CO_2 without the need for additional cryogenic refrigeration units. This paper takes a Kamsarmax vessel as an example to take advantage of the OCCS system above. Thermodynamic model analysis will be conducted based on Aspen HYSYS, and its advantages and feasibility were explained from the perspectives of energy and exergy. Exergy analysis in this paper includes not only physical sense, but also chemical exergy.

2. EEDI and OCCS conception

2.1. Required EEDI

The EEDI is called Energy Efficiency Design Index, which is a measure of the degree of CO_2 emissions inherent in the design and construction phase of a ship and represents the amount of CO_2 emitted per ton/mile of the ship. We are now dealing with phase 3 EEDI.

The mathematical formula of required EEDI is (Bayraktar M et al. , 2023):

$$\text{Required EEDI} = (1 - x/100) \times RLV, \quad (1)$$

where x is reduction factor; RLV indicates Reference Line Value, RLV for bulk carriers are as shown in Table 1.

Table 1.RLV for bulk carriers

Vessel type	DWT	RLV calculation formula
Bulk carriers	≤279000t	$961.79 \times DWT^{-0.477}$
	>279000t	$961.79 \times 279000^{-0.477}$

The Required EEDI for bulk carriers are shown under different phases in Figure 1 (calculated from the above empirical formula.

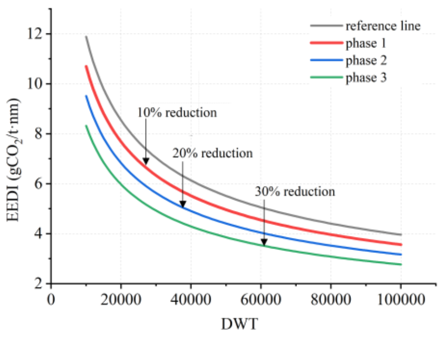

Figure 1. Required EEDI for bulk carriers under different phases

2.2. Attained EEDI

The Attained EEDI ($gCO_2/t \cdot nmile$) for ships is a measure of the level of energy efficiency of a ship and is calculated as follows (Ančić I et al. , 2018):

$$\frac{(\prod_{j=1}^{n} f_j)(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}) + (P_{AE} \cdot C_{FAE} \cdot SFC_{AE}) + PTI + EFF}{f \cdot Capacity \cdot V_{ref\,m}} \quad (2)$$

where ME and AE denote main and auxiliary machines respectively; i stands for number of engines; P stands for power; C_F stands for carbon conversion factor; f stands for fuel consumption parameter, all taken as 1 here; $Capacity$ stands for the deadweight tonnage of the vessel; V_{ref} refers to the speed of a ship in deep water under assumed windless and wave-free meteorological conditions; the PTI section calculates the CO_2 emissions from shaft motor assisted propulsion; the EFF section is a calculation of the CO_2 emission reductions resulting from the adoption of innovative energy efficiency technologies.

Meanwhile attained EEDI have to meet the following requirements (Ančić I et al. , 2015):

$$\text{Attained EEDI} \le \text{Required EEDI} = (1 - x/100) \times RLV$$

2.3. Reference ship and OCCS establishment

To effectively detect the impact of EEDI reference line value on bulk carriers to be built in the future, this paper selects a typical Kamsarmax ship with a dual-fuel main engine (Wärtsilä 12V50DF) as the reference ship. The detailed parameters of the reference vessel are shown in Table 2. LNG fuel is stored in tanks at a pressure of 100kPa and a cryogenic temperature of -162°C, the engine requires natural gas to have inlet temperature of 60°C and a pressure of 600kPa. The composition of exhaust gas is 75wt% N_2, 16.6wt% O_2, 4wt% H_2O and 4.4wt% CO_2. The parameters of LNG to engine and exhaust gas from engine are shown in Table 2.

Table 2.Main specifications of reference ship

Parameter	Value	Parameter	Value

Type	Bulk	LNG tank	600 m^3
Ship length overall	229 m	Heavy oil tank	1800 m^3
Ship beam	32 m	Marine diesel oil tank	400 m^3
Deadweight	81190 DWT	Main engine type	Wärtsilä 12V50DF
Reference speed	14 knots	MCR rating of main engine	9930 kW

To meet the actual demand of required EEDI, it is necessary to calculate the difference of CO_2 emission between the theoretical value of required EEDI and attained EEDI, and the difference above will be compensated by the OCCS system. The specific calculation formula is as follows:

$$Required\ EEDI\left(gCO_2/t\cdot nm\right) = Attained\ EEDI - \frac{\tau/1000}{f\cdot Capacity\cdot V_{ref}} \tag{3}$$

where τ stands for required CO_2 capture volume of the OCCS, expressed in *kg/h*.

In summary, the τ can be calculated through the formula above, which provides parameter setting criteria for OCCS. The calculations show that for the reference vessel to meet the Stage 2 and Stage 3 of EEDI requirements, the lower limits for the amount of CO_2 captured by the system are 113.7 kg/h and 613.8 kg/h respectively, as shown in Table 4.

Table 3. Attained EEDI and Required EEDI for the reference ship

	Phase 0	Phase 1	Phase 2	Phase 3
Attained EEDI ($gCO_2(tn\cdot m)^{-1}$)	3.61			
Required EEDI ($gCO_2(tn\cdot m)^{-1}$)	4.38	3.94	3.51	3.07
Ψ (kgh^{-1})	---	---	113.7	613.8

3. OCCS modeling

3.1. Process flow diagram

The OCCS enriches the CO_2 in exhaust gas emitted from the main engine through an alcohol-amine solution. The freshly prepared solution reacts with the exhaust gas in the absorption tower and is sent to the distillation column to separate CO_2. The regenerative heat of the distillation column comes from the exhaust gas. After two-stage isothermal compression, the cold energy provided by LNG gasification is used to liquefy CO_2. The overall design schematic of the OCCS is shown in Figure 2.

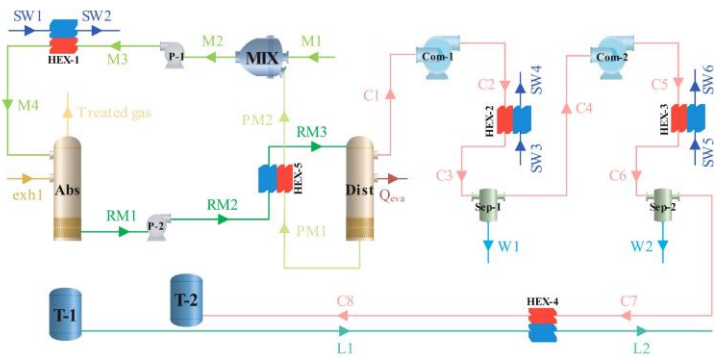

Figure 2. Simulated process flow diagram of OCCS

* In this diagram, exh stands for exhaust gas; M stands for freshly prepared alcoholic amine solution; RM stands for rich liquor; PM stands for lean liquor; SW stands for seawater; W stands for water; C stands for CO_2; L stands for LNG; MIX stands for solution mixers; P stands for pump; Abs stands for absorption tower; HEX stands for heat exchangers; Com stands for compressor; Sep stands for separator; T stands for tank; Q_{eva} is the energy required to condense water vapour.

3.2 Thermodynamic model

In this paper, Aspen HYSYS V12 software is used for simulation of the carbon capture, this paper uses regenerative heat consumption required to capture a unit mass flow of CO_2 which is called specific heat consumption as a key measure of the OCCS system, denoted by ε, measured in *GJ/tCO₂*, as follows:

$$\varepsilon = \frac{3.6Q_{dist}}{m_{CO_2,ca}} \quad (4)$$

where Q_{dist} stands for the regeneration heat required for distillation column, measured by *kW*; $m_{CO_2,ca}$ stands for the mass flow rate of captured CO_2, measured by *kg/h*.

Furthermore, the thermodynamic performance of the whole system will be judged by the energy and exergy efficiency. The equation for the work of each parameter point is as follows:

$$W = m \cdot h \quad (5)$$

where *m* is mass flow rate corresponding to each parameter point; *h* is specific enthalpy.

The net gain work of the system is denoted as:

$$W_{net} = \sum_{1}^{3} W_{HEX} \quad (6)$$

The total revenue work for the whole system is defined as:

$$W_{in} = Q_{exh,in} + Q_{LNG} \quad (7)$$

where $Q_{exh,in}$ is the regenerative heat consumption; Q_{LNG} is Cold energy provided by LNG during CO2 liquefaction.

The energy efficiency of the system can be denoted as:

$$\eta_{en} = \frac{W_{net}}{W_{in}} \quad (8)$$

Exergy (E_x) is made up of physical exergy ($E_{x,ph}$) and chemical exergy ($E_{x,ch}$). As follows:

$$E_x = E_{x,ph} + E_{x,ch} \quad (9)$$

The net gain exergy of the whole system is defined as:

$$E_{x,in} = \sum_{1}^{4} E_{x,ph-HEX} + \sum E_{x,ph-Pump} + \sum E_{x,ph-Com} + E_{x,ph-Dist} + E_{x,ch-Dist} \quad (10)$$

The exergy paid for the whole system can be defined as:

$$E_{x,pay} = \sum_{1}^{4} W_{HEX} + \sum W_{Pump} + \sum W_{Com} + W_{Dist} \quad (11)$$

The following is definition of exergy efficiency:

$$\eta_{e_x} = \frac{E_{x,in}}{E_{x,pay}} \quad (12)$$

4. Discussion of results

Figure 3. displays the effect of lean liquor temperature (T_{sol}) at inlet to the absorber tower on CO_2 capture (m_{CO_2}) and specific heat consumption (ε) under the condition of m_{exh} = 22000 kg/h, m_{sol} = 18000 kg/h at the inlet. As the temperature of the lean liquor increases from 20°C to 60°C, the amount of CO_2 captured gradually decreases, this is because as the temperature increases, the solubility of CO_2 in the lean liquor decreases, which results in decrease in the heat of regeneration required. Thus, specific heat consumption decreases from 5.34 GJ/tCO_2 to 5.24 GJ/tCO_2. In this paper, the greatest reduction in specific heat consumption, but the least reduction in CO_2 capture, occurs at 35°C to 40°C, so a background working condition of 40°C is selected.

Figure 4. displays the effect of exhaust gas mass flow rate (m_{exh}) and lean liquor mass flow rate (m_{sol}) at the inlet of the absorption tower on the amount of CO_2 captured (m_{CO2}). In order to visualise the carbon capture capacity of the OCCS system, the lower limit value of CO_2 emission for the second and third stages of the EEDI (113.7 kg/h and 613.8 kg/h) are indicated in the graph. It is easy to see that when the two masses are controlled at 40°C, the CO_2 capture increases significantly with the increase in m_{exh} and m_{sol}, but the rate of increase slows down after a certain point. In summary, OCCS systems can meet EEDI Stage III requirements when m_{sol} is greater than 13000 *kg/h*. Optimum operating condition can be positioned at 20000 kg/h.

Figures 5. and 6. show the regenerative heat consumption ($Q_{exh,in}$) and specific heat consumption (ε) of OCCS respectively. It can be observed that as the value of m_{exh} increases, the amount of CO_2 absorbed increases, but the heat of regeneration required by the distillation column also increases. Meanwhile, the heat of regeneration increases with increase in m_{sol} when m_{exh} is constant. As for the dramatic reduction in specific heat consumption, although both regeneration heat consumption and CO_2 capture increase as the exhaust gas mass flow rate increases, the rate of regeneration heat consumption increases much less than that of CO_2 volume.

Figure 7. shows η_{en} and η_{ex} of the entire system respectively. The value of η_{en} and η_{ex} of the system increases with increasing value of m_{sol} at the optimum operating parameters (m_{exh}=20000 kg/h). It's clear that the energy efficiency of the system increases slowly as m_{sol} increases. As for exergy efficiency, it is stable between 44.70% and 54.66%. It Max out at 16000.In summary, the optimum operating parameters for the working mass at optimum operating conditions are m_{exh}=20000 kg/h, m_{sol}=16000 kg/h. The amount of CO_2 captured at this point is 760.4 kg/h, which is well above EEDI Stage 3 requirements.

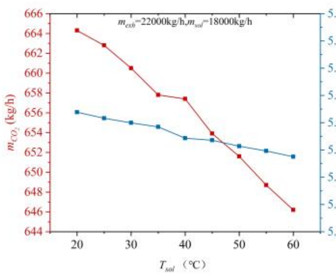

Figure 3. Effect of lean liquor temperature on CO_2 capture

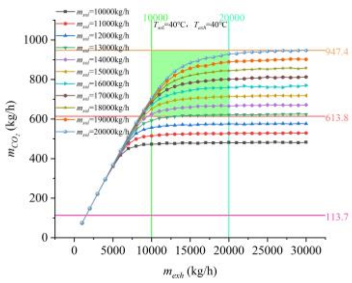

Figure 4. Effect of mass flow rate of exhaust gas and lean liquor on the amount of CO_2 captured

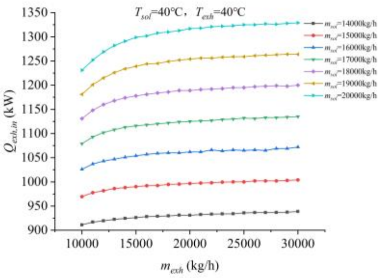

Figure 5. Regenerative heat consumption

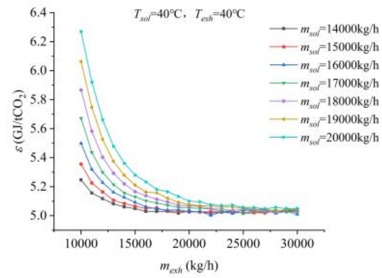

Figure 6. Specific heat consumption

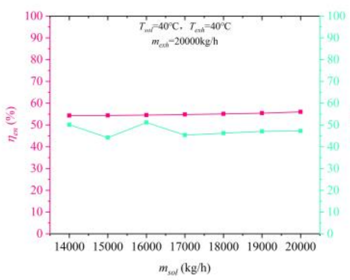

Figure 7. Energy efficiency and exergy efficiency of OCCS

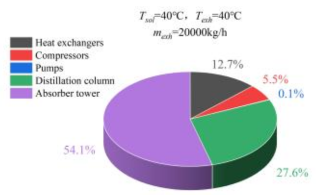

Figure 8. Account for exergy income of main equipment

Figure 8. shows percentage of exergy income of main components in the system under the optimum operating condition. It is clear that the absorption and distillation towers account for the largest share of exergy income, which is due to their internal chemical reactions, chemical exergy are generally an order of magnitude larger than physical exergy.

5. Conclusion

This paper designs a shipboard carbon capture system for LNG-fuelled vessels based on the integrated use of cold and heat energy, guided by the EEDI Stage 3 requirements. Harvesting waste heat from exhaust gas as a source of energy for the regeneration of CO_2 decomposition. Meanwhile, liquefying carbon dioxide with the cold energy released by LNG vaporisation. Take a Kamsarmax vessel as an example and describe the plasticity of the system from three thermodynamic perspectives: energy, physical exergy and chemical exergy with the help of Aspen HYSYS. The results show that there is still space for optimisation in terms of energy use. The next stage will be the thermodynamic optimisation, environmental impact analysis and economic analysis of the OCCS system

Acknowledgements

The authors would like to thank the financial support from the IAMU Research Project for Young Academic Staff in FY2022 (YAS20220201).

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A Zero Energy Increment Onboard Carbon Capture System for LNG-fueled Ship

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Abstract: In order to achieve green shipping, a zero energy increment Onboard Carbon Capture System (zero EI-OCCS) for LNG-fueled ship is proposed. The model was constructed using Aspen HYSYS. Energy and exergy analysis were performed. The results show that under the designed working conditions, the ORC system can generate enough electricity to fully meet the system's electricity demand. The maximum power generated by the ORC is 123.7 kW. Moreover, the CO_2 capture rate also reaches 78.64%, and the maximum exergy efficiency of the system is 28.03%. Under fixed solution flow rate, low exhaust gas flow rate has almost no effect on the capture amount. When the solution flow rate is 21000 kg/h and the exhaust gas flow rate is 20000 kg/h, the maximum CO_2 capture amount is 1686 kg/h.

Keywords: zero energy increment; onboard carbon capture system; organic Rankine cycle; LNG cold energy; waste heat

1. Introduction

Marine transportation has currently produced about 1 billion tons of CO_2 per year (Long NVD et al. , 2021). Unless measures are taken, the emission level in 2050 will be similar to the present (International Energy Agency, 2021). In 2018, global emissions related to transport in the maritime sector increased by 4.71% compared to 2012, accounting for 2.89% of the total global emissions (International Maritime Organization, 2021). In response to the current carbon emissions situation, the International Maritime Organization (IMO) has proposed a series of measures in order to achieve a reduction of at least 50% in greenhouse gas emissions compared to 2008 by 2050 (Güler E et al. , 2021). Among them, LNG, as a low-carbon fuel, has attracted attention (Yoo BY, 2017). Compared with fuel, LNG not only emits less CO_2 (Balcombe P et al. , 2021), but also contains a large amount of cold energy during the vaporization process before entering the engine. However, currently a large amount of cold energy is wasted into the seawater (He T et al. , 2019). Therefore, making good use of the cold energy from LNG vaporization is crucial.

Carbon capture technology is also an option for reducing carbon emissions (Ferrara G et al. , 2017). It is divided into three categories: pre-combustion carbon capture, oxygen-rich combustion carbon capture, and post-combustion carbon capture. Currently, the post-combustion carbon capture technology based on amine solution absorption is widely used due to its good absorption effect and large processing capacity. Therefore, it is completely feasible to use amine solution absorption carbon capture system (CCS) to treat CO_2 in exhaust gas of ship. However, the high regeneration energy consumption of amine solution limits its application (Raganati F et al. , 2021). In addition, the auxiliary equipment in CCS consumes a lot of electricity.

Organic Rankine Cycle (ORC), as a power generation technology that uses organic compound as the working fluid (Leveni M et al. , 2021), can fully utilize the waste heat from ship exhaust gas and the cold energy from LNG vaporization, and generate electricity through a turbine to provide power to the electrical equipment in CCS. In this paper, a zero EI-OCCS for an 80000 DWT LNG-fueled bulk carrier is proposed by integrating ORC and onboard carbon capture unit. For the ORC, the LNG cold energy and jacket cooling water are used as the cold source and the heat source, respectively. For the carbon capture unit, the chemical absorption method is adopted for CO_2 capture from the flue gas. Noticeable, the exhaust gas firstly provides thermal energy for CO_2 desorption before entering the absorber. Afterwards, the concentrated CO_2 is liquified with the low-grade LNG cold energy. The system makes full use of the ship's waste heat and cold energy without the supplement electricity.

2. System description

2.1. Overview of the proposed process

Figure 1 is a simplified diagram of the proposed system installed in a LNG-fueled ship with main specifications of Table 3(Zhen T et al. , 2022). The proposed process consists of three parts: ORC process, CO_2 capture process and CO_2 liquefaction process.

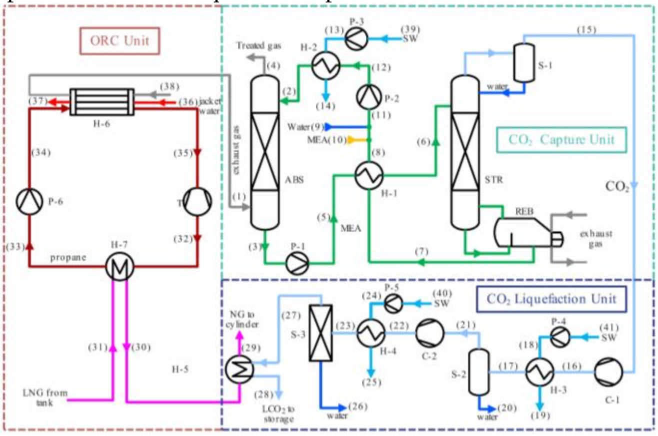

Figure 1. Simplified scheme of zero EI-OCCS system.

Table 3. Main specifications of the reference ship.(Zhen T et al. , 2022)

Parameter	Value
Type	Bulk
Length overall	229 m
Breadth	32 m
Deadweight	82400 DWT
Reference speed	14 knots
LNG tank	1000 m^3
Main engine type	Wärtsilä 12V50DF

2.2. ORC process

In the ORC process, LNG is used as the cooling source and stored in the compartment at a temperature of approximately -162 °C. The pressurized LNG is discharged from the compartment and supplied to the condenser (H-7) at a pressure of 600 kPa. The propane is selected as the ORC working medium, which absorbs the cold energy released by the LNG gasification at atmospheric pressure and condenses to a saturated state. To maximize the power generation of the ORC, the cold energy from the phase change section is fully utilized, raising the LNG temperature to -75 °C. However, at this point, not all the cold energy has been used up, which does not meet the temperature requirement for NG entering the main engine combustion. Therefore, the excess cold energy is used to liquefy CO_2, while the temperature of NG is raised to 35 °C, and then transported to the main engine for power generation. Afterwards, the saturated propane is pressurized by the working pump (P-6) and supplied to the evaporator (H-6), where the pressure is set to 2 MPa to obtain sufficient output power. The exhaust gas, which has provided heat from the reboiler, passes through the evaporator and exchanges heat with propane, reducing the temperature from 120 °C to 50 °C, and then enters the absorber for CO_2 capture. Meanwhile, the jacket cooling water also decreases from 96 °C to 80 °C, and then returns to the cooling loop to prevent the main engine from overheating. However, the minimum temperature of the jacket cooling water should not be lower than 70 °C, otherwise the fuel in the main engine will become too cold, affecting normal operation. At the same time, the propane vapor that is heated in the propane evaporator enters the turbine (T) to generate power, which provides electricity to satisfy the electrical demand of all equipment in the system.

2.3. CO_2 capture process

During the CO_2 absorption and desorption process, the partially cooled exhaust gas enters the absorber (ABS) at a temperature of 50 °C and reacts with the MEA lean solution. The CO_2 in the exhaust gas is absorbed by the MEA lean solution in the column. As a result, the treated gas (which contains almost no CO_2) is directly discharged into the atmosphere, while the MEA-rich solution discharged from the bottom of the absorber is transported to the stripper (STR) by pump (P-1). The MEA-rich solution is then heated by hot MEA-lean solution coming out from the bottom of the stripper. The recuperator (H-1) makes the MEA-rich solution temperature to around 80 °C to reduce the load of the reboiler. Subsequently, the cooled MEA lean solution is replenished with MEA and water to compensate for the solution loss. The cooled MEA lean solution then passes through the seawater heat exchanger (H-2) to decrease its temperature to around 50 °C, which is suitable for absorption. The cooled MEA-lean solution re-enters the absorber to react with the exhaust gas. Then, the preheated MEA-rich solution enters the stripper to desorb CO_2. To integrate ship waste heat, the exhaust gas from the main engine is fed into the reboiler to provide heat for CO_2 regeneration. In the reboiler, the temperature of the exhaust gas drops to 120 °C while the MEA solution absorbs heat to desorb CO_2, carrying away a large amount of water vapor and a small amount of MEA solute. Therefore, to obtain pure CO_2, the mixed gas leaving the tower's upper part needs to be separated using a phase separator (S-1) to remove the water, which is then entirely refluxed to the stripper. The extracted CO_2 from the separator is then subjected to compression and liquefaction.

2.4. CO_2 liquefaction process

During the CO_2 compression and liquefaction process, a two-stage compression method with inter-stage cooling is employed to prevent high exhaust temperature that may damage the equipment. Firstly, CO_2 is pressurized to 500 kPa by a low-pressure compressor (C-1), and then its temperature is reduced to 40 °C by a seawater heat exchanger (H-3). The CO_2 then enters a separator (S-2) to remove excess water. Afterwards, it is compressed to 1500 kPa by a high-pressure compressor (C-2). The cooling and separation steps are repeated until the CO_2 purity reaches 100%. Next, the temperature of the CO_2 is reduced to -30 °C in a condenser (H-5) utilizing excess cold energy from natural gas. As shown by the CO_2 phase diagram, the CO_2 is in a liquid state at this temperature and pressure. Finally, the liquid CO_2 is stored into tanks for further process.

3. Mathematical modeling

3.1. Simulation basis

Aspen HYSYS V12 is utilized to simulate the zero EI-OCCS process. The Acid Gas thermal property package and Peng-Robinson equation are applied for equilibrium calculation and kinetic reactions. The main parameters are shown in Table 4. The assumptions of the proposed system are made: (1) steady-state and adiabatic condition for all equipment. (no heat exchange with the environment). (2) The exhaust gas composition on a mass basis is of 73.1% nitrogen, 11.2% oxygen, 5% water and 10.7% carbon dioxide. (3) The LNG reference composition is assumed as 100% methane. (4) In the two-stage compression process, the cooling temperature of desorbed CO_2 is 40 ℃. (5) The maximum amount of regeneration heat that the main engine can provide is 3106.3 kW.

Table 4. Parameters assumed for system.

	Parameter	Value
ORC process	Jacket cooling water inlet temperature	96 ℃
	Propane liquid quality at the propane pump inlet	1
	Propane liquid quality at the vaporizer outlet	0
	Turbine isentropic efficiency	85%
CO_2 capture process	MEA mass concentration	30%
	MEA and exhaust gas inlet temperature	50 ℃
	Absorber and stripper packing type	Mellapak 500Y
	Absorber and stripper stage number	10
CO_2 compression and liquefaction process	Desorbed gas temperature after each heat exchanger	40 ℃
	Seawater inlet temperature	30 ℃
	Seawater inlet pressure	200kPa

3.2. Energy Analysis

The work produced by the turbine is defined as:

$$W_T = \dot{m}_T (h_{T,in} - h_{T,out}) \tag{1}$$

where $\dot{m}_T$ is the mass flow rate of the propane through the turbine; $h_{T,in}$ and $h_{T,out}$ are the specific enthalpies of propane at the inlet and outlet of the turbine.

The electricity demand of the zero-EI OCCS is:

$$W_{demand} = \sum W_P + \sum W_C \tag{2}$$

where W_P and W_C are the work consumed by the pumps and compressors.

To define the amount of captured CO_2, f_{CO_2} is used to present the carbon capture rate of the system:

$$f_{CO_2} = \frac{\dot{m}_{CO_2,cap}}{\dot{m}_{CO_2,exh}} \tag{3}$$

where the $\dot{m}_{CO_2,cap}$ and $\dot{m}_{CO_2,exh}$ are the mass of captured CO_2 and exhaust gas contained CO_2 , respectively.

The specific reboiler duty can be defined as:

$$\varepsilon = \frac{Q_{reg}}{\dot{m}_{CO_2,cap}} \tag{4}$$

where Q_{reg} is the regenerative heat consumed by the stripper.

To determine the profits of the liquefied CO_2, the heat duty of H-3 and H-4 can be regarded as the produced energy because the seawater is free, and the electrical demand of seawater pumps can be supplied by the ORC. Therefore, the energy efficiency of the zero-EI OCCS is defined as:

$$\eta_{en,sys} = \frac{W_T + Q_{LNG,CO_2} + Q_{H-3} + Q_{H-4}}{Q_{reg} + Q_{jcw} + Q_{exh} + Q_{LNG,tot} + W_{demand}} \tag{5}$$

where Q_{LNG,CO_2} is the cold energy of LNG liquefied CO_2 in H-5; Q_{reg} is the heat supplied by exhaust gas to the reboiler; Q_{jcw} is the heat of the jacket cooling water in H-6; Q_{exh} is the heat of the exhaust gas in H-6; $Q_{LNG,tot}$ is the cold energy of LNG in H-7 that is fully utilized before it enters the main engine for combustion.

3.3. Exergy Analysis

Exergy analysis defines the max useful work obtained from the system by calculating the irreversibility in the process. Since the process has little variation in height and velocity, the potential exergy and kinetic exergy can be neglected. Thus, the total exergy is presented as:

$$\dot{E}_x = \dot{m}(e_{ph} + e_{ch}) \tag{6}$$

where e_{ph} is the physical exergy; e_{ch} is the chemical exergy of the fluid (Szargut J, 2005).

During chemical reaction and heat or mass transfer, the exergy destruction occurs due to increased entropy. The exergy destruction of the equipment in system are given by:

$$\dot{E}_D = \dot{E}_{pay} - \dot{E}_{income} \tag{7}$$

The exergy destruction ratio of the equipment is expressed as:

$$\varphi_i = \frac{\dot{E}_{D,i}}{\dot{E}_{D,sys}} \tag{8}$$

where $\dot{E}_{D,i}$ is the i^{th} component exergy destruction and $\dot{E}_{D,sys}$ is the system exergy destruction.

Based on above, the system exergy efficiency is defined as:

$$\eta_{ex,sys} = \frac{\dot{E}_{LCO_2} + W_T + \dot{E}_{jcw,out} + \dot{E}_{NG,out} + \dot{E}_{tg}}{W_{demand} + \dot{E}_{mu} + \dot{E}_{exh,in} + \dot{E}_{jcw,in} + \dot{E}_{LNG,in}} \tag{9}$$

where $\dot{E}_{mu}$ is the exergy flow rate of replenished water and MEA; $\dot{E}_{jcw,in}$ and $\dot{E}_{jcw,out}$ are the exergy flow rate of inlet and outlet jacket cooling water; $\dot{E}_{LNG,in}$ and $\dot{E}_{NG,out}$ are the exergy flow rate of inlet and outlet natural gas; $\dot{E}_{tg}$ is the exergy flow rate of treated gas; $\dot{E}_{exh,in}$ is the exergy flow rate of inlet exhaust gas in ORC process; $\dot{E}_{LCO_2}$ is the exergy flow rate of the liquefied CO_2.

4. Result and discussion

Figure 2 shows the variation in CO_2 capture amount of the system with changes in the mass flow rate of exhaust gas and MEA solution. When the mass flow rate of exhaust gas increases, the CO_2 capture amount also increases. It is worth noting that when the mass flow rate of solution are 13000 kg/h and 15000 kg/h, the CO_2 capture amount does not vary much with the exhaust gas flow rate. This is because the amount of CO_2 that the solution can absorb is limited, and under these two operating conditions, the CO_2 load of the solution at a fixed flow rate has already approached the limit. When the solution flow rate is increased, the CO_2 capture amount increases significantly and gradually levels off as the solution approaches saturation. When the solution flow rate is 21000 kg/h and the exhaust gas flow rate is 20000 kg/h, the maximum amount of captured CO_2 is 1686 kg/h.

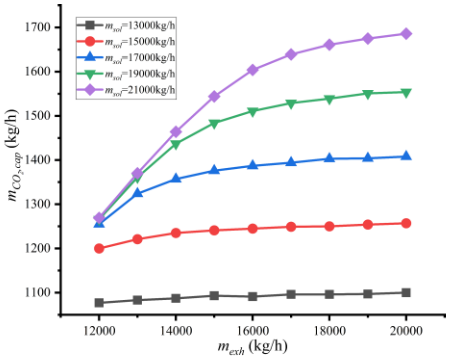

Figure 2. Effect of various m_{exh} and m_{sol} on the mass flow rate of captured CO_2.

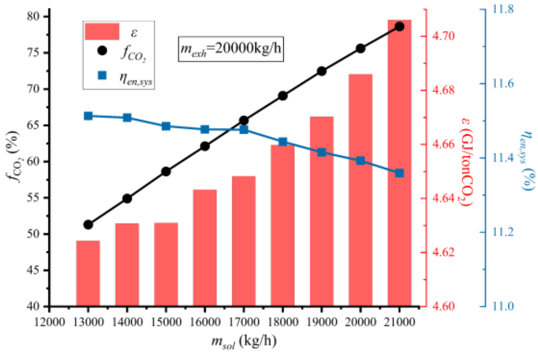

Figure 3. Effect of various m_{sol} on: CO_2 capture rate, the specific reboiler duty and the system energy efficiency.

Figure 3 presents the relationship between solution flow rate and specific reboiler duty, CO_2 capture rate, and the system energy efficiency. As illustrated in the figure, an increase in solution flow rate leads to a continuous rise in specific heat consumption, increasing from 4.62 GJ/tonCO_2 to 4.71 GJ/tonCO_2 , and the trend accelerates gradually. This is due to the significant changes in regeneration heat with the variation of solution flow rate. Additionally, Figure 2 shows that the CO_2 capture amount experiences a slower increase as the solution flow rate grows, which results in the accelerated increase of specific reboiler duty. Furthermore, since the solution's CO_2 load is limited, the CO_2 capture rate gradually increases from 51.31% to 78.64%. Increasing solution flow rate will greatly increase the system's heat load. The energy efficiency of the system decreases from 11.51% to 11.36%. As the CO_2 capture rate increases, the system energy efficiency and specific reboiler duty both trend towards unfavorable conditions.

It is evident from Figure 4 that at any solution flow rate, the electrical energy output by the turbine can exc

eed the electricity demand of the system, reaching a maximum value of 123.7 kW at a solution flow rate of 21000 kg/h. At the same time, the regeneration heat also reaches its maximum value of 2204 kW. Therefore, under these boundary conditions, it is possible to achieve zero energy increment of the system. At the highest system load, the CO_2 capture rate of 78.64% is an acceptable result. At the same time, the system exergy efficiency increases from 19.59% to 28.03% as the solution flow rate increases. This is because when the exhaust gas flow rate is fixed, the increase in solution flow rate leads to an increase in CO_2 capture amount and a decrease in the flow rate of the treated gas. In addition, the output power of the turbine also increases, leading to an increase in system exergy efficiency.

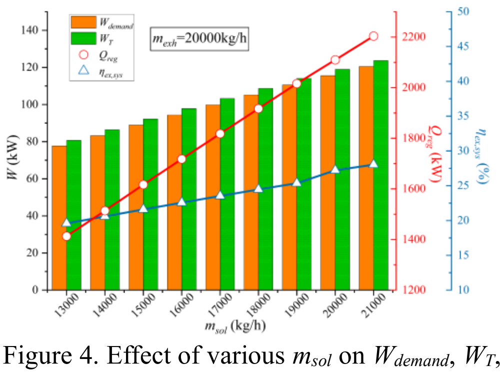

Figure 4. Effect of various m_{sol} on W_{demand}, W_T, the system exergy efficiency and the reboiler duty.

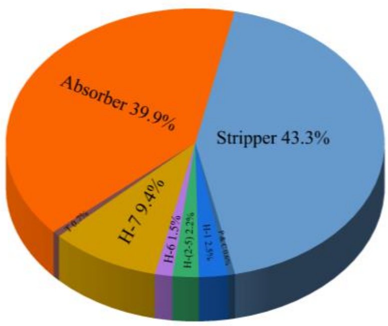

Figure 5. The exergy destruction of main equipment.

Figure 5 demonstrates the exergy destruction ratio of each equipment. The exergy destruction proportion of absorber and stripper is the largest, accounting for 39.9% and 43.3% respectively, due to the chemical reactions inside the column. Besides, because LNG and CO_2 both undergo phase changes in H-7 and the working temperature difference is large, the exergy destruction ratio of H-7 accounts for 9.4%. All the pumps have very little destructions, which is due to the small variation in temperature difference.

5. Conclusion

In this paper, a zero energy increment OCCS for LNG-fueled bulk carrier with an ORC that integrates waste heat and cold energy for electrical power supplement. The system is analyzed in the study from energy and exergy standpoint. The main conclusion drawn from the study are as follows: Under the designed working conditions, the ORC system can generate enough electricity to fully meet the system's electricity demand. The maximum power generated by the ORC is 123.7 kW and CO_2 capture rate also reaches 78.64%. Meanwhile, the system exergy efficiency increases from 19.59% to 28.03%. Increasing the exhaust gas flow rate will increase the amount of captured CO_2, but there is an upper limit to the capture amount. When the solution flow rate is 21000 kg/h and the exhaust gas flow rate is 20000 kg/h, the maximum amount of captured CO_2 is 1686 kg/h. The system energy efficiency increases with the increase of exhaust gas flow rate and decreases with the increase of solution flow rate. As the CO_2 capture amount changes slowly and the regeneration heat changes significantly with the solution, the specific reboiler duty also increases from 4.62 GJ/tonCO_2 to 4.71 GJ/tonCO_2.

Acknowledgements

The authors would like to thank the financial support from the IAMU Research Project for Young Academic Staff in FY2022 (YAS20220201)

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Visualization and Simulation of Ocean Scenes with Physically-Based Models in Marine Simulators

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Abstract: A physically based marine scene simulation method is proposed to enhance the realism of the marine simulator visual system and improve the immersion and training quality of seafarers participating in marine simulator maneuvering training. A position-based dynamical framework is used to construct a fluid particle system model and impose velocity divergence constraints. The results show that the position-based fluid particle hybrid model can effectively simulate the roll and break of waves on the complex sea surface. Furthermore, the particle system of the obtained velocity field can simulate the wave surface realistically to a certain extent, which can effectively improve the realism of the navigational simulator scenery system and thus improve the quality of seafarer training.

Keywords: Physically Based Simulation; Marine Simulator; Position Based Fluid; Maritime Education;

1. Introduction

The rapid development of marine simulators provides a solid foundation for the training and delivery of many high-quality seafarers in navigation colleges and scientific research institutes. Use a marine simulator to conduct simulated training for seafarers. Compared with real ship training, simulated training has high efficiency, low economic cost, and safety of strength training. Ship driving operation drills through simulators can improve seafarers' awareness of ship collision avoidance; proficiency in entering and exiting ports and berthing and unberthing operations can reduce the probability of marine safety accidents (Ping, 2003). The marine simulator is a crucial training link for crew training and certification. The International Maritime Organization's "STCW78/98 Convention" clearly stipulates the relevant technical design and training assessment standards, providing a theoretical basis for developing marine simulators from the level of rules and regulations.

The early marine simulators used by countries worldwide were radar simulators (Quangen, 1996). Simple radar detection images cannot simulate the real ship-driving environment, and participants have no sense of immersion. With the development of science and technology and the impetus of relevant treaties on simulators, the marine simulator has begun to change from no vision to simple to complex. Today, the main research directions of the marine simulator can be roughly divided into virtual operating systems, ship motion mathematical models, and visual simulation systems, which correspond to three measurement indicators of physical realism, behavioral realism, and operating environment realism, respectively. The companies producing marine simulators in the industry mainly include Norway Kongsberg Company, British Transas Company, American Military Professional Resources Corporation (MPRI), and Danish Force Technology Company. Kongsberg Company uses the self-developed SeaView R5 visual system, uses Multigen Creator software for modeling, and finally uses OSG 3D graphics engine for image processing to meet the requirements of the STCW convention for the visual system of the marine simulator(Aud, 2020; Steven, 2019; Martin, 2011). The NTPRO 5000 series marine simulator produced by British Transas Company can simulate different types of ships through a large field of view and high-fidelity ship bridge equipment, and its visual system is based on the OpenGL rendering pipeline. The V.Dragon-4000 large-scale ship-maneuvering simulator developed by Dalian Maritime University is widely used in the teaching, training, and scientific research of domestic maritime colleges and universities. It adopts distributed interactive simulation technology to provide a natural bridge operating environment and meet the daily training requirements of the crew.

In the marine simulator, the sea waves occupy about half the viewing area, and the realistic simulation dramatically influences the environment's realism. Currently, the wave modeling methods in marine simulators mainly adopt the approach based on structure, including the method based on geometric models and the method based on statistics and spectrum. At the same time, most of the rendering engines used in marine simulators at this stage are rasterized rendering pipelines based on the underlying OpenGL, which are less realistic than those based on ray tracing rendering. With the rapid development of computer GPU equipment, the method based on physical models and real-time ray tracing rendering gradually appeared. The wave modeling methods based on physical models are divided into the Euler grid and Lagrangian particle methods. The Euler grid method simulates the movement of the fluid on the unit by fixing the grid unit, but the disadvantage is that the time step condition limits it. The Lagrangian method analyzes the physical quantities of the fluid particles at any time, such as velocity, trajectory, density, pressure, etc., uses particles to represent the particles, and uses particle discrete control equations. The advantage of the Lagrange method is that the simulation has a strong sense of reality, and it can simulate richer fluid details such as water splashes and foams in three-dimensional space and deal with more complex fluid surfaces. Commonly used Lagrangian methods include Smoothed Particle Hydrodynamics and the Position Based Fluid method. The PBF method allows a large time step and better real-time performance than the traditional SPH method. The position-based fluid rendering method has become a hot spot in the research of ocean wave simulation. Müller (Müller, 2007) first proposed the PBD framework and used it to simulate cloth. Macklin et al. (Macklin, 2013) used the PBD framework for fluid simulation for the first time. They proposed a PBF framework incorporating an iterative density solver to achieve incompressibility and convergence close to the current SPH solver, strong stability, large time step, and suitable for real-time render. Kang et al. (Kang, 2014) constructed a divergence-free velocity field to speed up the convergence. Köster et al. (Köster, 2016) proposed an adaptive iterative APBF method ideal for real-time simulation of more extensive scene fluids.

Combining the above analysis and considering the physical wave fluid modeling method, a realistic wave simulation method based on positional dynamics is proposed, mainly by constructing the Divergence-Free PBF fluid model and using the eddy constraint method to restore the details of the turbulent flow to realize the realistic wave scene simulation.

2. Fluid Simulation

2.1 Position Based Fluids

The PBF method is a meshless, Lagrangian particle method based on the PBD framework. The essence of the PBD framework is to construct constraints and then update the position information of fluid particles by projecting the constraints. The PBF, as a fluid simulation method based on the PBD framework, iteratively solves the displacement bias of fluid particles by constructing density constraints and then updates the fluid particles in real time according to the displacement bias velocity. Then the fluid particles are plotted out. The traditional method updates the velocity values by solving for the force values and then integrating numerically based on the force values. Unlike the conventional force-based solution method, the framework of position-based dynamics uses constrained means. In the PBD method, when penetration of two objects is detected, the positions of the objects are directly corrected according to the constraints employed. Then the velocity information of the objects is updated.

By combining with the traditional SPH interpolation method, Macklin et al. [5] proposed a fluid simulation method PBF based on the PBD framework. Unlike the position constraint used in the traditional PBD framework for solving solid problems, the PBF method uses a density constraint method to update the positions of fluid masses by calculating their densities. To ensure the incompressibility of the fluid for each fluid particle, we need to satisfy the density constraint that:

$$C_i(\mathrm{p}) = \frac{\rho_i}{\rho_0} - 1 = 0 \tag{1}$$

ρ_0 is the rest density, ρ_i is given by the standard SPH density estimator:

$$\rho_i = \sum_j m_j W(\mathrm{p}_i - \mathrm{p}_j, h) \tag{2}$$

In the fluid model, it is considered that all fluid particles have equal mass, so the mass term mj is discarded from the following equation. W is the smooth kernel function, according to the kernel function used by Muller [8] when the SPH method was first used to model fluids; in this paper, the Poly6 kernel function is chosen for density estimation, and the Spiky kernel function is used for gradient calculation, and the kernel function is as follows:

$$W_{poly6}(r, h) = \frac{315}{64\pi h^9}\begin{cases}(h^2 - r^2)^3 & 0 \le r \le h \\ 0 & \text{otherwise}\end{cases} \tag{3}$$

$$W_{spiky}(r, h) = \frac{15}{\pi h^6}\begin{cases}(h - r)^3 & 0 \le r \le h \\ 0 & \text{otherwise}\end{cases} \tag{4}$$

Monaghan et al. [9] gave a formula for the SPH gradient at the particle level, which, when applied to the density constraint, gives the gradient of the constraint for an arbitrary fluid particle k as:

$$\nabla_{p_k} C_i = \frac{1}{\rho_0}\sum_j \nabla_{p_k} W(P_i - P_j, h) \tag{5}$$

The gradient equation varies with the type of fluid particle, and the fluid particle k can be classified as an object particle as well as a neighborhood particle:

$$\nabla_{p_k} C_i = \frac{1}{\rho_0}\begin{cases}\sum_j \nabla_{p_k} W(P_i - P_j, h) & \text{if } k = i \\ -\nabla_{p_k} W(P_i - P_j, h) & \text{if } k = j\end{cases} \tag{6}$$

From this, the value of the Lagrangian operator λ can be derived as:

$$\lambda_i = -\frac{C_i}{\sum_k \left|\nabla_{p_k} C_i\right|^2} \tag{7}$$

As a result, the displacement values of fluid particles considering the neighborhood particle density constraint correction and guaranteeing the fluid incompressibility condition can be obtained as:

$$\Delta p_i = \frac{1}{\rho_0}\sum_j (\lambda_i + \lambda_j)\nabla W(p_i - p_j, h) \tag{8}$$

2.2 Velocity divergence constraint solver

To improve the incompressibility of the traditional PBF method and enhance the computational efficiency of the PBF algorithm, it is proposed to improve the conventional PBF method by using a velocity scatter constraint solver, which directly derives the velocity variables from adjusting the velocity field to a scatter-free field, thus imposing a double incompressibility constraint on the fluid model.

The velocity divergence constraint solver imposes constraints on the divergence directly at the velocity level, eliminating the need to calculate the pressure gradient term:

$$C_i^v(v) = \nabla \cdot v_i^* = -\frac{1}{\rho_i}\sum_j m_j v_{ij}^* \cdot \nabla W_{ij} = 0 \tag{9}$$

In the formula, Inspired by the density constraint solver, the projection of the velocity to the divergence-free field by introducing a velocity correction quantity yields:

$$C^v(v + \Delta v) \approx C^v(v) + \nabla C^v(v) \cdot \Delta v = 0 \tag{10}$$

$$\Delta v = \lambda^v \nabla C^v(v) \tag{11}$$

λ^v is the Lagrangian multiplier. Thus, the gradient representation of the velocity dispersion constraint at the neighborhood particle j can be obtained as:

$$\nabla C_{j\leftarrow i}^v(v) = \frac{1}{\rho_i} m_j \nabla W_{ij} \tag{12}$$

Bringing Eq. 11 and Eq. 12 into Eq. 10 the Lagrange multiplier can be solved as:

$$\lambda_i^v = -\frac{C_i^v(v)}{\left|\nabla C_i^v(v)\right|^2 + \sum_j \left|\nabla C_{i\leftarrow j}^v(v)\right|^2} = \rho_i^2 \alpha_i C_i^v(v) \tag{13}$$

The velocity correction can be calculated from Eq.11 as:

$$\Delta v_i = \lambda_i^v \nabla C_i^v(v) + \sum_j \lambda_j^v \nabla C_{i\leftarrow j}^v(v) = -\frac{1}{\rho_i}\sum_j m_j(\lambda_i^v + \lambda_j^v)\nabla W_{ij} \tag{14}$$

3. Results and Discussions

We validate the stability and effectiveness of our improved PBF fluid model by implementing various specific maritime scenarios in the marine simulator, such as dam break scenarios, lifeboat-in-water scenarios, and lighthouse-water coupling scenarios. The specific configuration of the computer used in our experiments is Intel(R) Core(TM) i5-9400F CPU (2.90 GHz), 16.00 GB RAM, and NVIDIA GeForce GTX 1660 SUPER GPU. The physical model in the paper is implemented in C++, modern OpenGL does the fluid particle rendering part of the experimental results, and Cycles renderer in Blender does the real water rendering. The integrated development environment is Microsoft Visual Studio 2019 Enterprise. Due to the space limitation of the paper, only the dam break scene and lighthouse-water coupling scene are shown.

3.1. Dam break scene

In this paper, we simulate a dam break scene based on the improved position based fluid model. The number of fluid particles in the dam break scenario is 6859, and the simulation time step is set to 0.005s, with an average simulation time of 12.29 ms per step.

The simulation results of this paper show that, compared with the existing construction-based methods used in marine simulators, the improved PBF fluid modeling method proposed in this paper has the obvious advantage is the flexible fluid surface, which can effectively realize the simulation of large deformation scenarios such as wave roll, break, splash, and surge. The fluid model in this paper can simulate realistic sea surface effects without other aids methods because of the advantages of the particle-based simulation system itself in the Lagrangian perspective.

The height-field grid, which is difficult to produce large deformations, limits the wave spectrum model and the height-field grid itself does not break, so wave breaking and splashing of water droplets are achieved with the aid of particles. In addition, the PBF approach is to link the particles of the mass conservation equation and the momentum equation by constraints.

The results are rendered by Blender V2.8, with Cycles renderer.

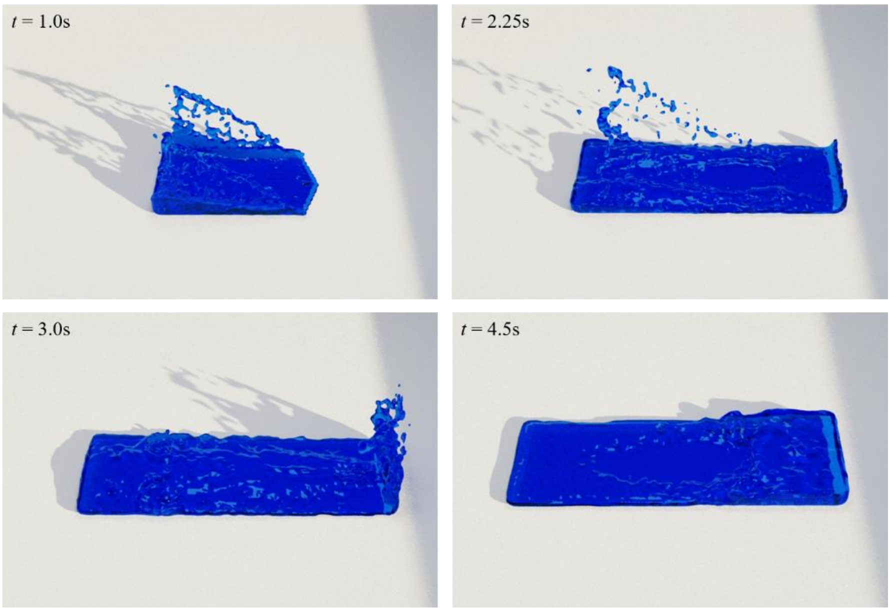

Figure 1. Dam break scene

3.2. lighthouse-water coupling scene

To verify the physical accuracy of the improved position based fluid model proposed in this paper and the effectiveness of the fluid-solid interaction with specific markers at sea, a typical nautical scenario of seawater interacting with a lighthouse impact is set up in this paper. The number of fluid particles in the interaction scenario is 59319, the simulation time step is 0.005s, and the velocity field of seawater particles is represented by color change. From the velocity field distribution, it can be seen that the velocity of the seawater particles located near the lighthouse is significantly smaller compared with the seawater particles at similar locations, which proves that the proposed seawater model successfully interacts with the rigid lighthouse. At the same time, the seawater model produces a divergence and merging of the water flow after bypassing the lighthouse, and the seawater particles produce an obvious splash at the boundary of the bounding box, which is consistent with the general law of water motion.

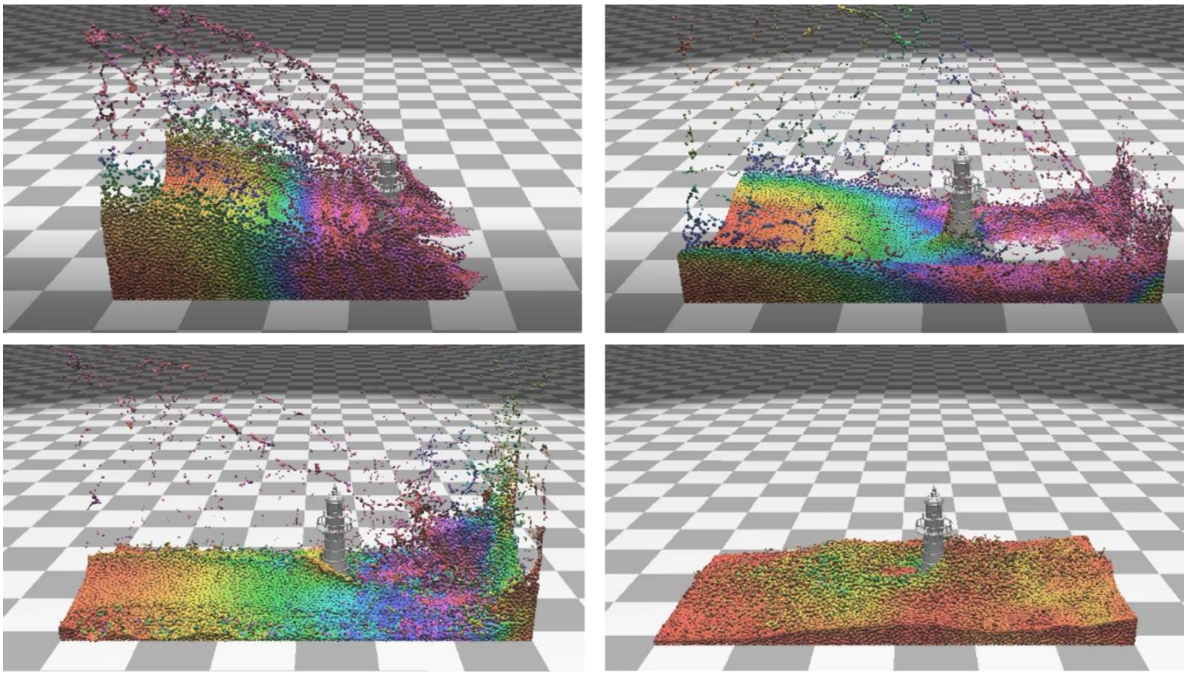

Figure 2. Lighthouse-water coupling scene

4. Conclusion and Future work

Based on the international conventions and nautical practice requirements, this paper introduces the position based fluid modeling method into the marine simulator visual system for the lack of physical realism in the existing visual system and proposes an improved PBF fluid modeling method combined with a velocity divergence constraint solver. Experiments prove that the fluid modeling method proposed in this paper has great advantages in simulating large deformation scenarios such as wave overturning, breaking, splashing, etc. It can interact with nautical markers, thus simulating classical nautical scenarios, effectively improving the integration of wave models in nautical simulators and the scalability of the system, and solving the coupling problem between models. In the future, the work of this paper can play a role in intelligent ship information monitoring, environment perception, etc. in addition to its application in the navigation simulator, and relevant research can be carried out to help the development of intelligent ships.

Acknowledgments

This research was funded by the National Natural Science Foundation of China, grant number 52071312; by the Transportation Industry Key Science and Technology projects, grant number 2022-ZD3-035.

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Does Location Matter? Cultural Awareness Via Experiential Learning for Maritime Professionals

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Abstract: Educating and training future generations of maritime professionals in a diverse, multicultural world is vital for the sustainability of the maritime sector. In a survey of hundreds of key maritime stakeholders, cultural/diversity awareness, and sensitivity (or cultural awareness) were identified as one of the 28 competencies needed for future global maritime professionals. Our research examines the experiential learning program at Massachusetts Maritime Academy and how this program should be utilized in other maritime institutions. The focus of our research was to answer the question of why institutions are not using these programs in there curriculums. The research looks at student data from previous years' trips. Using pre- and post- cultural intelligence data, our team was able dissect the data via regression analysis to determine which countries are the best to have the most cultural awareness growth. This quantitative approach was very useful in utilizing cultural awareness data. These learning programs have shown to enhance cultural understanding and have been crucial for the development of these soon to be maritime professionals. This paper will present our experiences, regression analysis, and support our hypothesis of how cultural differences between countries will increase the cultural awareness of traveling students.

Keywords: Cultural Awareness, International Experiences, Global Maritime Professionals

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1. Introduction

In recognition of the fact that, since 2015 Massachusetts Maritime Academy has implemented an experiential learning program which sends students to foreign countries to enhance cultural experiences for cadets. This program has been an excellent opportunity for furthering education for the next generation of maritime professionals. Our research focuses on the growth students are showing in their cultural awareness knowledge from these specific trips. Looking at data via the Hofstede's scale, where this scale measures certain categories of culture for each country. The International Maritime Business (IMB) department collaborates with international contacts to set up 3-week programs where students travel abroad to get full exposure to a new culture. The IMB department creates an itinerary where students will travel to ports, terminals, and academic institutions to participate in these international learning experiences. The role of the IMB department is to prepare students to be business professionals to serve in land side maritime operations and in the global supply chain. Students take classes that include accounting, finance, economics, admiralty law, port terminal operations, and shipping. These classes ensure graduates are prepared with the tools to be effective in the workplace. The nature of the IMB department and the experiential learning program is to gain maritime experience and develop a global perspective of the industry. The experiential learning program is crucial to the industry, as more students enter the field other institutions should consider the benefits from participating in these programs.

Cultural awareness is a significant component of cultural competence. (Curricula Enhancement,2023) In today's world, cultural awareness is more important than ever before. As a result of the implementation of advanced technology and transportation, global connectivity has become more effective than in previous times. (Yeganeh, 2023) It is imperative that we are educated to respect and understand the diverse cultures that make up the complex world we live in. This education must be provided in the workforce, throughout the government, and particularly within the educational system. Within the school setting, there are various ways to enhance cultural awareness. Various universities around the world engage in study abroad programs. In these programs, schools send students to foreign countries where they take classes whilst being immersed in the local culture. The programs send prospective students to study at other universities where they learn about culture, ethics, classes, etc. Study abroad programs are vital for the expansion of the participating students' minds while providing benefits for the host country. These benefits can include increasing cultural awareness, learning a new language, career opportunities, networking, etc. Opportunities that fully immerse students into a new culture allow them to communicate and work together with people from different cultures and ethnicities. These trips are a tool that will benefit maritime students as they enter the workforce in a global industry.

During the experiential learning program, each student is required to take a pre- and post-Cultural Intelligence (CQ) assessment, which measures a person's capability to function effectively in various cultural contexts- both internationally and domestically. The test is designed to measure how well a student's cultural intelligence grows from attending an experiential learning trip. Our group has based our research on using both Hofstede's scale and the CQ assessment, to see how well these programs are and what specific countries to send students. Our team used the CQ data from past trips dating back to 2017. We then took the scores from the overall CQ categories Drive, Knowledge, Strategy, and Action. This then allowed us to form multiple regression models to help dissect this data. The research was conducted to determine which of the countries was the best to send students and what countries students would benefit from the most cultural growth. We hope to accept our hypothesis and use this data as evidence for other maritime institutions around the world to hopefully implement experiential learning programs in their curriculum. Our team believes these experiences will create work-ready maritime professionals and that maritime curricula will be changed for future generations to come.

2. Data

The study uses the CQ data extracted from previous years' experiential learning trips to help us visualize the positive effects of attending these abroad learning courses. To meet this objective, we decided to use a quantitative approach to support our hypothesis. A collection of data from the CQ data 2017-2023 experiential learning trips will be dissected to complete our analysis. We wanted to use the data from the previous trips to shows how students have expanded their cultural awareness from participating in these programs. We hope to show how these programs should be utilized by maritime professionals around the world so the students of the industry can grow their cultural intelligence. The CQ assessments are always administered to participating students before departing the United States and once more when they return state side. The students are usually in their second year of study when they participate in the experiential learning program. Although we do see some 3rd and 4th year students in the program. The purpose of the self-assessment is for students to reflect on what they may know or not know when traveling abroad to a foreign country. The purpose of these self-reflection assessments is for the students to individually assess their cultural intelligence before and after the experiential learning program. The regression models are to see what country is the best for improvement in cultural intelligence.

Cultural Intelligence (CQ) is a person's capability to function effectively in various cultural contexts- both internationally and domestically. The Cultural Intelligence Center is a cultural consultant group based out of Grand Rapids, Michigan. They are a research and consulting firm that uses data to help individuals and organizations to increase their Cultural Intelligence. Their mission is to build bridges and relationships across multiple cultures around the world. The Cultural Intelligence Center developed a variety of different assessments that can measure CQ and give personalized feedback to individuals and institutions. Specifically, our group is familiar with using the pre- and post-CQ assessments as we used these assessments during our experiential learning trips abroad. The cultural intelligence pre/post assessment is used across the world to assess the four divisions and thirteen subdivisions of cultural intelligence. The CQ test dives into individual cultural values (CV) and measures changes in cultural awareness over time. The CQ scores are broken down into two scores, a pre- and post-travel score. The test is divided into four divisions of culture: CQ Drive, CQ Knowledge, CQ Strategy, and CQ Action. CQ Drive focuses on a person's level of interest, persistence, and confidence during multicultural interactions. CQ Knowledge reflects a person's understanding of how cultures are similar and different. CQ Strategy explains one's awareness and ability to plan for multicultural interactions. CQ Action shows one's ability to adapt when relating to and working in multicultural contexts. Under the CQ Drive division, there are sub-categories of intrinsic interest, extrinsic interest, and self-efficacy. CQ Knowledge has sub-categories of business, values & norms, socio-linguistic, and leadership. CQ Strategy has sub-categories of planning, awareness, and checking. Lastly, CQ Action has sub-categories of speech acts, verbal, and nonverbal. All these subcategories are calculated to create a total score for each of the four culture divisions. Those four scores are then averaged to create a total CQ score. For our research, we decided to focus on the four main divisions of culture. We wanted to look at this from a broad spectrum rather than dissecting each individual sub-category. Some of the questions asked include I am conscious of the cultural knowledge I use when interacting with people with different cultural backgrounds, I know the legal and economic systems of other cultures, I enjoy interacting with people from different cultures, I change my verbal behavior (e.g., accent, tone) when a cross-cultural interaction requires it. (*Van Dyne,2023)* These questions are based on a 7-point Likert scale. After completing the test, the individuals receive unique feedback reports to see the growth over time. The feedback reports include a profile summary and a development plan for everyone. The profile summary breaks down the scores in depth and these are shown on a 100-point scale. The development plan allows everyone to reflect on their CQ scores. This gives the opportunity to see what areas can seek improvement. Individuals create personalized goals, which are developed into action plans to increase their cultural intelligence and awareness. The goal of this is to create a plan so that each person can grow when they are on their next abroad program. This gives the individual test taker more time to reflect and think about what they did well or what they need to improve on for the future. The Cultural Intelligence Center has created this tool as a way for people and cultures to unite and create diplomatic opportunities. Creating unity throughout the various cultures can guarantee success for generations to come. These types of tests can be used by maritime organizations and professionals worldwide to create a quality international experience and gives them a way to measure growth within their students. (*Cultural Competency & Awareness Trainings, 2023*)

According to Geert Hofstede, "Culture is the collective programming of the mind that distinguishes the members of one group or category of people from others". The Hofstede Scale, created by Geert Hofstede, acts as a framework that is utilized to comprehend the differences among countries’ cultures. The scale is the primary dimension utilized for ranking countries based on their level of economic development or modernization. It ranks societies on a scale from traditional to modern. Countries are categorized based on six dimensions: power distance, individualism, masculinity, uncertainty avoidance, long-term orientation, and indulgence. Power distance is the extent to which the less powerful accept that the power within the country is distributed unequally. In a small power distance society, parents treat their children as equals and power use is legitimate. In a large power distance society, parents instill a sense of obedience within their children, and powers’ legitimacy is irrelevant. Power distance relates to the levels of human inequality within a society. Individualism is the extent to which people within the country are assimilated into groups. In an individualistic culture, privacy and speaking one’s mind are encouraged. In a collectivist culture, harmony and collaboration as a group is the main priority. Masculinity relates to how roles are distributed between men and women. This ranking depends upon how traditionally masculine the members of the society behave. Uncertainty avoidance applies to the stress countries suffer due to not knowing what the future holds. Long-term orientation is ranked based on what efforts people within the country choose to focus on. In a country where short-term orientation is valued, people place importance on events in the present. In a country where long-term orientation is valued, people are invested in the future. Finally, societies are ranked on indulgence, or the scale of how much they allow gratification and natural human desires. Every country has been evaluated on each dimension in relation to other countries. (Hofstede, 2011) This scale can be used to easily understand the similarities and differences between two countries.

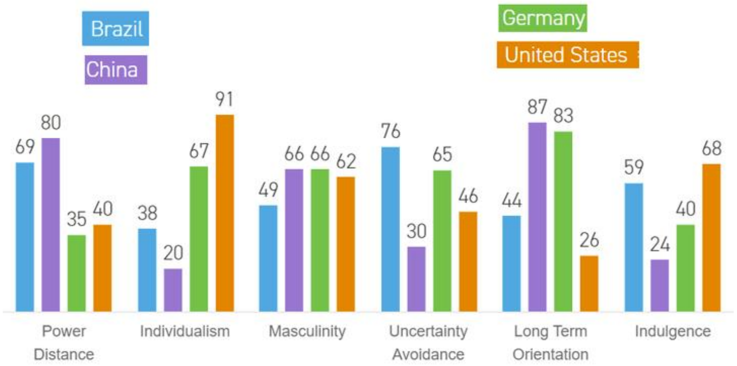

Figure 1. Hofstede’s scale comparing 4 countries.

3. Methodology

Data will be analyzed through a regression model. We formulated six regressions models that took the overall CQ scores to see if the cultural awareness growth was dependent on the location of the experiential learning location. The function we created implemented dummy variables for each of the corresponding countries. This method helped compare each country to the control group, which was the online learning experience. This approach allowed us to visualize the correlation between the country traveled to and the growth students gained. We then ran a separate regression model that focused on the Hofstede's cultural dimensions scale. The purpose of this regression was to see if one dimension was better acquainted to a certain country. For example, if a student were looking to improve their indulgence, what country would they have to travel to, to gain the best results.

CQ DRIVE OVERALL	Intrinsic Interest	Extrinsic Interest	Self-Efficacy	CQ KNOWLEDGE OVERALL	Business	Values & Norms	Socio-Linguistic	Leadership	CQ STRATEGY OVERALL	Planning	Awareness	Checking	CQ ACTION OVERALL	Speech Acts	Verbal	Nonverbal
51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
91	78	95	98	53	51	78	34	51	87	78	98	84	69	89	51	67
95	84	98	98	96	92	98	98	93	95	98	98	84	84	84	84	84
98	98	98	98	50	51	84	18	47	76	67	98	62	49	51	51	45
80	62	78	98	46	51	67	26	41	71	67	84	62	34	29	45	29
91	73	98	98	66	67	73	59	67	78	56	78	98	74	67	62	95
87	73	98	89	35	34	78	3	27	87	84	95	84	80	84	73	84
95	84	98	98	51	51	51	51	51	98	98	98	98	56	51	51	67
51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
82	78	84	84	62	84	89	9	67	73	51	84	84	71	84	73	56
73	67	78	73	54	75	73	9	60	80	56	98	84	52	51	56	51
71	62	78	73	24	18	29	3	47	41	34	51	40	29	45	29	12

Figure 2. Sample table of CQ Pre-assessment student scores (2022 South Africa Trip #1)

CQ DRIVE OVERALL	Intrinsic Interest	Extrinsic Interest	Self-Efficacy	CQ KNOWLEDGE OVERALL	Business	Values & Norms	Socio-Linguistic	Leadership	CQ STRATEGY OVERALL	Planning	Awareness	Checking	CQ ACTION OVERALL	Speech Acts	Verbal	Nonverbal
51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
98	98	98	98	92	98	98	84	84	93	78	98	98	62	89	51	45
96	89	98	98	90	92	95	75	98	98	98	98	98	51	67	45	40
98	98	98	98	93	98	98	84	90	95	98	98	84	76	95	56	78
95	84	98	98	73	51	78	75	90	80	73	89	78	51	51	12	89
98	98	98	98	86	98	98	59	87	93	89	89	98	98	98	95	98
56	51	51	67	51	51	51	51	51	51	51	51	51	51	51	51	51
80	78	78	84	61	84	73	18	70	78	73	78	84	74	67	73	84
80	84	84	73	47	26	73	26	64	69	56	67	84	41	51	45	29
62	56	67	62	39	26	62	26	44	47	7	62	73	47	56	40	45

Figure 3. Sample table of CQ Post-assessment student scores (2022 South Africa Trip #1)

4. Results

Our first regression model was formed using the equation…

$$\Delta CQij = b_0 + b_{1*} * year + \sum_{i=1}^{n-1} b2_i * D_i + e_{ij}$$

To break this equation down, we have the change in $\Delta CQij$ for each of the students (Coefficient i) and country (Coefficient j) they attended. This is equal to the pretest score, b_0 plus the post test score, b_1. This is then multiplied by the year the student traveled. This is added to the sum of the country minus the coefficient, $\sum_{i=1}^{n-1} b2_i$. Then this is multiplied by the dummy variables for each country, D_i. Then this is added to the sum of all terms, e_{ij} . This first regression model takes the overall change in the CQ scores and analyzes its dependence on the different countries. This allows us to see the correlation between cultural awareness and the country traveled. We also split the overall CQ equation into the four components of cultural quotient. Those are drive, knowledge, strategy, and action. We then created regression models between pre and post scores for each of these categories. These regressions will be in the tables below.

Model 1		
Variable	Coefficient	P Value
Intercept	3478.58	0.01338001
Year	-1.719	0.01349461
D_SG	6.09	0.09400512
D_SA	2.653	0.37671611
D_NO	-3.15	0.40850394
D_UK	-8.104	0.05114126
D_NL	-2.968	0.5546253
D_TH	10.53	0.00854016

Figure 4. Regression results from equation 1. (Location Data)

Variable	Coefficient	P Value
Intercept	4304.12796	0.0298906
Year	-2.1280265	0.03002979
D_SG	10.1775451	0.04773752
D_SA	9.6018804	0.02413215
D_NO	3.03589981	0.57339278
D_UK	-10.714256	0.06763636
D_NL	-2.7425253	0.6989598
D_TH	17.5838662	0.00193424

Figure 5. Regression results from equation 1A (Drive) (Location Data)

Variable	Coefficient	P Value
Intercept	6497.71545	0.01045387
Year	-3.2158571	0.01051085
D_SG	11.8057074	0.08666718
D_SA	12.5801024	0.05549679
D_NO	4.69059453	0.5069409
D_UK	-9.5616373	0.19394973
D_NL	-6.5272483	0.15346973
D_TH	24.6777141	0.01171082

Figure 6. Regression results from equation 1B (Knowledge) (Location Data)

Variable	Coefficient	P Value
Intercept	1593.09621	0.47776053
Year	-0.7844954	0.4803019
D_SG	3.31344374	0.58836297
D_SA	-1.9466927	0.73841814
D_NO	-2.9199793	0.64306337
D_UK	-8.2696471	0.20764502
D_NL	-1.5433252	0.40131445
D_TH	4.60464826	0.00522335

Figure 7. Regression results from equation 1C (Strategy) (Location Data)

Variable	Coefficient	P Value
Intercept	6161.69925	0.01513842
Year	-3.049331	0.01522093
D_SG	9.60556338	0.16296126
D_SA	6.64402171	0.31031758
D_NO	-4.0848149	0.56346199
D_UK	-7.3259453	0.31938438
D_NL	-2.1227749	0.12387973
D_TH	16.2401811	0.00183242

Figure 8. Regression results from equation 1D (Action) (Location Data)

Our second regression model was formed using the equation…

$$\Delta CQij = b_0 + b_{1*} * year + \sum C_k * x_{ik} + e_{ij}$$

To break this equation down, we have the change in $\Delta CQij$ for each of the students (Coefficient i) and country (Coefficient j) they attended. This is equal to the pretest score, b_0 plus the post test score, b_{1*} This is then multiplied by the year the student traveled. This is added to the sum of the country minus the coefficient, C_k.This second regression model takes the change in CQ scores and measures the Hofstede's score for each country. This is to see if the scores are dependent on one of the Hofstede's dimensions.

Model 2		
Variable	Coefficient	P Value
Intercept	3450.91777	0.0134841
Year	-1.7191862	0.01349461
H_PD	0.51922969	0.25989071
H_INV	-0.0882208	0.88230699
H_MAS	-0.1408274	0.42003558
H_UA	-0.0208459	0.94772604
H_LTO	-0.2320666	0.40001201
H_IND	0.45067694	0.74438244

Figure 9. Regression results from equation 2. (Hofstede Data)

The results of the regression analysis were very interesting. It was discovered that when the country being traveled to is far different from the United States, countries such as Thailand, South Africa, and Singapore, the students endured more growth in terms of cultural awareness. The data showed that overall, these students' Post CQ scores experienced more growth than those who chose to do their experiential learning online or in a country that shares more similar characteristics with the United States (European countries). Our initial assumption going into our research was that, in accordance with location, students would experience cultural awareness to different degrees, even possibly at random. We had expected that the outcome of our analysis would show that developing nations such as South Africa or Thailand would result in a higher means of cultural awareness. While it's certain that each student on these trips likely achieved some improved form of cultural awareness, it is interesting to note that in countries that are farther away leave more of an imprint on the cultural awareness of students. If we had to choose a particular country for the best growth in CQ, the country that scored the best was Thailand. On the other hand, the worst score for CQ was Norway and Netherlands. After conducting our research, we have concluded to accept our hypothesis of how cultural differences between countries will increase the cultural awareness of traveling students.

5. **Conclusion**

The outcome of the conducted research was both informative and useful. It was found that the most improvement in CQ assessment scores was when students completed their experiential learning trips in countries that are significantly different from the United States (Ex: countries found in Asia). The surprising aspect of our research was that we discovered that students who traveled to European countries cumulatively did worse on their post-CQ Assessment. For example, students who traveled to Norway or Netherlands had the poorest scores. Thus, indicating that the cultures between the two nations were very similar. Students who completed their Experiential learning requirement online received better scores than those who traveled to Europe. Using Hofstede's scale measures an individual country's national culture. We suspected there would be a greater increase in growth of cultural awareness if the two countries were less similar than one another.

Hofstede's scale showed that Asian cultures were less like the United States. We saw throughout the CQ scores of the Massachusetts Maritime students, growth from pre-trip to post-trip.

After conducting this research, we hope that maritime institutions and maritime professionals around the world will take the jump to implement these experiential learning opportunities in their institutions. This can be a tool for professionals to use in what countries to send the students and what countries will help increase their cultural awareness. These experiential learning programs are quite expensive to send numerous students to a foreign country for multiple weeks at a time. Professionals want to send their students to countries where they will get the most out of their experience and make their trip worth the money they spend. We hope this data will be used for when faculty can look at how they can improve these experiences. This can be a consistent global tool to help prepare students to enter the workforce and can expand the cultural awareness and intelligence of current maritime workers.

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Environmentally sustainable technology for building composite boat equipment

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Abstract: This paper demonstrates the process of building the seat of a composite boat powered by solar energy for the Monaco Energy Boat Challenge. Composite materials reinforced with natural fibers were used for the construction, which represents a modern sustainable concept in the construction of vessels. The use of composite materials can offer advanced construction solutions in modern marine industry, which can contribute to increased strength, reduced weight, and improved corrosion resistance. With the increase in global environmental awareness, various adaptation to regulations and environmental agendas in the maritime industry, there is an expanding need and desire to use "green" products and materials for the construction of vessels, ships, equipment, and other parts of maritime constructions that will be a segment of sustainable technologies in maritime industry. It is also improving the expansion of environmental awareness among students who, through their future work in practice, can greatly influence the preservation of biodiversity on Earth.

Keywords: sustainability, composites, natural fibers

1. Introduction

Previous research on the topic of using composite materials in shipbuilding has shown that the disposal and recycling of commonly used fibers is becoming a problem. Trends of the future suggest that the use of “green” materials must be made by the designers and manufacturers (Castegnaro et al. 2017). The main advantages of using natural fibers in the making of composites are low cost, lesser weight, better mechanical properties, possibility of recycling, greater source of materials. Still the issues of moisture sensitivity and the influence of cultivation and production on quality must be resolved (Dabrowska et al 2022.).

The use of composite materials can offer many solutions for problems in terms of weight, firmness and corrosion resistance in ship building. In the last decade increased environmental awareness opened the market for small ship building companies to use “green” materials. Composite materials consist of two or more different materials bonded together to form a new material with better physical and chemical properties. This enables fine tuning of material for a specific parts where different properties are necessary. Natural fibers can be an alternative material to glass fibers not only by being sustainable but also by their economic advantages.

Monaco Solar & Energy Challenge is a yearly competition where students are set to build their own energy-efficient boat. Having participated for several years in a row, it became clear that the use of natural fibers was not incorporated in any of the competing team vessels. Therefore, the motivation for this research is a promotion of energy efficiency and environmental sustainability in the maritime industry by building part of the boat equipment using composites made of natural fibers. The task was done by, among others, the students of the Faculty of Maritime Studies Rijeka, Croatia and volunteers of the Croatian Association of Applied Technical Science. With joint effort, a solar composite vessel was built for the purpose of competing in the Monaco Solar & Energy Challenge. In addition to that, this paper deals with new ways of natural fiber application and handling in seafaring.

2. Composite materials and building techniques

2.1. Natural fibers

Natural fibers are primarily designed to replace commonly used carbon, glass and other fiber materials because of their issues of sustainability and non-renewable resources (S Luise et al 2020.). Natural fibers are plant based, so that makes them common and ecologically acceptable because of the possibility to be simply cultivated. Growing plants absorb carbon dioxide and release oxygen which makes them a more desirable in these times of increased environmental awareness. Also, natural fibers are economically more profitable. Most common natural fibers used for polymer composites are jute, hemp, flax and basalt. Green composites are classified as bio composites in combination with biodegradable resins. They are also called “green” because their sustainable and degradable properties which enable them to be disposed of without making any harm to the nature (Nikolla et al 2022.)

Below are listed some advantages and disadvantages of natural fibers (Bhat, K. M. et al 2021.):

- Advantages of natural fibers - renewable source, easy accessibility, possibility of recycling, low price, lower usage of energy while being produced, non-toxic while being handled, low electrical conductivity etc.
- Disadvantages of natural fibers - quality of the product varies depending on the way of production, conditions of cultivation and the grower himself (humidity and climate conditions), natural fibers are prone to rotting if not stored properly etc.

Cultivation process and production of fibers conditions their material properties which are shown in Table 1.

Fiber	Elastic Modulus [GPa]	% Elongation	Tensile Strength [MPa]	Young Modulus [GPa]	Density [g/mL]
Hemp	70	1.6	550-900	30-80	1.48
Flax	60-80	1.2-3.2	345-2000	15-18	1.45
Jute		1.5-1.8	300-700	13-55	1.3
Bamboo		1.4	190-600	21-50	0.6-0.9
Carbon fiber		1.3-1.8	~ 4000	235	1.4

Table 5 Material properties of selected natural fibers (Dabrowska et al 2022.)

2.2. Vacuum bagging

Vacuum bagging as a technique of building composite laminates is one of the most popular techniques because of its simplicity. Except the materials needed for the lamination, vacuum bagging requires additional expendable materials and tools such as rollers, brushes and spatulas which help with the application of matrix to all the fibers and materials used in the laminate. Surplus of the matrix is sucked by the vacuum pump, until it leaves the optimal ratio of matrix and fibers.

Vacuum bagging process implies that, first, the edges of the mold must be degreased so the seal can be properly glued. On a prepared, smooth and degreased mold surface a few hands of release agent are applied so the matrix does not stick to the surface while curing. After preparing of the surface, pre-cut layers of fibers are placed according to the laminate plan and saturated by hand with tools mentioned before until all the parts are equally drenched. Following the last layer of the reinforcement the first technical layer is set, peel ply, which helps absorb matrix excess and prepares the surface for further work by making it rough, afterwards a layer of perforated foil and breather is put in place above all other layers to help with distribution of the vacuum load, they also absorb possible surplus of matrix. At the and a vacuum bag is glued to the seal covering all the layers, to ensure the possibility of vacuum a place for tubes must be enabled from inside the bag, connecting the tube to the vacuum pump the system is ready for vacuuming.

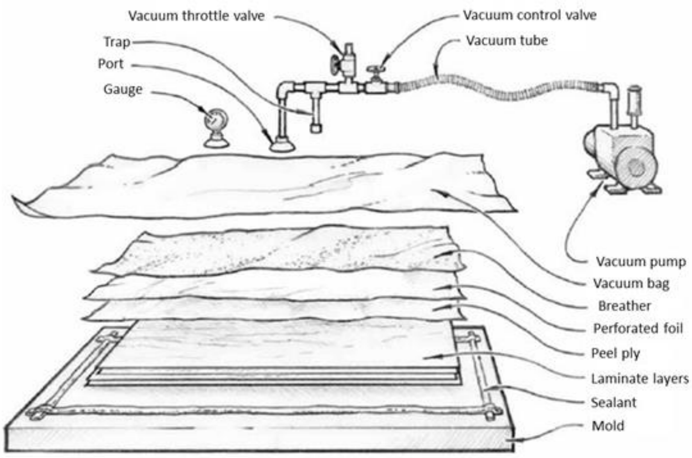

Figure 1. Vacuum bagging process (Geerts et al 2019)

2.3. Vacuum infusion

This process optimizes matrix to reinforcement ratio by compactly pressing down layers of fibers under the pressure of vacuum before letting the resin in the system and filling all the voids. The main difference between vacuum bagging and vacuum infusion is that in vacuum infusion process there is no need for manually saturating the layers, that is done by vacuum so that makes it a cleaner process.

Putting two tubes on each side of the mold with valves to regulate the pressure enables the resin to be sucked on the one side and pulled by the vacuum pump on the other side. The layers do not differ from the layers in vacuum bagging process except one, that is the layer of infusion mesh which secures the flow of the resin trough the laminate, Figure 2.

Figure 2. Seat vacuum infusion.

3. Construction and building of a seat

When constructing the seat for a competition boat, following measures were taken from the pilot: 186 cm tall, 81 kg in weight. Following pilot's measures, the constructed seat was 47 cm wide, the length of the back rest measured 60 cm, while the seat itself was 50 cm in length. After modeling, 5 cm are added so that ultimately the seat would be cut, to entirely follow the contours of the vessel, and to accommodate additional gear that was necessary to pass the technical inspection (fire extinguisher, hand pump, etc.).

While building a composite seat, an important part of the making is choosing the type of the mold. There are two types of molds, female and male. For the purpose of the seat building, the chosen mold was the female type because of the finishing look and the order of reinforcement layers. The mold was built of plywood and the surface of the mold was made from a thin poplar wood sheet covered with two layers of hand laminated glass fibers for rigidity of the mold. To ensure a fine finish, the surface of the mold was smoothened with layers of body fillers later sanded and painted. The paint was later wet sanded and polished to until a glass like surface is accomplished, to ensure that the laminate does not stick.

The materials used for the seat were two layers of twill flax fibers, one layer of biaxal flax fibers and the finishing layer was a net made from a combination of hemp and linen commonly known as *PowerRibs* which ensures the rigidity of the laminate with minimal weight but also works as a flow media during the infusion process.

4. Results

After the infusion, curing of the laminate and separation of the mold the product is revealed. The seat has a layer of unclean resin. To get rid of the unclear layer the seat is wet sanded and polished until the surface of the seat is clean and clear revealing the flax fibers, Figure 3a).

Figure 3. a) Final product. b) Competition boat at sea trials.

5. Discussion and conclusion

Cutting the seat to follow the contours of the boat, the seat was mounted close to the keel which helped with the stability and mandatory test of pilot evacuation. Later on, a grip tape was added to the seat to help with sliding during slalom races. Sea trials and the final competition race proved that the design and the choice of material was adequate, Figure 3b). The seat was capable to withstand the static and dynamic stresses imposed to it. Also, it proved as a weight-saving option comparing to traditional seat construction. As is has been written through this paper, with increasing environmental awareness more and more of green materials will be used. Parts like this seat are only the beginning for these types of reinforcements and with new research and innovations these types of materials will surely be a worthy replacement for traditional materials.

Acknowledgements

This research was funded by the University of Rijeka, Faculty of Maritime Studies, under the project "Marine Composite Materials Recycling and Re-use".

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Paving the Way for the Introduction of Code for Autonomous Vessels: Critical Review of Regulatory Framework for Safety of Navigation

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Abstract: The shipping sector is unique in its nature. Its primary goal is to progress innovation and new technologies to ensure sustainable supply of goods, as it is established in the SDG 9. For what many authors refer to as the fourth industrial revolution, autonomous ships are a reality. MASS degree IV, in essence, is a vessel that won't require any human involvement to complete even the most complex tasks, such as SAR missions. The necessity of the human element onboard for compliance with the regulations is a clear expression of the safety of navigation as governed by chapter V of the SOLAS convention. The purpose of this study is to assess Chapter V of the SOLAS convention in relation to the value of the human element onboard the ship in the widest range of circumstances and whether or not the MASS degree IV will necessitate a new regulation. The document also critically analysis the outcome of the Regulatory Scoping Exercise conducted by IMO addressing the debate of how to amend the existing regulatory framework and its relationship to Chapter V of SOLAS. Findings of the study suggested that a separate regulation is required to ensure compliance with MASS degree IV. The authors do insist that a deeper understanding of the operational nature is required for smooth introduction of MASS degree IV.

Keywords: MASS (Maritime Autonomous Surface Ship) Code; SOLAS (Safety of Life at Sea); Safety of Navigation; Maritime Safety

1. Introduction

With the advent of sailing, human species entered a new age of transportation and trade using the sea and ever since we have been developing rules and regulations to govern the sector. There has been negligible technological advancement in the shipping sector for the past five centuries. The scenario changed with the introduction of steel ships and steam engines. Shipping has never seen such a phenomenal advancement in technology in last 100 years. A rapid advancement in technology has always found us wanting towards updating rules and regulations. Many-a-times major incidents were required like HMS Titanic or Herald of Free Enterprise to overhaul the governing framework which provides a safe and secure shipping sector (Schröder-Hinrichs et al., 2013). Regulatory framework has always been lagging behind the technology. First time in the history of the shipping industry, we are making an effort to update and overhaul the regulatory framework in anticipation of the introduction of new technology which is Maritime Autonomous Surface Ships (MASS). Some authors believe that MASS will be a reality in the twenty-first century. As per Kretschmann et al., cargo carrying MASS can be a reality within the next 10-15 years (Chou et al., 2022).

As per the Regulatory Scoping Exercise (RSE) for introduction of MASS, Safety of Life at Sea (SOLAS), Chapter V - Safety of Navigation is one of the high priority instruments which needs to be reviewed for development and introduction of MASS. The human interface with machines plays a major role in Chapter V. This paper will systematically examine all regulation dealing with human presence onboard in light of MASS degree IV, which deals with fully automated vessel able to undertake all aspects of a ship's operation without the need for human intervention which includes entering and leaving a port, berthing and unberthing and navigation at sea to name a few. The main aim of the paper is to bring out the impact of exclusion of humans from the decision-making matrix onboard a ship and how the instrument needs to be amended for the introduction of MASS.

2. Discussion on Present Regulation and Human Presence Onboard

Analysis of SOLAS Chapter V based on the significance of the human presence onboard and their functions, highlights that out of 34 plus 2 regulations 18 regulations directly pertain to human presence onboard. For critical examination, these regulations have been clubbed into five categories. These categories were developed with the goal of demonstrating the value of the human element onboard in a specific area and, as a result, the viability of introducing MASS in context of SOLAS Chapter V and how it affects the instrument as a whole. All five categories are discussed in the succeeding paragraphs along with the role of human beings onboard and what it implies for introduction of MASS.

Table 1 - Categorisation of Regulations Pertaining to Human Presence Onboard

Category	Regulations Covered	General Theme of the Regulations
Warning and Communication Services	Regulation 4 and 5	Both regulations applies to the contracting Government and deals with transmission of information about navigational and meteorological warning to the ships at sea
Search and Rescue	Regulation 7	This regulation covers the state's responsibility towards the Search and Rescue (SAR). This single regulation has been kept alone in one category because of the unique nature of SAR services and requirement of human presence onboard ship for providing such services
Role of Master	Regulations 11, 14, 16, 34 and 34-1	These regulations deals with issues which requires a direct intervention of the Master for safe navigation of the ship, the emphasis on the discretion which a Master exercises in his capacity as competent personnel onboard ship
Role of Crew and Pilot	Regulations 15, 19, 23, 26, 28, 31 and 32	These regulations cover issues which need to be dealt with by humans onboard the ship such as transmission, reception and understanding of danger messages. Role of Pilot and his responsibility in ensuring safety of the ship is also covered in the regulations.
Ship Design and Technology	Regulation 22, 24 and 25	The regulations covered in the category are those which relate to the design and equipment fitted onboard ship and its utility for the humans presence onboard ship.

2.1 Category 1- Warning and Communication Services (Regulation 4 and 5)

Ship-to-ship and ship-to-shore navigational and meteorological warnings are crucial for maintaining safe and secure shipping. At present the system relies heavily upon the presence of humans onboard for analysing the data presented in text or graphical form (Munaf and Halida, 2015). Both regulations talk about the responsibility of the contracting govt. in setting up and maintaining the services and are not directly related to the ship. However, the outcome of these regulations is to utilize such information for safe navigation. A human mind is required to comprehend and analyse the data received, as oftentimes, what appears on paper is not the true reflection of the external environment.

As per regulation 5.2.7, when facing tropical cyclone, the ship is expected to take regular observations and transmit the same. In such extreme conditions malfunction of met equipment cannot be ruled out and the role of the officer on watch becomes more important. Will MASS degree IV be able to perform the task of humans in such a situation is something which needs to be answered in detail and considered carefully. Therefore it is necessary to develop a robust system based on research and technology that will be able to replace human intelligence and experience with artificial intelligence so as to ensure safety of navigation.

The shipping industry has been human centric from its nascent stage. The legal framework and regulations developed for over 200 years are based on the concept that humans are always present onboard a vessel. The next two categories will discuss the role and responsibility given to humans onboard ship and what is expected w.r.t Safety of Navigation. As per various regulations in Chapter V, the Master, the Pilot and Crew have different roles and responsibilities towards safe navigation of the vessel.

2.2 Category 2 – Search and Rescue (Regulation 7)

SOLAS convention primarily deals with the safety of life at sea and one of the major aspects for safety of life in the Search and Rescue (SAR) services provided by the contracting states. Regulation 7 of Chapter V lays forth the conditions and obligations of the states for the SAR facilities, with due regards to existing navigational danger and other factors in their areas of jurisdiction. Merchant ships at sea also form part of the SAR system. This is possible because of the presence of humans onboard, who can comprehend and undertake the complex SAR operation.

The authors contend that regulation 7.3. is more significant, for this discussion. The existence of an evacuation strategy plan for passenger ships by the flag state and the company, is required under this convention. This is carried out by the ship's crew in an emergency to prevent needless loss of life. The Costa Concordia accident is an example of the application of the emergency plan established by the regulation, which resulted in minimum fatalities because, according to sources, the ship's crew was able to evacuate panic stricken passengers from the ship effectively despite adverse conditions which the ship was facing due to a well-rehearsed plan which was executed by the crew of the ship (Bartolucci et al., 2021).

It is opined by the authors that regulation 7 is in consonance with International Maritime Search and Rescue Convention (IMSAR), 79 due to the presence of humans onboard. However, with the introduction of unmanned vessels at sea, the role played by vessels in SAR operations requires more deliberation and consideration. Especially in case of unmanned passenger ships the evacuation of passengers can be a challenge and needs consideration and clarification. SAR services provided by the merchant ship with human onboard cannot be replaced by unmanned ships.

2.3 Category 3 - Role of Master (Regulations 11, 14, 16, 34 and 34-1)

The captain of the ship is in charge as well as accountable for everything that occurs. Bielic et al. (2017), in his study extols the ship's captain as being in charge of safety onboard. All the regulations defining the role of Master gives final authority and accountability to the master of the vessel. The Master's leadership qualities, his influence on the crew and safety culture developed onboard plays a vital role in compliance with the regulations of Chapter V w.r.t. his role.

Regulation 11 emphasizes the responsibility and significance of the ship's master in reporting all information required as per the applicable reporting system to the appropriate authority. It is at the discretion of the master for reporting said information and to the extent which it is to be reported. In the maritime industry of the nineteenth century, a ship's master played a crucial role. He had to take action not just to protect the ship, its crew, passengers, and cargo but also to make choices on the owners' behalf (Due, 2013). While acting on behalf of the company, the master ensures safe manning and rotation of personnel and establishes a working language onboard in accordance with regulation 14. Nothing in the entire convention brings out the importance of the role of Master as Regulation 16 does. It is the Master of the ship, who is supposed to take all possible factors into account while sailing from a port with inoperative equipment or missing information. The safety of the ship is based on the decision taken by the Master with all his experience (Vojković & Milenković, 2020). Similarly, the Master's discretion is expected in regulation 34 and 34-1.

The question of how a ship will anticipate and develop these capabilities after the implementation of MASS degree IV still has to be answered because it typically depends on the master's personality, skill set and most importantly the present situation. In accordance with the regulations, the introduction of MASS will only be feasible if the ship is autonomous enough to analyse the situation and decide based on the information available to the system. Once again, the decision-making process is a key point for the ship and this is the responsibility of the master of the ship.

2.4 Category 4 – Role of Crew and Pilot (Regulations 15, 19, 23, 26, 31 and 34)

A ship can be considered as a system of systems in which the master holds the ultimate authority. But he cannot always be present at all positions, so the crew is there to assist him in performance of his duties. The complexity of the ship makes it necessary that the crew and in some cases pilot perform various functions to ensure safe navigation (Demirci et al., 2023). Regulations in this category cover such roles and responsibilities of the crew and the pilot.

The provisions contained in regulations related to the role of ship's crew are essentially dealing with requirements which the ship's design has to meet to ensure safe functioning of the vessel. Also, regulations like 31 and 32 relies on human intelligence to process the information which is required to be transmitted and in what sequence. Testing of steering gear and drills required to be performed as per regulation 26 can be performed exclusively by the personnel onboard. Regulation 23 speaks about the pilot transfer arrangement which only works if there is some crew available onboard. With no seafarer present onboard transfer of pilot will not be possible and such regulation will have no meaning. It is important to emphasize the role of the pilot, who possesses the local knowledge of the area which assists in safe navigation of vessels in restricted waters near ports (Carrey, 2017).

Substituting the crew onboard a ship is not an easy task. Because the process of decision making and critical thinking is a trait that is unique to humans. Replication of the human brain in the form of an Artificial Intelligence (AI) is a difficult task to achieve and may require a high level of technology. MASS degree IV may be able to perform the task designated to the crew and pilot onboard in due course of time. However, it is considered best to develop a new governing framework for the introduction of MASS degree IV vessels at a commercial level.

2.5 Category 5 – Ship Design and Technology Onboard (Regulation 22, 24 and 25)

Conventional ships are designed and built keeping the presence of humans onboard as the core concept. The equipment and machinery are so placed as to assist human beings in controlling the ship and handle any possible scenarios (European Maritime Safety Agency, 2023). All the regulations in this category describe the design of the bridge and placement of equipment like heading and/or track control system so as to assist the personnel present onboard in navigating and operating the ship at sea. Regulation 24.3. and 24.4. provides the interface between the machinery and human element onboard the ship with the possibility of changing from the automatic steering system to the manual and vice versa. The procedure requires human presence and cannot be undertaken by AI. With the advent of MASS degree IV, the usage of bridge and other control rooms will significantly reduce as there is no one present onboard to monitor the input and the output of the system. Existing regulations will not have much meaning and application. A new regulation with new specifications accommodating unmanned vessels will be required.

3. Critical Analysis of RSE w.r.t. SOLAS Chapter V and Risk Assessment of Absence of Human Element Onboard

3.1 Warning and Communication Services

There was consensus amongst all participating member states and agencies that, both regulation 4 and 5 is not relevant for MASS operations and even if relevant than no change in the text is required as the regulations are applicable to the Governments and not to the ships. However, both the regulations oblige the contracting govt to collect data of navigational danger and meteorological nature (International Maritime Organisation [IMO], 2012). Majority of the time this data is provided by the ships at sea. Some of the very common examples for the navigational warning data is the reporting of a semi-submerged container or half-sunken boat at sea, this is possible only because of the presence of human onboard in the form of look-out (IMO, 2009). In a similar manner the most accurate meteorological data is provided by the ships at sea, failure or malfunction of met equipment onboard ship is not uncommon during the voyage, however, with the presence of human onboard, the recording of met data can be moderated in case of faulty equipment. With the introduction of MASS such information or data from a MASS degree IV vessel may not be available in the first place; even if available, then the AI will depend of the met equipment for the data, which could not be verified as no human in present onboard. Also, as per regulation 5.2.1, the warning of gale, storms and tropical cyclones as transmitted in text and, as far as practicable in graphical form. Such information is transmitted either from a shore-based facility or a satellite. It is to be ensured that MASS degree IV vessel can process such information and take decision, in case such information in the form of text or graph cannot be used by MASS, then a standardized uniform format needs to be developed which can be used by both conventional ships as well as MASS.

3.2 Search and Rescue Services

12 out of 14 members who commented on the topic agrees that the topic is relevant for MASS and can be implemented by MASS operations, however, the regulation needs to be amended or clarified and/or may contain

some gaps. As per the comments from France the regulation 7 is applicable to MASS, however its compatibility with SAR 79 conventions needs to be ensured. This brings out the fact that MASS vessels must be able to participate in SAR operations when required. The Republic of Korea also holds the same opinion that the rescue scope of MASS must be considered for the regulation to be effective. Major concern was highlighted by the Netherlands towards the unmanned passenger ships and how the system will function in case of an eventuality in the absence of well-trained crew onboard to assist.

Absence of humans onboard does not on prima facie affect the provision of regulation 7 which primarily speak about the responsibility of the contracting government in establishment and operations of SAR facilities. However, without crew onboard, the vessels may not be able to comply with the true purpose of the regulation which is to provide SAR services at sea. There exists a need to analyze the impact which MASS will have on SAR 79 before we can say that MASS can be implemented in light of regulation 7 of Chapter V.

3.3 Role of Master

During the RSE one of the major gaps that were identified was the meaning of master for MASS degree IV (IMO, 2021). For all the regulations which speak about the role of master onboard ship, the common theme for the comments was, who, if at all anyone will carry out the duties of the master of the vessel.

Clarification towards the role and authority of the master onboard a vessel is a topic which needs detailed study. Majority of the participating members and agencies also agree to the fact that this aspect can be dealt with the development of a new regulation, as major amendments to the existing framework may disturb the balance and uniformity of other conventions which closely relate to SOLAS. It is a unanimous agreement between all participating members that to resolve this issue a new instrument needs to be developed which governs only MASS and its application. In the view of the authors also, the role and responsibilities undertaken by the master of a vessel will be difficult to replicate by AI, the only possible solution is to write a new framework for MASS with due consideration to absence of humans onboard.

3.4 Role of Crew and the Pilot

During the RSE it was brought out that, regulations 26, 28 and 32 are all relevant for MASS operation and requires further clarification and/or contains some gaps. There exist differing opinions for applicability of regulations 19, 23 and 31, whether these regulations are compatible with MASS degree IV or requires some amendments/clarifications and/or contains some gaps. Regulation 15 has consensus that it is relevant for MASS operation and cannot be implemented by the MASS. There exists a gap in the definition of the terms like ‘role and interaction of bridge team and pilot’, ‘responsible officer’ and ‘role of pilot’ which needs to be defined in coordination with industry developing MASS degree IV. With no crew onboard regulation 15 cannot be compiled with MASS degree IV. Similarly, pilot transfer arrangements (regulation 23) which dictates safe embarkation/disembarkation of the Pilot is only possible due to the presence of crew onboard which can operate the rigging. Also, the requirement of compulsory pilotage which is a port state prerogative needs to be considered while discussion of MASS degree IV operations. Various activities like pilot communication with the vessel, pilot onboard ship and transferring control to pilot for pilotage also needs consideration. A complete overhaul of the requirement as per the legal framework or introduction of new regulations are required for smooth functioning of MASS degree IV for all aspects of ship operations.

3.5 Ship Design and Technology

There exists consensus during the RSE about regulations 22 and 24 that the operation of MASS degree IV does not confer with these regulations. These regulations are the tools to assist the work of human onboard ships. The specification of the bridge visibility does not apply in case of MASS degree IV due to the unmanned nature of the vessel and also the manual steering concept needs revision. All member states agree that regulation 25 can apply to MASS degree IV vessels as it is and does not hinder MASS operations. The absence of seafarers onboard ships will vary the requirement of bridge design vastly. Also the functional checks of the manual steering system cannot be undertaken. Need exists for the discussions, in coordination with the industry developing MASS degree IV about the possibility of inclusion of manual override for the operation of the vessel, in case of any eventuality. If such a requirement is realized then inclusion of coining position and manual control in the ship will be a requirement and needs to conform with regulation 22 and 24. There is a resounding majority for the development of a new instrument which deals with the design and technical specification of vessels in MASS degree IV.

4. *Conclusion*

Development in the field of MASS is progressing at a fast pace, fully autonomous vessels will soon be introduced in the main line shipping industry. This paper aimed at bringing out the importance of human presence onboard as per SOLAS Chapter V (Safety of Navigation) and how, if at all, it can be replaced by AI. The paper discussed in detail various provisions relating to human presence onboard, with special emphasis on the role of the Master, Crew and the Pilot. A critical analysis of the RSE was then conducted which brought out various concerns about the introduction of MASS degree IV. All member states and participating agencies are of the opinion that development of a new instrument is the best possible way moving forward with the development of MASS. However, the authors are of the opinion that a deeper understanding of the operational nature is required for MASS degree IV to work. Such as, amalgamation of MASS is SAR facilities, definition of Master, role of crew and pilot and modification of design of bridge & associated system. MASS is the future of the shipping industry and it is inevitable. Best we can hope for is to develop a regulatory framework which can introduce MASS degree IV smoothly in the main line shipping industry.

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Band Bending Mechanism in Dye-Sensitized Solar Cells Using Ruthenium and Indoline Dyes

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Abstract: Dye-sensitized solar cells (DSSC) have been developed as a method of power generation using renewable energy. Unlike conventional silicon solar cells, these cells are more flexible, can be installed in a variety of locations, and are expected to be used in marine environments. We have been using ruthenium dye (N719) and indoline dye (D131) as sensitizers for DSSC. Those are known to exhibit excellent photocatalytic properties. In this study, with the aim of investigating the properties of these dyes when used in a marine environment, electrodes sensitized with N719, D131, and a mixture of the two dyes were prepared, and experiments were conducted to investigate the photopotential and dye adherence. The results showed that the mixed dye exhibited superior photocatalytic properties, and removal of the dye was also suppressed.

Keywords: Dye-Sensitized Solar Cell, Band Bending, Renewable Energy

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1. Introduction

Among various power generation systems that use renewable energy, solar power generation is relatively efficient and can be used on large vessels such as car carriers. There are several types of solar cells, but silicon solar cells are currently the most widely used. Silicon solar cells are relatively efficient but have the disadvantages of high manufacturing costs and rigidity, which limit the locations where they can be installed.

Dye-sensitized solar cell (DSSC) can compensate for the disadvantages of silicon solar cells because they are less expensive to produce, more flexible, and can generate electricity even in low-light conditions. By taking advantage of these merits, the number of installation locations can be increased and more light energy can be utilized. In maritime industry, DSSC will be able to make a significant contribution to the realization of a sustainable society.

The DSSC consists of three parts: a dye semiconductor electrode, an electrolyte, and a counter electrode [1]. TiO_2, which has high light absorption and photocatalytic properties that assist in electron transfer, is used as the semiconductor electrodes. In addition, in our laboratory, seawater is used as the electrolyte and copper oxide as the counter electrode, expecting that the DSSC will be used in an actual marine environment. Copper oxide is an inexpensive and resource-rich material that can contribute to increasing the number of installations in seawater. Figure 1 shows the mechanism of dye semiconductor layer (dye sensitized TiO_2 layer) which receives energy from light and excites electrons. TiO_2 has a valence band filled with electrons and a conduction band empty of electrons. Similarly, dye has HOMO (Highest Occupied Molecular Orbital) and LUMO (Lowest Unoccupied Molecular Orbital). Therefore, band gaps exist between them. To work as a functional dye, electrons accumulated in the HOMO must cross the band gap and move into the LUMO. The band gap represents the minimum energy required for an electron to be excited and move into the LUMO, and in DSSC, it utilizes light energy. When light strikes the dye, the energy excites electrons in the HOMO to move into the LUMO and flow along the band bending formed between the dye, TiO_2 and substrate into the electrode. Band bending is formed as electrons move across dye, TiO_2, and substrate until the redox potential of dye and the respective Fermi levels of TiO_2 and substrate match when they are contacted with each other and in equilibrium [2]. Excitation of electrons to the LUMO and the presence of band bending are important for DSSC because electrons tend to move to lower energy levels.

In this paper, a ruthenium dye (N719) and an indoline dye (D131) are used. N719 has a relatively small band gap of 2.33 eV between -5.34 eV (HOMO) and -3.01 eV (LUMO) [3]. Therefore, N719 shows excellent photocatalytic properties as a sensitizing dye and is widely used as a sensitizing dye for DSSC [5]. D131 has a band gap of 3.00 eV between -5.16 eV (HOMO) and -2.16 eV (LUMO) [4]. D131 acts as a co-adsorbent and is expected to have better photocatalytic properties when mixed [6]. Also, TiO_2 has a band gap of 3.20 eV between -4.26 eV (conduction band) and -7.46 eV (valence band) [3].

We investigate photocatalytic properties of electrodes with N719, D131, and a mixture of the two dyes as sensitizers, as well as the relationship between the band bending and photopotential, to confirm which dye exhibits superior photocatalytic properties in marine environment.

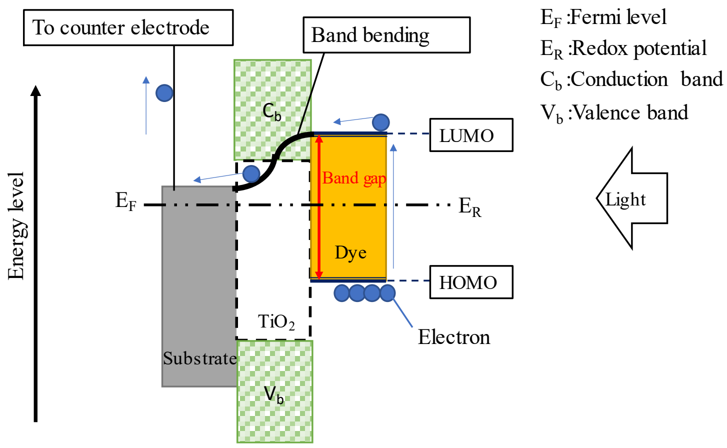


Figure 1. Band bending mechanism of dye sensitized semiconductor electrode

2. Methods of Experimental

2.1 Electrode Preparation Procedure

The procedure for preparing sensitized electrode is shown in Figure 2, and the method of preparing each layer is described.

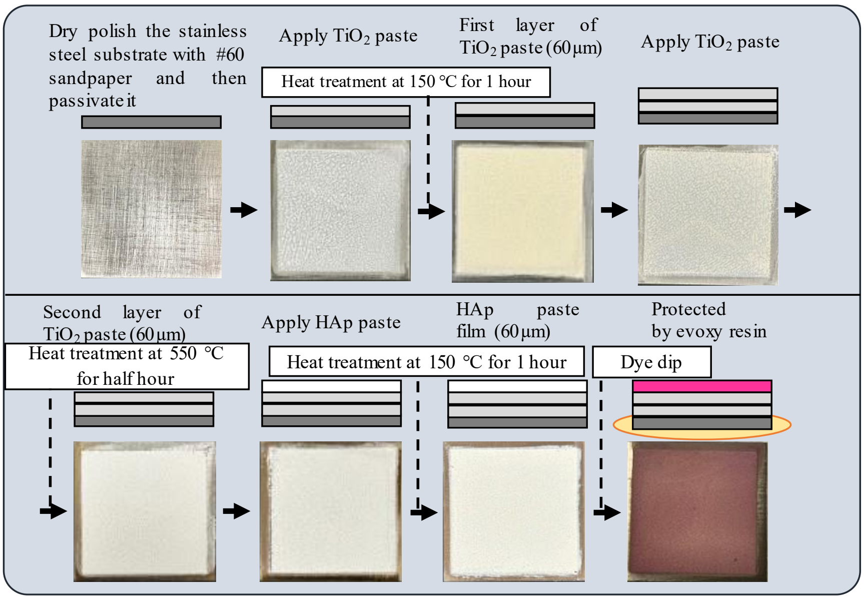


Figure 2. Preparation process of dye sensitized TiO_2 electrode

Type 329J4L stainless steel with the composition shown in Table 1 was used as the electrode substrate. 40 mm × 40 mm samples were dry polished with #60 abrasive paper to make a lattice groove, and then cleaned with acetone for 10 minutes (28 Hz, 45 Hz, and 100 Hz repeatedly for 20 seconds each minute) using an ultrasonic cleaner. The samples were then passivated in nitric acid aqueous solution (10 wt. %) in a constant temperature water bath at 60°C for 30 minutes.

Table 1. Chemical composition of Type 329J4L stainless steel (wt. %)

C	Si	Mn	P	S	Ni	Cr	Mo	S	W	N	Fe
0.024	0.47	0.71	0.031	0.001	6.45	24.71	3.25	0.001	0.12	0.17	Bal

TiO_2 electrode was prepared in two layers using TiO_2 paste with compositions shown in Table 2. The first layer was formed by applying the paste with a thickness of 60 μm using the squeegee method, heat treating in a dry oven at 150°C for 1 hour, and cooling in oven. The second layer was formed by proceeding in the same process, then heated at 550°C for 30 minutes in a muffle furnace and cooled by natural cooling. The squeegee method is shown in Figure 3.

Table 2. Chemical composition of TiO_2 paste (wt. %)

TiO_2	PEG2000	C_2H_5OH	CH_3OH	Pure water
16	1~10	5~15	0~1	Bal

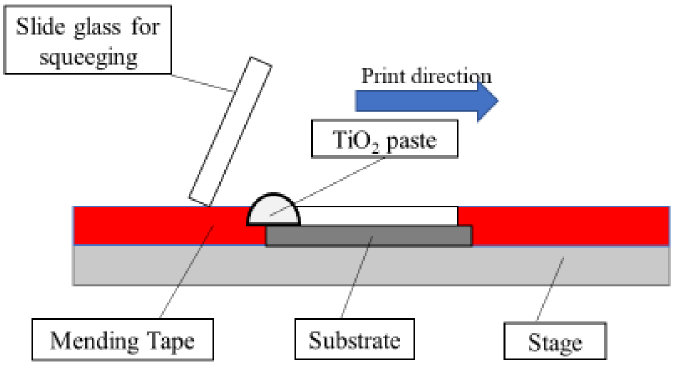


Figure 3. Schematic representation of paste dispensing by squeegee method

HAp is a co-catalyst and its main role is to support dye sensitizing. The composition is shown in Table 3. The coating method was the same squeegee method as in TiO_2 electrode, and after coating, the film was heat-treated in a dry oven at 150°C for 1 hour and then air cooled.

Table 3. Chemical composition of HAp paste (wt. %)

HAp	Ethanol	Triton-X	Pure water
14	43	14	29

Ruthenium dye (N719) and indoline dye (D131) were used for dye sensitizing. The solvent was prepared by mixing t-butyl alcohol and acetonitrile at room temperature in a volume ratio of 1:1 and stirring for 15 minutes. Then, N719 or D131 was added and stirred for 1 hour, and the dye solution was dispersed in an ultrasonic cleaner for 10 minutes (28 Hz, 45 Hz, 100 Hz repeatedly 20 seconds each minute). The mixing ratio of dye solutions prepared in this study is shown in Table 4. Dye sensitizing was performed by immersing the sample electrode in 500 ml of dye solution for 8 hours at room temperature.

Table 4. Chemical composition of dye solutions

	N719	D131	Mixture of N719 and D131
Acetonitrile	250ml	250ml	250ml
T-butyl alcohol	250ml	250ml	250ml
N719 dye	4mg	-	4mg
D131 dye	-	4mg	4mg

2.2 Photopotential measurement

Experimental setup for photopotential measurement is shown in figure 4. Light from a xenon lamp, as the light source, was irradiated the electrode through the transparent glass in a wavelength range of 250 to 800 nm and a lamp power rating of 150 W. The light intensity to the substrate surface was adjusted at 10.5 mW/cm². The tank was filled with artificial seawater and potentiostat was used for the photopotential measurement of dye sensitized TiO_2 electrode.

Measurements were taken for 2 hours. After 3 minutes of measurement in a dark condition, light was irradiated by a xenon lamp, and the change over time of photopotential was measured. Standard Calomel Electrode (SCE) was used as the reference electrode.

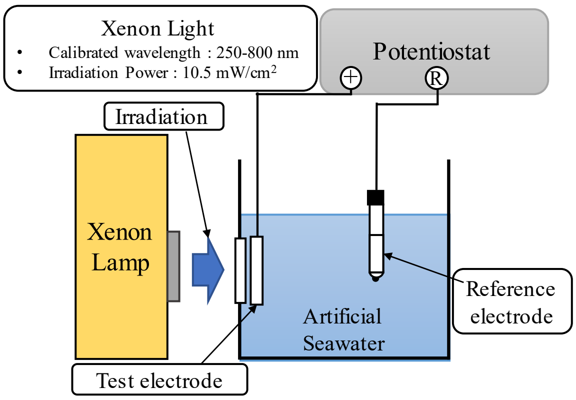


Figure 4. Schematic representation of experimental photopotential measurement

3. Experimental Results and Discussion

Electrodes coated with HAp on titanium dioxide film were sensitized with three types of dye solutions: N719 dye, D131 dye, and a mixture of N719 and D131. Figures 5 and 6 show surfaces of the three types of electrodes and the changes over time of the photopotential, respectively.

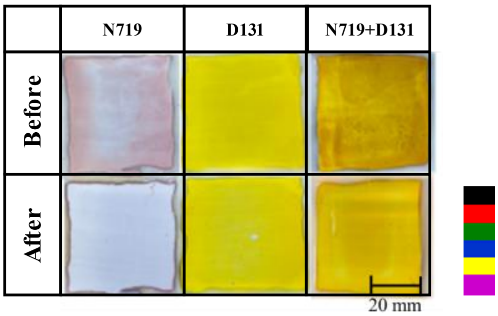


Figure 5. Electrode surfaces before and after experiment

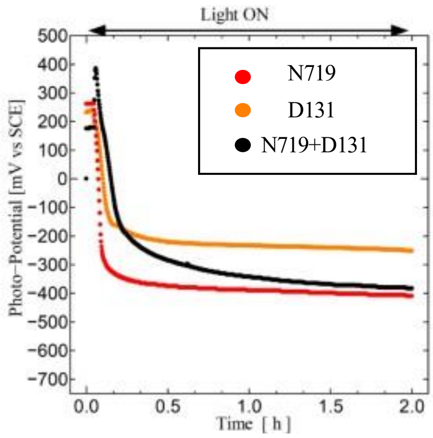


Figure 6. Photopotential of electrode over time

3.1 Removal of dyes from the electrodes

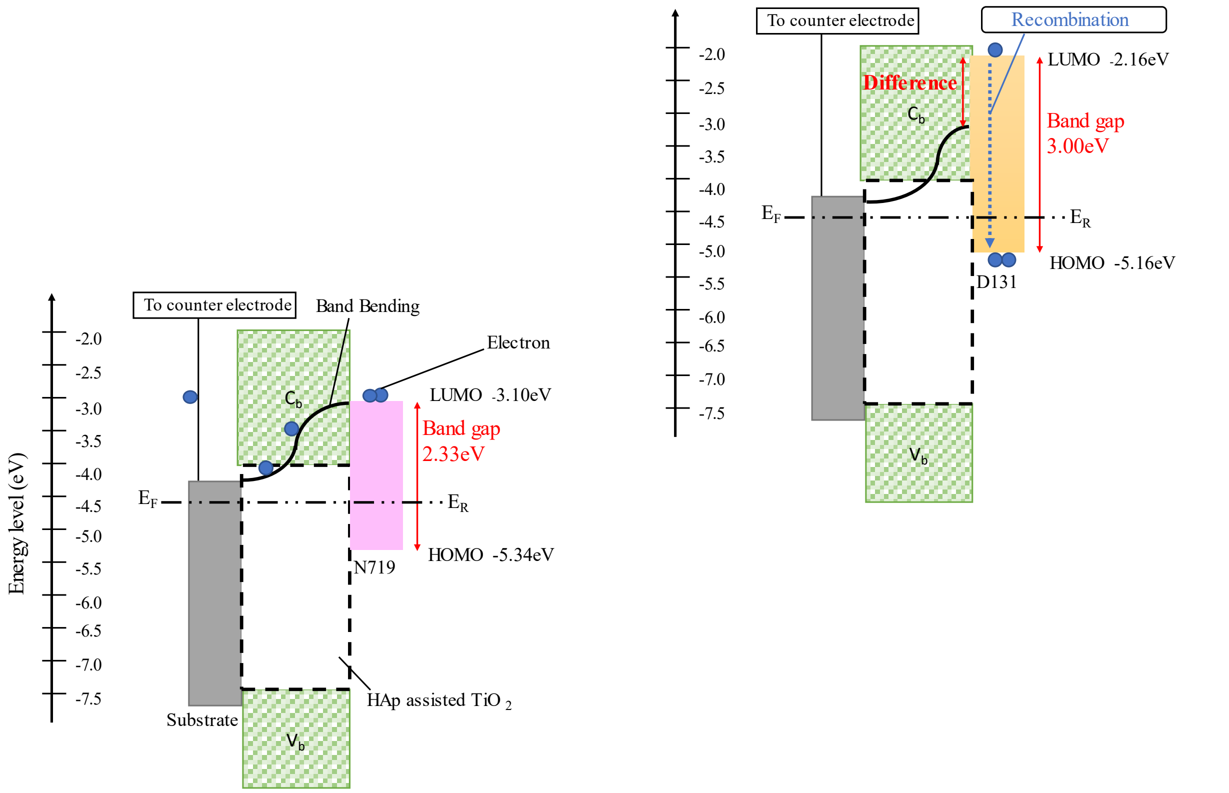
As shown in Figure 5, for electrode with N719, the dye did not attach easily to the electrode, as in the image before the experiment, and was removed almost completely after the experiment. For electrode with D131, the dye attached well to the electrode and was not removed after the experiment. For electrode with N719 and D131, the dye also attached well to the electrode. The color was considerably darker than electrode with D131, suggesting that the amount of N719 attached to the electrode had increased. After the experiment, the color of the dye became a little faded, but since it was darker than the color after the D131 experiment, it is thought that N719 was not removed and remained.

The reason of N719 removal is the decomposition of the dye due to the photocatalytic effect of TiO_2, which is known to generate strong oxidizing effect on its surface when exposed to light, decomposing and removing harmful substances such as organic compounds and bacteria that come into contact with it [7]. This action may decompose and cause the removal of dye. The other reason is due to seawater being used as the electrolyte. N719 dye has a carboxylic acid group (-COOH), which forms an ester bond with the hydroxyl group (-OH) on the TiO_2 surface, and the ruthenium dye is chemically fixed in a single layer on the TiO_2 surface [8]. However, this ester bond is easily hydrolyzed by moisture in the electrolyte, and the sensitizing dye is removed from the TiO_2 surface [9]. Furthermore, it is known that the presence of chloride ions Cl^- in the aqueous solution causes adsorption of chloride ions and hydroxide OH^- ions on the metal surface [10]. This action is thought to cause ester bond breakdown and dye removal.

On the other hand, the addition of D131, a co-adsorbent, considerably suppressed the removal of N719. This indicates that mixing D131 with N719 changes the adsorption structure of N719 and has a positive effect on dye sensitizing and properties of photocatalysis.

3.2 Band bending mechanism and Photocatalytic properties of electrodes

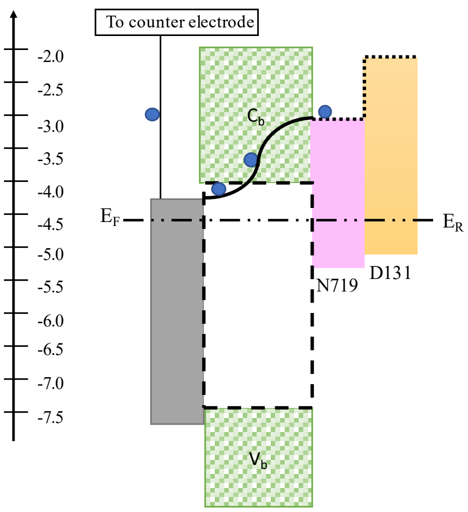
From Figure 6, photopotential of electrode with N719 decreased to about -400 mV, the most active value. Electrode with D131 decreased to about -200 mV, about 200 mV more noble than electrode with N719. Electrode with N719 and D131 decreased to about -400 mV, about the same as that of electrode with N719, which showed the most active potential.



(a)Electrode with N719 (b) Electrode with D131

(c)Electrode with mixed dye

Figure 7. Band bending mechanism of each electrode



The mechanism of band bending greatly affects photocatalytic properties. In the case of electrode with N719, excellent photopotential was measured immediately after the measurement, suggesting that a band bending smoothly down to lower energy level was formed as shown in figure 7(a). However, N719 showed removal of the dye over this experiment, which was expected to cause a change in the photopotential, but after an initial drop, it stabilized at a constant value. It was not possible to confirm in this experiment how the photopotential of electrode with N719 would change without removal. The photopotential of electrode with D131 was about half that of electrode with N719, and although there was no removal, the potential initially decreased and then remained constant. The reason for this is the process of recombination. It is a phenomenon that excited electrons in the conduction band recombine with holes from the valence band and return to their ground states, which negatively affects the efficiency of DSSC [11]. The large difference in energy levels between the LUMO of the dye and the lower end of the TiO_2 conduction band created a band gap, and the excited electrons could not move and were returned to the HOMO by recombination, as shown in Figure 7(b). The final photopotential of electrode with mixed dye was almost the same as that of electrode with N719. Unlike the others, the potential continued to decrease gradually at the end of the experiment. This indicates that mixing D131, a co-adsorbent, with N719 suppresses the removal of N719 and that D131 does not interfere with the function of N719, thus maintaining the excellent photocatalytic properties of N719. As shown in Figure 7, the difference in energy levels between the dye and TiO_2 is reduced by N719, suggesting that recombination is reduced.

4. Conclusion

In this paper, to confirm which dye exhibits superior photocatalytic properties in marine environment, we investigated photocatalytic properties of electrodes with N719, D131, and a mixture of the two dyes as sensitizers, as well as the relationship between the band bending and photopotential. As a result of the experiment, electrode with N719 was found to have an excellent band bending mechanism. And it was also found that mixing D131, a co-adsorbent, with N719 having a small band gap, suppresses removal of the dye, and gives a relatively active photopotential in marine environment.

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Running miles and running lines, can seafarers do both while being happy?

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Abstract: Seafarers spend half or more of their life at their workplace, a workplace that controls their sleep, social connections and their access to physical activity. It is well known today that physical activity can positively impact areas in life that affect well-being. But does physical activity impact seafarers' well-being when they live in anything but a comfortable environment?

The study aimed to investigate what opportunities there are for the crew to perform physical activity, how they utilise it and how it affects their perceived well-being whilst at sea. A questionnaire aimed towards crew on Swedish-flagged ships over 3000GT was used, which generated 187 answers.

The answers indicated that there were good opportunities to exercise onboard and that most of the seafarers utilised the space and equipment available. However, no connection could be found between exercising and increased perceived well-being. One group of seafarers, those working 12 hours and then resting 12 hours, were found to have poorer well-being than the general population.

Establishing that some seafarers have poor well-being is the first step towards the development of a safer, more sufficient and healthier onboard workplace environment than that of today.

Keywords: Well-being; physical activity; shift work; seafarers

1. Introduction

Well-being can be defined by how an individual perceives their general happiness with their life and is affected by a combination of factors, one being physical activity (CDC, 2018). An inactive lifestyle can lead to multiple physical problems and poor mental well-being (Lesser & Nienhuis, 2020; Penedo & Dahn, 2005; Reljic et al., 2020).

There are many factors impacting a seafarer's well-being, for example, demanding workloads, sleep deprivation, social isolation and long watches in harsh work environments. These factors often lead to increased stress and fatigue which can affect their general feeling of well-being (Oldenburg et al., 2010).

A seafarers' natural physical activity pattern often consists of only walking to the galley to eat, or down in the engine room, distances often not longer than 100 m. On land, the worker can take the bike home, walk to the bus stop or go grocery shopping. These are effective everyday exercises that contributes to an active lifestyle and improved well-being (Garber et al., 2011).

The Swedish Transport Agency stipulates that any ship larger than 3000 GT needs to have a designated space for seafarers to perform physical activities (TSFS 2013:68). To increase the seafarer's perceived well-being through physical activity there must be opportunities like enough spare time and appropriate equipment. Different stress causing factors due to the harsh work environment must also be overcome. These factors risk decreased perceived well-being (Oldenburg et al., 2009). It is well known that physical activity positively affects well-being but not how the accessibility and utilisation of physical activity affect the lives and well-being of seafarers whilst at sea. Therefore, this study aimed to map out the perceived well-being of seafarers and how it is affected by the opportunity for physical activity.

2. Research questions

- What opportunities are there onboard for the crews to perform physical activity?
- How are these opportunities for physical activities utilised by the crew?
- How are the crews' perceived well-being affected by physical activities onboard?

3. Theory

Many factors affect seafarers' physical and mental well-being whilst at sea. According to the International Maritime Organisation (IMO) (n.d.a), the most impactful factors are opportunities to be physically active, the amount and quality of sleep, social environment, work environment, stress management and shift work.

3.1 Work environment and stress impact on seafarers' well-being

According to the World Health Organisation (WHO), the definition of stress is how your body reacts to a physical, emotional or psychological strain due to changes that affect your life. A seafarer's life is filled with stress-causing factors, so called stressors. The most common stressors for seafarers are working in shifts, separation from family and time pressures (Oldenburg et al., 2009), but there is also vibration, noise and movement of the ship (Nielsen et al., 2013; Oldenburg et al., 2010).

Statistics also indicate that there is an increase in overall injury and mortality in the shipping industry when compared to shore-based industries (Baygi et al., 2018; Jensen et al., 2005; Jensen et al., 2006). It is more common for engineers to get work-related injuries and pains than, for example, the deck crew. This is because the nature of the work is often in difficult working postures that are unergonomic in combination with heavy lifts (Forsell et al., 2017). Furthermore, engineers often have a more noisy, vibrating and warm workplace environment when compared to other workplaces on a ship (Palella et al., 2016). The temperature in the engine room can be so high that it leads to fatigue, more accidents, and metabolic problems. It has also been shown that sometimes the heat difference between the engine room and control room can be so significant that it causes thermal shock (Orosa & Oliveira, 2010).

3.2 Sleep and the effects of sleep deprivation

Many aspects of a seafarer's life can affect sleep negatively. Vibrations, noises, and motion from the ship can increase the likelihood of becoming fatigued (Oldenburg et al., 2010). Seafarers who become fatigued run a greater risk of damaging their health and well-being, while also increasing the risk of work-related accidents caused by, for example, involuntary falling asleep on-watch (Boivin & Boudreau, 2014; Hystad & Eid, 2016; IMO, n.d.a).

For a healthy adult to achieve an adequate amount of sleep they often need 7 or more hours of continuous sleep (CDC, 2022). Multiple studies show that seafarers struggle with achieving an adequate quantity and quality of sleep leading to an increased risk of becoming fatigued (Carotenuto et al., 2012; Hystad & Eid, 2016). IMO (n.d.a) defines fatigue as ''A state of physical and/or mental impairment resulting from factors such as inadequate sleep, extended wakefulness, work/rest requirements out of sync with circadian rhythms and physical, mental, or emotional exertion that can impair alertness and the ability to safely operate a ship or perform safety-related duties.''. The circadian rhythm is the rhythm which impacts our feelings of when to eat, sleep and work on a 24-hour basis (National Institute of General Medical Sciences, n.d.a). It is affected by multiple environmental factors, such as working hours, sunlight and sleeping schedule (Roenneberg et al., 2003; Wittmann et al., 2009).

3.3 Shift work impact on sleep

Several studies imply that a big gap between the circadian rhythm and the person's day-to-day schedule leads to a sleep debt during workdays (Wittmann et al., 2009). Since the majority of seafarers work 7 days a week, they have no time to repay their sleep debt, which is one of the prime reasons that seafarers are not able to get satisfactory quality and quantity of sleep (Dohrmann & Leppin, 2017). Working in shifts greatly impacts sleep since it disrupts the circadian rhythm (Boivin & Boudreau, 2014). There are many types of shift works, such as 12/12 and 6/6 watches, which can be dangerous for the health of seafarers because it makes them work against their circadian rhythm (Oldenburg, Jensen, et al., 2013).

4. Method

The study had a quantitative research approach and was based on a survey aiming to reach a wide range of seafarers across different ship types in a set period of 7 weeks (Denscombe, 2016). The survey was conducted in the form of a web-based questionnaire with 28-30 questions, the amount differed depending on answers leading to different questions (Denscombe, 2016,). The survey used the WHO - Five well-being Index (WHO-5 Questionnaires, n.d.), combined with demographic questions and questions that aim to investigate the opportunities for physical activity onboard and how the crew utilised it. The selection of participating ships was based on ships carrying the Swedish flag and over the size of 3000 GT, this to adhere to the Swedish Transport Agency's regulation, TSFS 2013:68 3:39 § 2 which states that ships larger than 3000 GT should have a space for seafarers to play sports, do physical activities or perform other hobbies while onboard. The questionnaire was sent via email to 20 companies that fulfilled the requirement of owning Swedish-flagged ships over 3000 GT.

5. Result

The results from 187 respondents' answers to the questionnaire are presented in the form of text, percentages and bar diagrams. In the results concerning shifts, the study will only look at 12/12, dayman and 4/8. This since there were not enough answers from respondents working other shifts. The respondents had answered in alternatives that ranged from ‘’0 at no time’’ to ‘’5 all the time’’ on the Likert scale, these were in the result divided into two categories where 0-2 became ‘’less than half of the time’’ and 3-5 became ‘’more than half of the time’’ for a clearer presentation of the result.

5.1 Space, equipment, energy and time

The result showed that a majority of the respondents did exercise onboard, 135 (72,2%) while the remaining 52 (27,8%) responded that they did not exercise onboard. The results indicate that the majority of ships provide sufficient space to perform exercise and enough equipment for the exercise the respondents want to do. Although, the results show that the opportunities for physical activity differ between energy and shifts.

When it comes to having enough time after shifts for exercise the results show a difference. 73,3% of respondents who exercise answered that they have enough time after their shift for exercise meanwhile 55,8% of responders who do not exercise onboard answered that they have time over after their shift for exercise, more than half of the time.

The difference in answers between those who exercise and do not exercise is larger when asked if they have enough energy to exercise when they want to. 64,4% of the respondents who exercise answered that they have the energy to exercise when they want to more than half of the time, meanwhile, 21,6 % of the respondents that do not exercise responded that they had the energy to exercise when they wanted to more than half of the time.

5.2 Shift work impact on physical activity and energy

The results show a bigger difference in which respondents exercise and do not, depending on which shifts they are working. In the 4/8 shift 88,2% exercised, Dayman shift 80,0% exercised and 12/12 shift only 57,1% exercised. There is also a variation between respondents from different shifts when asked if they have enough energy to exercise when they want to. 67,6% of respondents on 4/8 shift have enough energy to exercise when they want to, more than half of the time, 57,7% of the respondents on Dayman and 26,5% of respondents on 12/12. The majority of respondents who work the 12/12 shifts are engineers (54,3%) and the most common position to work 4/8 is Officer (50%) shortly followed by Chief officer (26,5%). The majority of respondents on the 12/12 shift worked on ro/pax ships (77,1%), the rest worked on passenger ships and ro/ro ships.

5.4 The crews' perceived well-being

The following histogram (figure 1) shows the well-being score of all respondents based on WHO-5. A score under 13 indicates that the responder has poor well-being and responders with a score under 10 are recommended to get tested for depression. Most respondents (71,4%) had a score between 14-22 which suggested good well-being, although there are multiple respondents (25,9%) who land on or below the score of 13 and some (10,8%) on or below the score of 10.

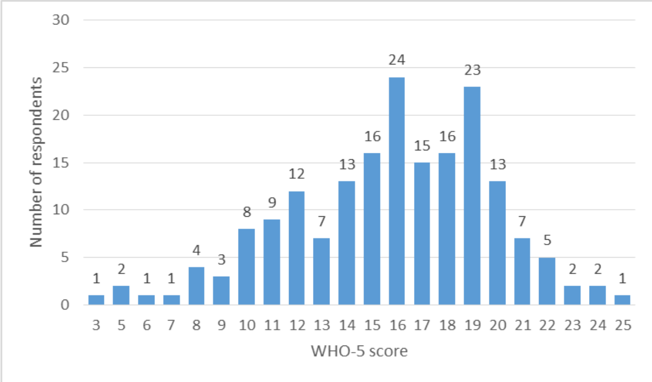

Figure 1. A histogram showing the number of respondents and where their WHO-5 scores are on a scale 0-25.

The results do not show a notable difference in the perceived well-being of the respondents who exercise and do not exercise. Although the result indicates that there is a notable difference in perceived well-being depending on which shift the respondent works. When comparing shifts the 4/8 shift has a mean score of 16,3, Dayman shift has a mean score of 15,9 and the 12/12 shift has a mean of score 13,5. When looking at the distribution of scores from respondents who work 12/12 shifts (figure 2) one can see that there is a notable amount (48,5%) on or below the score of 13 and some (25,7%) on or below the score of 10.

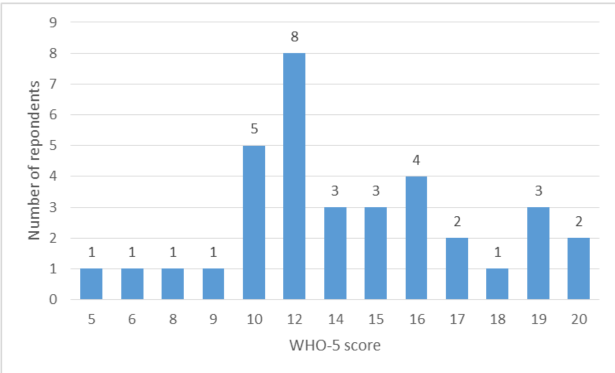

Figure 2. A histogram showing the number of respondents that work 12/12 shifts and their WHO-5 scores.

6. Discussion

The results indicate that there are good opportunities to perform physical activities onboard and that access to facility space and equipment is sufficient for exercising onboard Swedish-flagged ships. Most of the crew does utilise the opportunities for physical activities that are given. Furthermore, the results did not indicate a connection between exercising and increased perceived well-being at sea.

The results from this study showed that there is, however, a substantial group of respondents (25,9%) that have poorly perceived well-being. It is important to pay attention to those with poorly perceived well-being as for some it can be early signs of both physical and mental problems. The physical work environment onboard is highly demanding in many ways and previous research has identified several issues that could affect perceived well-being (Lesser & Nienhuis, 2020; Oldenburg, Jensen, et al., 2013; Penedo & Dahn, 2005).

One of the issues that affect the sense of well-being is lack of sleep (IMO, n.d.a). Within the group with poorly perceived well-being, 48,5% of them work the 12/12 shift. This group also exercised less and had less energy than respondents from 4/8 and Dayman. Although those who work 12/12 can achieve 7 or more hours of continuous sleep they are working against their biological clock and circadian rhythm (CDC, 2022). This might lead to it getting increasingly difficult to get proper quality of sleep, hence increasing the hours needed to sleep. This increase in the likelihood of seafarers becoming fatigued is very dangerous and a serious hazard for both the health of the seafarers and the general safety at sea (Boivin &

Boudreau, 2014; Hystad & Eid, 2016). 12/12 is also the longest continuous watch type which can also be a reason for poorly perceived well-being.

Looking closer at the 12/12 shift, the majority of the respondents with poor well-being work as engineers onboard and also make up 43,8% of respondents that do not exercise. The nature of the engineer's work is often more active and gives a lot of everyday exercises. Their work environment is also often more tiresome due to hot temperatures, loud noises, and more vibrations than, for example, on the bridge (Forsell et al., 2017; Palella et al., 2016). Enduring a harsh work environment and working 12-hour shifts 7 days a week sets seafarers up for less energy for a physically active lifestyle and poorly perceived well-being. These results suggest that fatigue and a harsh work environment could be more decisive factors influencing the feeling of well-being than exercising.

Working 4/8 gives a better opportunity to have a natural sleeping rhythm compared to other shift solutions, for example 12/12. 12/12 might even be dangerous for the health since the seafarer might work against their circadian rhythm (Oldenburg, Jensen, et al., 2013). This divergence with the circadian rhythm as well as more sleep debt causing fatigue might be one of the reasons that those working 12/12 have poorer wellbeing.

It is well known that the work environment onboard is regarded as harsh and working at sea is regarded as a high-risk occupation with an elevated risk of injuries and health problems (Baygi et al., 2018; Jensen et al., 2006). Work onboard is a 24/7 operation which brings on challenges such as shift work, disrupted sleep and fatigue (Boivin & Boudreau, 2014; Dohrmann & Leppin, 2017; Oldenburg et al., 2010). Other challenges are social isolation, vibrations, noisy environment, and high-intensity work (Brooks & Greenberg, 2022; Orosa & Oliveira, 2010; Palella et al., 2016). All of these mentioned above can affect the seafarers' perceived well-being (IMO., n.d.a; Oldenburg et al., 2009), hence only looking at access and opportunity for physical activity as a single factor is not enough to make a difference in seafarers' perceived well-being. It is necessary to pay attention to other barriers to achieve a clear result.

The shipping industry is very broad and comes in as many shapes and forms as the waves it sails upon. It must be so diverse to be able to handle all the transportation and service our society currently needs. We are nowhere near knowing them all, but if in the future the reason for some seafarers' poor well-being could be found there would be a lot to win. Not least for the shipping companies, who might earn more money when their seafarers gain energy and inspiration in a sustainable work environment that leads to more effective, safer, and reliable ways to transport cargo on the seas.

7. Conclusion

Previous research has shown that physical activity can improve health, sleep, stress and physical and mental well-being. This study aimed to investigate what opportunities crew on Swedish-flagged ships over 3000 GT have to be physically active if they utilise those opportunities and how it affects their perceived well-being.

The results from this study do indicate that there are good opportunities to perform physical activities onboard and that access to facility space and equipment is sufficient for exercising onboard Swedish-flagged ships. Most of the crew does utilise the opportunities for physical activities that are given but the results did not indicate that there was any connection between exercising and increased perceived well-being at sea.

Although, it is important to note that the result did point out a group onboard that reports poor well-being. However, the work environment for seafarers is well-documented to be complex and demanding. To be able to understand what elements that have an impact on the perceived well-being of the crew members, more comprehensive studies need to be performed embracing the known risk factors that we know are present in the everyday life onboard. This knowledge is a prerequisite to be able to make necessary changes to achieve a better work environment onboard.

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