RECOMMENDED ADJUSTMENTS TO SHIP CREW TRAINING IN PREPARATION FOR LEVEL 2 MARITIME AUTONOMOUS SURFACE SHIP TECHNOLOGIES

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SUMMARY

Maritime autonomous surface ship (MASS) technologies promise substantial advantages and benefits. These technologies are not expected to immediately replace existing commercial vessels and crews, but they already face challenges related to regulation, legislation, reliability, and scepticism. Although ship crews are considered the primary operators and adopters of unmanned vessels, they must continue to refine their skills in response to future challenges associated with technological advancement. Given the aforesaid circumstances, this study proposed various recommendations for crew training following the transition to Level 2 MASS technologies. The decision analytic network process was used to analyse the causality and weight of both main constructs and their sub-criteria. The results indicate that crew competencies is the most crucial construct. Future ship crews will require training focused on their ability to monitor MASS decision-making and increasing their proficiency in integrating software and hardware. MASS vessels should be designed with a modular approach, and more extensive training in artificial intelligence should be provided to ship crews.

KEYWORDS

Maritime autonomous surface ship, Crew, Unmanned ship, Artificial intelligence

NOMENCLATURE

di	Obtain the sum of each column
L	Limit super matrix (weights)
ri	Obtain the sum of each row
D	Direct relation matrix
T	Total influence matrix
W	Normalised matrix
X	Relation matrix
ANP	Analytic Network Process
COLREGs	Convention on the International Regulations for Preventing Collision at Sea
DANP	Decision Analytic Network Process
DEMATEL	Decision Making Trial and Evaluation Laboratory
IMO	International Maritime Organization
MET 5.0	Maritime Education and Training 5.0
MSC	Maritime Safety Committee
PSCOs	Port State Control Officers
ROCs	Remote Operation Centres
STCW	International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers

1. INTRODUCTION

Ship crews are the most essential constituent of the maritime shipping industry. However, the Covid-19 pandemic exposed the vulnerability of maritime shipping operations globally (Millefiori et al., 2021) and created various challenges for ship crews (Zhao et al., 2023; Stepien, 2023; Wong, 2021). The International Maritime Organization (IMO) has set a target for net-zero greenhouse gas emissions by 2050 (IMO, 2023). Moreover, artificial intelligence (AI) assisted decision-making (Veitch and Alsos, 2022) is expected to greatly affect the maritime industry (Li and Fung, 2019; Fan et al., 2020; Kurt and Aymelek, 2022), such as by enabling the development of maritime autonomous surface ship (MASS) technologies to overcome various problems encountered by ship crews (Osaloni and Ayeni, 2022). However, after the introduction of this new technology into the maritime industry, many concerns and challenges have arisen in research regarding the regulatory framework for MASS between countries (Fenton and Chapsos, 2023; Stepien, 2023), the risks of AI decision-making (Wen et al., 2023; Wu et al., 2023), and the accompanying technical training for crew members (Ino et al., 2023; Lynch et al., 2022).

Training guidelines for MASS crews must be established to facilitate the adoption of advanced technologies by such crews (Shahbakhsh et al., 2021). Crew members could navigate vessels remotely by relying heavily on digital information instead of on-site observation. This necessitates the development of new-generation training simulators (Heffner and Rodseth, 2019). Level 2 MASS technologies will require the maritime sector to complete the challenging transition to a human–machine collaboration model. Although crew members need not fear their replacement (Talmor and Kitada, 2022), this process will have transformative effects on individuals serving on future MASSs and their training. Therefore, identifying the skills for serving on a MASS and how to acquire them is an urgent task. Currently, the literature lacks a systematic and quantitative prioritization of MASS crew training standards, making it impossible to provide a reference for crew education or training institutions, as well as for government decision-making in various countries.

This study explored the changes necessary to respond to Level-2 MASS technologies in terms of four maritime navigation considerations: ship developing, navigation technologies, crew training, and crew competencies. The goal is to identify the optimal developmental direction and recommendations for each of these aspects. Furthermore, the interrelationships and significance of various criteria of these four major considerations are explored.

This article compared to previous research, the biggest contribution of this study is the proposal of standardized and comparable criteria at different levels, enabling countries to assess and plan seafarer training progress over various timelines based on their own resources and circumstances, following the sequential positioning of criteria in the causal diagram of research outcomes. These criteria have high practical value for the future training of MASS crew members and when adjusting relevant standards for maritime operations. Academically, it provides direct guidance to IMO member countries in training MASS crew members, including their competency requirements, suitability, supervision, and certification qualifications. The results could guide technological advancements to promote the development of the maritime industry and enhancing human welfare.

2. LITERATURE REVIEW

2.1 SHIP DEVELOPMEN CONSIDERATIONS FOR MASS

Ship developing is a critical aspect of MASS (Fan et al., 2020; Dittmann et al., 2021; Hwang and Youn, 2022). The adoption of MASS technologies requires installing new equipment or software and could greatly change ship designs. Although novel software and hardware technologies can greatly enhance system automation, operational changes are inherently risky. The review of recent literature on MASS design in Table 1 reveals a focus on remote MASS control, software and hardware design, information security, and technical support.

Fan et al. (2020) suggested that the factors affecting MASS design should be categorized into four groups: human, ship, environment, and technology. Asplund and Ulfvengren (2022) identified the collection and sharing of information as key factors for MASS remote control. Hoem (2023) further proposed that future core risk factors for MASS would involve the interaction between human operators and the system. Additionally, Wang et al. (2023), Koo et al. (2023), and Illiashenko et al. (2023) explored the application of advanced technologies to strengthen MASS structures. Munim and Haralambides (2022) concluded that large-scale commercial deployment is only practical if sufficient MASS operations are available to meet the requirement of transporting large quantities of goods.

While studies generally agree that MASS has value, they also concur that if new MASS technologies do not enhance maritime service efficiency or meet expectations, the

Table 1. Studies on MASS-related ship developing

Findings or Contribution	Source
Information collection & sharing are key for remote operation centres	Asplund and Ulfvengren (2022)
ROC operators must adapt to their working environment quickly	Porathe (2022)
Propose new technologies for reinforcement systems	Chen et al., 2023
Design and development of a new control system	Wang et al., 2023
Satellite 5G and 6G technologies are sufficient to MASS	Koo et al., 2023
Analysis of Cyber Attacks	Illiashenko et al., 2023
Assessing the Risks of Human-Machine Interaction	Hoem, 2023
Design alternative solutions for on board incidents	Lee et al., 2023
Modification of existing cabin space to increase cargo capacity	Utne et al., 2020
Information must be shared among all parties	Sinohara and Tannuri, 2022
Auto berthing must reinforced MASS abilities	Wu et al., 2023
Introducing a new automatic magnetic mooring system	imoor (2023)
Time-based maintenance & Condition-based maintenance	Caglar et al., 2022

continual development of higher-level MASS technologies may not occur. This study compiles key criteria for future ship development, including feasibility of implementation, human–machine collaboration, and remote control. Enhanced support for the crew members on board is also crucial; this can include changes to ship piloting systems, ROCs, engine control room, mooring equipment, cargo gear, modularisation, navigation safety, security and cybersecurity, and logistical provisioning. These should be carefully considered to ensure that Level-2 MASS vessels do not have significant deficiencies or are not deemed too risky by stakeholders.

2.2 NAVIGATION TECHNOLOGIES CONSIDERATIONS FOR MASS

Vessels equipped with Level 2 MASS technologies should maintain a crew for safety and contingency reasons (Fan et al., 2020; Blindheim et al., 2023). The vessel operation should focus on integrating traditional nautical operations with MASS technology (Liu et al, 2022), and the crew should not be replaced entirely with AI. If traditional crews can be supplemented with remote control and on-site monitoring, vessels could be scaled up, operational costs reduced, labour streamlined, and emissions decreased without compromising security and safety. In emergencies, an immediate response capacity is maintained. This situation represents a win-win scenario in which human experience, skills, and technology are combined.

Miyoshi et al. (2022) from the perspective of seafarers, they consider whether it is necessary to change the Convention on the Regulations for Preventing Collisions (COLREGs). Many studies have focused on revising collision avoidance rules, developing MASS collision avoidance technologies, training AI, and assessing the impact of Level 2 MASS technologies on traditional techniques. Table 2 summarizes significant research findings from 2022–2023 on these topics.

Liu et al. (2022) identified four criteria of MASS, including navigation behaviour modelling, enhanced situational awareness, human-machine collaborative decision-making, and navigation control, which is excellent. Xu et al. (2023) examined the latest MASS path tracking control technologies through an extensive literature analysis, including discussions on their control structure, guidance law-, control methods, stability results, environmental disturbances, and kinetics. Wu et al. (2023) used the maximum detection distance of MASS vessels and algorithmic techniques to establish a safety domain for these vessels. Despite these advancements, providing practical pre-emptive avoidance training to AI has not been investigated. This paper also references the new autonomous navigation decision-making technology developed by Wang et al. (2023), that presents covered 54 types of multi-ship encounter scenarios. Wen et al. (2023) noted that the speed and accuracy of MASS motion control could still be improved.

Table 2. Studies on MASS-related navigation technologies

Findings or Contribution	Source
Development of a collision avoidance system capable of sending alerts	Lee et al., 2023
Development of a Collision Avoidance System (CAS)	Wu et al., 2023
Propose monitoring the MASS navigation system	Xu and Soares, 2023
Development of an innovative heuristic search algorithm for AI	Lee and Cho, 2023
Efforts are needed to negotiate and update laws and policies	Fenton and Chapsos, 2023
In AI training, algorithms still need improvement	Wen et al., 2023
Third-party certification is key to trust in artificial intelligence	Levence and Wooldridge, 2023

The literature does not adequately discuss how ship crews should monitor AI decisions when transitioning to remote operators; in particular, their understanding of AI responsibilities and logic requires further clarification. Narayanan et al. (2023) suggested that younger crews are more proficient with digital technologies than older crews; older crews may be less adaptable to advanced technologies because they often regard traditional navigation skills as infallible. This mindset poses significant risks that have not been sufficiently addressed. Other challenges include that crews lack familiarity with MASS technologies, and engineers may not have seafaring experience. The literature suggests that future exploration of Level 2 MASS technologies should focus on four key areas: navigation technology training restructuring, collision avoidance rule details, AI knowledge establishment, and route monitoring assurance.

2.3 CREW TRAINING AND COMPETENCY

The literature underscores the significant challenges of the transition from maritime personnel to remote operators for MASSs. Hwang and Youn (2022) raised concerns about the insufficient duration of training programs for remote MASS operators and stressed that they should achieve seafaring proficiency comparable to traditional maritime navigators. Some article advanced serious issues in future crew training, such as inadequate course content and teacher (Mohamad et al., 2022; Shahbakhsh et al., 2021). Fenton and Chapsos (2023) explored the legal and operational challenges of MASS. However, there is a growing consensus in the literature that MASS technology could reduce traditional human errors (Nakashima et al. 2023; Osaloni and Ayeni 2022). Tables 3 and 4 present notable studies on MASS crew training and competency, respectively, from 2022–2023.

The literature identifies several key factors or criteria for MASS crew training and competency, including the uncertainty of future seafarers' skill sets, the lack of consensus on training content and facilities, issues with maritime instructor quality, seafarer adaptation to new technologies, and the lack of societal support for developing seafarers' skills. These observations are highly indicative (Talmor and Kitada, 2022; Shahbakhsh et al., 2021). Some studies have also discussed the best strategies for promoting MASS operations (Munim and Haralambides, 2022) as well as the inevitable need for human–machine cooperation (Liu et al., 2022). Discussions on enhancing crew competency have proposed closer integration with human–machine systems (Fan and Yang, 2023) and identified the need to ensure the modular and continuous operation of ships (Torben et al., 2023). The present study examined these arguments and acknowledges that new technologies will inevitably introduce new risks to crew training and that training requires defining competency standards and assessments.

Based on a comprehensive literature review, this study established essential criteria for evaluating the training, qualification certification, mindset transformation, collaboration, and repair skills of MASS crew members. A significant focus is placed on remote decision-makers, particularly in situations where human operators lose the immediacy of on-site observation and instead must rely entirely on information from sensors. Additionally, the capability of operators to rapidly and accurately process large volumes of data and make correct decisions in urgent, heavy-traffic situations was explored. Moreover, complete reliance on an infallible AI in imminent, risky situations was considered; this could shift the responsibility traditionally held by seafarers directly onto AI.

2.4 SUMMARY

Kim and Hinrichs (2021) clearly stated that remote-control and autonomous ships are new concepts with significant safety and economic potential. The development of human- machine collaborative navigation as a critical breakthrough (Liu et al., 2022). Theotokatos et al. (2023) analysed the benefits of MASS operations and noted significant disparities between shipping communities; they suggested that misconceptions about the next generation of autonomous navigation should be urgently resolved. MASS five key aspects for future research and development: mechanical reliability and maintenance, software, risk assessment, collision prevention, communication, and human factors (Li et al., 2023). These aspects are crucial for enhancing the efficiency and safety of MASS operations. Although most of the literature promotes human-machine collaboration from a positive perspective, anticipating that the use of MASS (Maritime Autonomous Surface Ships) will make future shipping safer and more efficient, some studies present contrasting and negative viewpoints. These studies emphasize crew members' concerns about losing their jobs to AI and highlight their psychological resistance to new technologies (Luchenko et al., 2023; Talmor and Kitada, 2022).

Table 3. Notable studies on MASS crew training

Findings or Contribution	Source
Core nautical competencies and skills must be reinforced	Emad et al., 2023
Awareness, role, training, and design are key factors	Lynch et al., 2022
Exploring the main reasons for reluctance to use unmanned.	Luchenko et al., 2023
Establishment of a set of MASS operational standards is difficult	Ino et al., 2023
Progressive relaxation of relevant codes and regulations	Ahmed et al., 2023
Companies should increase crew new technologies training	Talmor and Kitada, 2022
Greater influence needs to be exerted at the international and national regulatory levels	Lynch et al., 2023

Table 4. Notable studies on MASS crew competencies

Findings or Contribution	Source
Human machine collaborative navigation merits long-term research	Liu et al., 2022
Crew on board traditional repair skills still a necessity	Fan et al., 2020
Crew members must know how to respond to system malfunctions	Chen et al., 2023
Extensive testing has proven that the MASS must be modular	Torben et al., 2023

This study built upon previous research and focused on four key areas: ship developing, navigation technologies, crew training, and crew competencies. We conducted a questionnaire survey of experts to identify critical criteria for modifying crew training following the implementation of Level 2 MASS technologies. These insights are vital for guiding future technological advancements in maritime navigation. Ship crew skills will require further specialization, but their role in maritime operations remains significant.

3. MASS DEVELOPMENT AND CHALLENGES

In 2017, the Maritime Safety Committee (MSC) classified MASSs as vessels with varying degrees of automation from partially automated systems assisted by crew to fully autonomous systems that operate without human intervention. MASS technologies are divided into four levels: Level 1 ships have automated processes and decision support for the crew. Level 2 ships are remotely controlled but have crews on board. Level 3 ships are remotely controlled without crews on board, and Level 4 ships are fully autonomous. Successful regional, single-voyage, and transoceanic journeys have been made with both newly-built MASS vessels and existing vessels retrofitted with MASS technologies; most of these ships still require crew members on board. A list is provided in Table 5.

Chang et al. (2020) suggested that MASS reduces human errors and enhances safety. However, its risks include interactions between MASS and crewed vessels, object detection, cyberattacks, human error, and equipment failures. Wang et al. (2020) noted that a challenge of MASS introduction is restructuring seafarers' knowledge and talent cultivation. Navarro (2023) stressed that maritime educators should consider the responsibilities of future seafarers when designing curricula. They also raised concerns about whether these novel systems might lead to increased human stress and isolation.

The literature considers two key perspectives that are dichotomous: the 'human' aspect of ship crews, who remain essential, and the 'freedom of choice' in adopting new technologies. Although systems may eventually replace ship crews and MASS vessels will become dominant, these vessels must coexist with traditional, non-MASS vessels. Both national IMO regulations legalizing MASS vessels have not yet been formally established; hence, stakeholders can freely choose the future direction of the maritime industry.

MASS technologies face challenges related to their safety, regulation, multi-party collaboration, and specialized support requirements. Bellingmo et al. (2023) suggested that unmanned cargo ships are unlikely to operate in international waters in the next five years. Therefore, during the transition from MASS Level 2 to Level 3, crews will still be required to handle nautical and engineering tasks. Traditional nautical education should continue but gradually incorporate foundational courses on MASS technologies, such as on system maintenance and cybersecurity. The role of seafarers may evolve to providing auxiliary support, following remote engineering instructions for troubleshooting, or manually taking control in the case of system failures. This approach aims to alleviate the concerns of flag states, shipping operators, and port states to accelerate the acceptance of MASS. Shahbakhsh et al. (2021) highlight the core competencies in Maritime Education and Training 5.0 (MET 5.0) as including collaboration with nonhuman intelligent agents, innovation and creativity for rapid response to dynamic maritime environments, and continual adaptation to evolving technology.

Table 5. Notable MASS vessels

Year	Vessel Name	Achievement
2017.6.20	Svitzer Hermod	The first tugboat to have completed a short voyage and docking, with the ship master conducting navigation remotely from the shore.
2017.12.05	Great Intelligence	The first cargo ship to be equipped with a novel intelligent system that reduced the crew from three people to one (Liu, et al., 2022).
2018.4	Folgefonn	The first Ro-Ro ship to have completed its voyage under AI control within port waters, with the ship master monitoring on board
2018.12.03	Falco	The first fully autonomous car ferry
2018.12.04	Suomenlinna II	Proof that current technology allows for manual ship supervision from any location
2019.9	Iris Leader	The first large cargo ship to complete an automated port-to-port navigation trial in open waters
2020	Yara Birkeland	The first autonomous and zero-emissions full container ship, which reduced annual costs by 90% after entering service in 2022
2021.11	Segero	The first vessel to utilize various novel technologies to complete a maritime voyage in complex environments in Korea
2022.4.22	Zhi Fei	A ship operated on domestic routes that can be controlled remotely and is capable of intelligent perception, autonomous route planning, collision avoidance, and automated docking and undocking
2022.6.02	Prism Courage	The first liquefied natural gas ship to complete a voyage across the Pacific
2022.6	May Flower	The largest unmanned ship to complete a transatlantic voyage
2023.05.26	Eidsvaag Pioner	A vessel featuring advanced technologies such as automatic dry docking, docking, and intelligent machinery, demonstrating the maturation of MASS technologies

Data Source: Author (2023). (selected from various articles and Website)

The widespread adoption of MASS technologies requires the relaxation and amendment of various codes and regulations. With the anticipated ratification of the MASS Code by the IMO in 2025, subsequent updates to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) and the development of new model courses tailored for MASS crews are expected. As MASS technologies transition into Level 2, the skill set required for seafarers serving on these vessels will become more specialized. Seafarers will be users, adapters, and active learners. In consideration of the current international context and relevant literature, future seafarers aiming to serve on Level 2 MASS vessels will need to possess specific technical abilities as illustrated in Figure 1.

With the transition to Level 2 MASS technologies, crew training must be adapted to cover different ship structure and nautical skills; thus, competency assessments must change accordingly. This study identified four main aspects as listed in Table 6: ship developing, navigation technologies, crew training, and crew competency. Challenges include the transformation of the bridge into a command or information centre, space optimization for new equipment, new kitchen facilities, the elimination of manual mooring equipment due to rope less mooring designs, the reliability of AI in route monitoring, the modular design of MASS software and hardware for training and easy replacement, and real-time troubleshooting at sea. These challenges can be initially categorized into the four main constructs as summarized in the Table 6.

Research and practical navigation successes for MASS vessels is limited to smaller vessels operating in specific areas or port waters. These successes have been overseen by hand-picked and well-trained ship masters, researchers, development engineers, and a full crew on board that can intervene in AI decisions as needed. For MASS technologies to be fully successful, they must be usable by crew members with widely accessible training. Internationally, IMO member state are beginning to address the challenges of training crew for MASS operations.

Talmor and Kitada (2022) stated that the new technologies can significantly affect the career experiences of seafarers. Seafarers can decide whether to serve on MASS vessels, and those that do not can be traditionally trained. However, this approach is unsustainable in the long term because untrained seafarers may become uncompetitive for employment in the maritime industry. The IMO maintains a neutral stance on automation but actively promotes understanding through short films and seminars. It respects member states' suggestions and enables discussions and negotiations during conferences. This approach

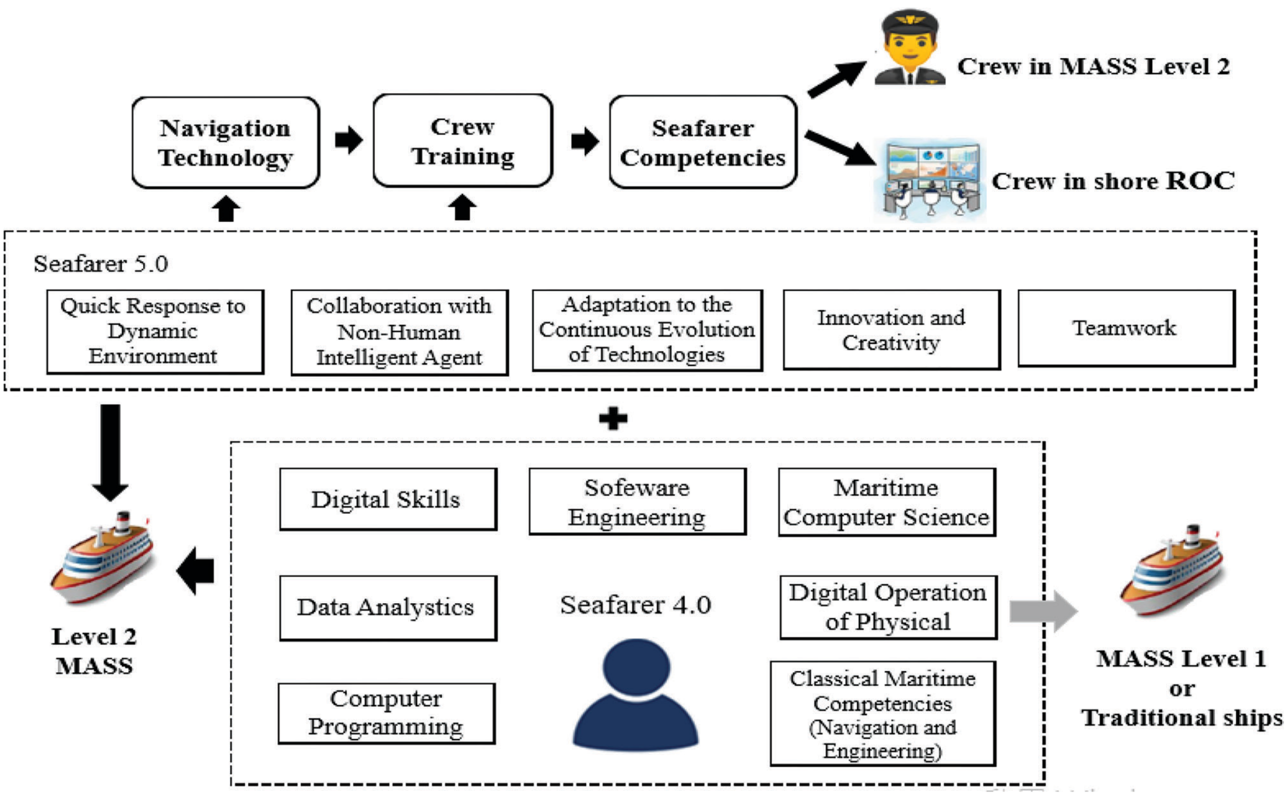

Figure 1. Technical abilities required for future MASS crews (Data Source: Transport 2040, World Maritime University; Shahbakhsh et al (2021)).

Table 6. Crew training standards criteria after transitioning to Level 2 MASS technologies

Main Constructs	Criteria Under the Main Construct	Interpretations
Ship Developing	• Ship space design • Cargo gear design • Modular design of MASS • Sailing safety planning • Security and cybersecurity planning • Logistics and maintenance planning	Unmanned ships will have changes in the ship space and cargo gear. Adopting modular hardware designs is key. MASS navigation is reliable, meets operational needs, and is highly efficient, crew size could be substantially reduced, helping to overcome anticipated manpower shortages. Security and cybersecurity will become greater challenges. Logistics and maintenance support are indispensable to ensure that MASS vessels remain reliable and operational under all weather conditions and should require a minimal crew for inspections, maintenance, and module replacement in failures.
Navigation Technologies	• Reform of nautical education • Establishment of collision avoidance rules • AI input data • Route monitoring	The adoption of MASS vessels necessitates a reconsideration of nautical education, which has traditionally been focused on crewed vessels. Moreover, current collision avoidance rules will require revision. The decision-making in MASS vessels relies on built-in AI processing that requires large datasets for high reliability. To ensure safety, both on board personnel and remote operators should be able to reliably monitor the vessel and its route at all times.
Crew Training	• Balance between new and traditional training • Qualification certifications • Familiarity with software and hardware integration • Transition to an operator mindset	Crew members must adapt and operate, and require appropriate education, and training regarding unmanned ship technologies. Consequently, new qualification certifications and accreditation criteria for teaching aids, training institutions, instructors, and curricula are required. Crew members must become proficient in integrating software and hardware from various models and brands. Finally, the transition of crew members from hands-on operation to monitoring or remote control will likely require a period of mental adaptation.
Crew Competencies	• Ability of human–machine collaboration • Ability of traditional repair • Ability of modular maintenance • Ability of monitoring AI decision-making	Crews must cooperate with machine-operated systems. MASS requires on board crew members with traditional maintenance and repair skills for keep running all the times. The software and hardware components associated with MASS should be designed in a modular fashion to minimize the crew expertise required to troubleshoot ship systems or electronics. Finally, human that can maintain and supersede AI control is essential to reduce risk.

significantly contributes to the advancement of maritime technologies. Emerging MASS technologies are anticipated to eventually enable complete AI control of ships, ports, and cargo loading and unloading. Over time, humans are expected to shift from a dominant to supporting role or even become observers and monitors. The willingness of seafarers to adapt to these changes is crucial for driving maritime development and achieving a mutually beneficial outcome for both humans and machines.

4. RESEARCH METHOD AND ANALYTICAL FRAMEWORK

In this study, the decision analytic network process (DANP), a multiple-criteria decision-making model that combines the analytic network process (ANP), was used with the decision-making trial and evaluation laboratory (DEMATEL) method. In general, the DEMATEL approach simplifies identifying complex cause-and-effect relationships based on expert opinions, enabling the analysis of interrelationships and impact degrees among various criteria. Subsequently, the ANP was used to establish the weights of each criterion, leading to the final identification of cause-and-effect relationships (Chang and Tai, 2021).

Due to the specialized nature of this topic, traditional census-base questionnaires currently available in the literature are not available for use. A comprehensive literature review was used to identify the most suitable constructs, and nine experts knowledgeable about the topic were consulted for review (Table 7). These experts unanimously approved of the criteria, which are presented in Table 6 and Figure 2.

A total of 18 criteria were selected for the 4 constructs in Table 6. The questionnaire was conducted from September to October 2024, and the nine expert decision-makers listed in Table 7 completed the questionnaire. The experts were meticulously selected and included government officials knowledgeable about MASS vessel regulation, port state control officers (PSCOs) with a deep understanding of crew competency issues and the authority to enforce regulations, seafarers with insight on the operational challenges of ROC for ships, and senior shipping scholars.

Table 7. Details of interviewers for survey

No.	Affiliation	Status	Experience
1	Government	Head of maritime tech.	> 15Year
2	Government	Ship master and senior PSCO	>15Year
3	Government	Senior PSCO	< 15Year
4	Shipping business	Ship master and port pilot	> 20Year
5	Shipping business	Ship master	< 15Year
6	Shipping business	Ship master	< 15Year
7	Academia	Professor	> 20Year
8	Academia	Professor	> 20Year
9	Academia	Ship master and assist. professor	> 20Year

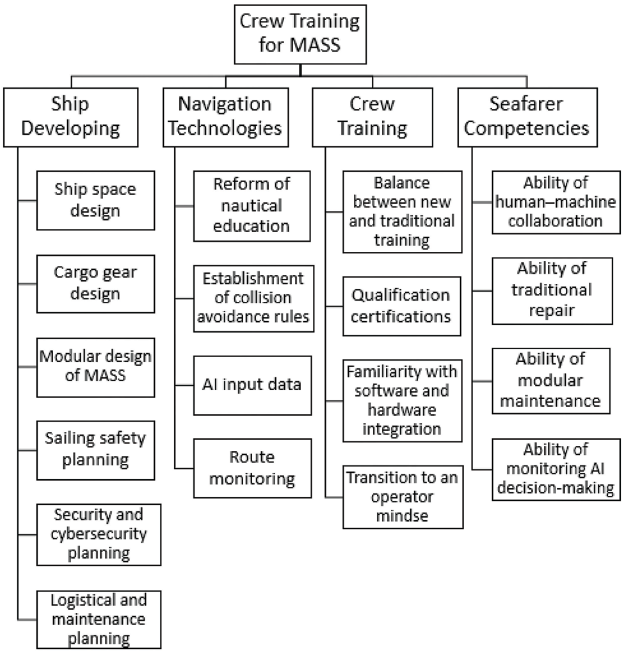

Figure 2. Main constructs and criteria affecting crew training after the introduction of Level 2 MASS

4.1 DEMATEL METHODOLOGY

The DEMATEL method was first used to establish the degree of influence and interrelationships among the aforementioned constructs and criteria. This process involved identifying the relationships and extent of influence between the constructs and criteria (Tzeng et al., 2007). This study followed the process outlined by Chang and Tai (2021).

Step 1: Obtain the data for the relationships and extent of influence between the constructs and criteria

The criteria were compiled and clearly defined to obtain, through expert questionnaires, the values of the inter criteria influence relationships. The assessment scale has five items, 0, 1, 2, 3, and 4, representing 'no influence,' 'low influence,' 'moderate influence,' 'high influence,' and 'very high influence,' respectively.

Step 2: Direct relation matrix X

Expert questionnaires are used to compare the degrees of influence between various criteria. The total number of criteria was n, and the results were recorded in an n × n direct relation matrix X. Each element Xij represents the degree that criterion i influences criterion j. The diagonal elements were 0 because no criterion influences itself.

$$X = \begin{bmatrix} 0 & x_{12} & \cdots & x_{1n} \\ x_{21} & 0 & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & 0 \end{bmatrix}$$

Step 3: Normalised direct relation matrix D

The sum of the elements in each row and column was calculated, and the largest such sum was denoted as S for normalisation. Each element of X was then divided by S, obtaining the normalised direct relation matrix D. Specifically, D and S were calculated with Equations (1) and (2), respectively:

$$D = SX \tag{1}$$

$$S = \frac{1}{max\left[max_{1\le i\le n} \sum_{j=1}^{n} x_{ij},\ max_{1\le j\le n} \sum_{i=1}^{n} x_{ij} \right]} \tag{2}$$

Step 4: Total influence matrix T

The total influence matrix T was then derived from D with Equation (3), where I represents the identity matrix.

$$T = \lim_{k\to\infty} \left(D + D^2 + \cdots + D^k \right)^n = D(I-D)^{-1} \tag{3}$$

Step 5: Determine *d* and *r* values through the total influence matrix

The elements of each row and column of T to obtain the aggregate values *di* and *rj*, respectively, as in Equations (4) and (5), respectively.

$$d_i = \sum_{i=1}^{n} t_{ij} \ \ (j = 1,2,3\cdots n) \tag{4}$$

$$r_i = \sum_{j=1}^{n} t_{ij} \ \ (i = 1,2,3\cdots n) \tag{5}$$

Step 6: Calculate centrality *(di+rj)* and causality (*di–rj*)

Quadrant II: Driving criteria	Quadrant I: Core criteria	
Low centrality, high causality. This quadrant criteria that are largely independent unaffected by other criteria and influence a limited number of other criteria. These are the second priority for resource and support.	High centrality and high causality. Thes criteria are key influencers and should be prioritized when allocating resources and support.	Causes
Quadrant III: Independent criteria	**Quadrant IV: Influenced criteria**	
Low centrality, low causality. These criteria interact little other criteria and should be monitored individually. These criteria are the lowest priority for resource allocation and support.	Characteristics: High centrality, low causality. These criteria are critical but have low causality and do not greatly affect other factors; improving the criteria in Quadrants I and II can indirectly improve this.	Effects
Low centrality	High centrality	

Figure 3. Implications of the four quadrants of the DEMATEL (Data Source: Adapted from chang and tai (2021))

If $i = j$, $di+ri$ is the total extent that a criterion i influences and is influenced by other criteria; this is its centrality. Similarly, $di–ri$ is the difference between its exertion and reception of influence its causality. If the causality is positive, the criterion is assigned to the cause cluster; otherwise, it is assigned to the Effect cluster.

Step 7: Create a cause-and-effect diagram

A cause-and-effect diagram plots each criteria with centrality on the horizontal axis and causality on the vertical axis. The average values of each axis are used to divide the diagram into four quadrants, facilitating an analysis of these causal relationships. The quadrants are described in Figure 3.

4.2 CALCULATION OF CRITERIA WEIGHT

The results obtained from DEMATEL are further applied to the ANP to determine the importance of each factor. The calculation steps of the DANP method are as follows:

Step 8: Normalise and transpose the total influence matrix to a W^T

First, the total influence relationship matrix T [Equation (6)] is normalised with Equation (7) to obtain W [Equation (8)], which is then transposed to WT. di is the sum of the values in each row of T.

$$T = \begin{bmatrix} t_{11} \cdots & t_{1j} \cdots & t_{1m} \\ \vdots & \vdots & \vdots \\ t_{i1} \cdots & t_{ij} \cdots & t_{im} \\ \vdots & \vdots & \vdots \\ t_{m1} \cdots & t_{mj} \cdots & t_{mm} \end{bmatrix} \quad (6)$$

$$d_i = \sum_{j=1}^{n} t_{ij} \quad (7)$$

$$T_1 = \begin{bmatrix} t_{11}/d_1 \cdots & t_{1j}/d_1 \cdots & t_{1m}/d_1 \\ \vdots & \vdots & \vdots \\ t_{i1}/d_i \cdots & t_{ij}/d_i \cdots & t_{im}/d_i \\ \vdots & \vdots & \vdots \\ t_{m1}/d_m \cdots & t_{mj}/d_m \cdots & t_{mm}/d_m \end{bmatrix} = W$$

$$W = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1n} \\ w_{21} & w_{22} & \cdots & w_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n1} & w_{n2} & \cdots & w_{nn} \end{bmatrix} \quad (8)$$

Step 9: Establish the limit super matrix

W^T is then repeatedly multiplied by itself z times until it converges to the limit matrix L. The elements of L are then the weights of each criterion.

$$\mathrm{L} = \lim_{z \to \infty} \left(W^T\right)^z \quad (9)$$

The simplified complete procedure of the Decision Analytic Network Process (DANP) method is shown in Figure 4.

4.3 DANP RESULTS

In October 2023, the questionnaire was provided to professionals in the maritime industry, government regulatory bodies, and academia; all had over 15 years of relevant experience (Table 7). Table 8 reveals that crew competencies was the construct with the highest centrality (8.949), suggesting that national governments should prioritize improving crew competency. The causality values for A, B, and C were all greater than 0; these were cause clusters. By contrast, Construct D was an effect cluster. This suggests that constructs A, B, and C can directly influence government resource allocation for enhancing crew competency.

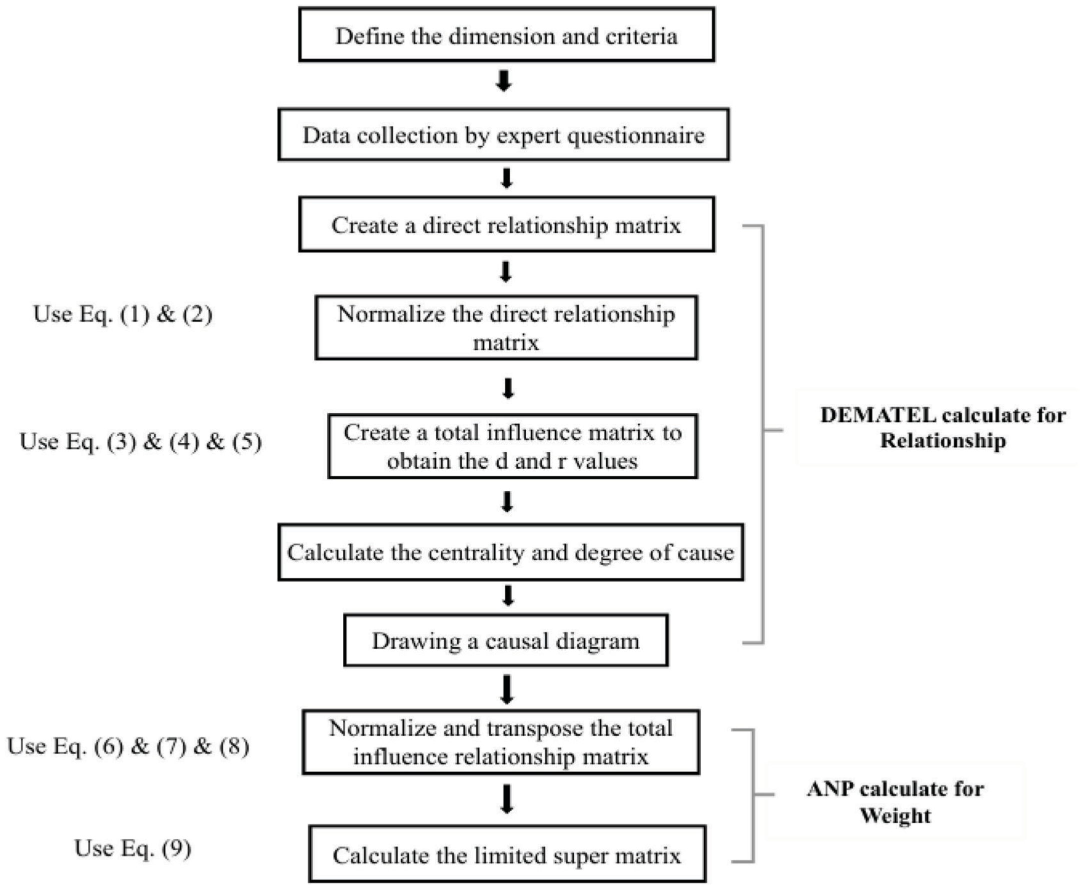

Figure 4. The DANP method procedure

Table 8. Centrality and causality of important constructs

Const. Code	d i	r i	Centrality d i + r i	Causality d i – r i	Cluster
A	4.075	3.252	7.327	0.823	Cause cluster
B	4.183	4.122	8.305	0.062	Cause cluster
C	4.451	4.400	8.851	0.051	Cause cluster
D	4.006	4.943	8.949	–0.936	Effect cluster

Table 9 presents the survey results for each criterion. For example, in Construct A (Ship Developing), criterion A3, 'modular design of MASS,' had the highest centrality (31.976), suggesting that this criterion is highly influential in Construct A. Planning for modular design of MASS-related components is essential for reliable all-weather navigation. This approach enables crew members to repair complex equipment directly on the ship without needing additional interdisciplinary training and is key for the popularization and safety reliability of MASS vessels. The causality values of criteria A1, A2, and A3 were greater than 0, indicating they were in a cause cluster. By contrast, criteria A4, A5, and A6 had values less than 0 and were in an effect cluster. Therefore, future researchers should prioritize ship space design, modular design of MASS, and cargo gear design when allocating resources for MASS ship development.

For Construct B (navigation Technologies), criterion B3, 'AI input data', had the highest centrality (25.507), suggesting that training AI is crucial because MASS vessels are mostly controlled by ROCs and have few crew members on board for monitoring and emergency purposes. If regulators affirm the reliability of AI, it can replace human navigation duties. Of the remaining criteria, B1 is in a cause cluster, and B2, B3, B4 are in effect clusters. This suggests that future resources should primarily be invested in building human trust in AI.

For Construct C (Crew Training), criterion C3, 'familiarity with software and hardware integration', had the highest prominence (24.130). This suggests that crew adaptability to new MASS technologies is a top concern in crew training. Because multiple parties are involved in MASS research and development, the final product will likely feature software and hardware from various brands. Shipping companies can choose their preferred brand as they can select radar or electronic chart display and information systems. C1 and C2 are cause clusters, whereas C3 and C4 are effect clusters. This suggests that crew training should prioritize familiarizing crews with various MASS software and hardware systems, similar to how airplane pilots are intensively trained for different aircraft models.

For Construct D (Crew Competencies), the most critical criterion is D4, ‘ability of monitoring AI decision-making’ (16.290). This suggests that the primary responsibility of the few ship crewmembers remaining on board MASS vessels in the future is to supervise the MASS AI’s decisions. If there are doubts, crews should immediately review them or take emergency operational measures. Crews are the last line of defence in ensuring MASS navigation safety. In terms of causality, D1 and D2 are in cause clusters, whereas D3 and D4 are in effect clusters. Therefore, decision-makers should focus on strengthening crew–machine and ship–base collaboration, as well as ensuring traditional repair and maintenance capabilities, to empower ship crews to supervise decisions made by MASS AI.

The results in Tables 8 and 9 were plotted on cause and effect diagrams (Figures 5–9). Points above the *x*-axis represent cause clusters, and those below represent effect clusters. The criterion values were calculated, and quartiles were used as the threshold for retaining the main and sub-constructs. Criteria with values greater than this threshold were retained; otherwise, its value was set to 0.

Figure 5 present the cause-and-effect relationships among the main constructs. Construct A (Ship Developing) and Construct B (Navigation Technologies) were driving criteria in Quadrant II, Construct C (Crew Training) was a core criterion in Quadrant I, and Construct D (Crew Competencies) was an influenced criterion in Quadrant IV. This suggests that resources for improving MASS crew competency should primarily be invested in crew training, followed by ship development and navigation skills; training is the key factor affecting whether crew navigation Technologies can complement new MASS technologies. Ship development affected crew competency but not the other constructs. This may be because developers, not ship crews, are more exposed to advanced technologies. MASS systems will likely not be monopolized by a single global manufacturer; the ship’s crews are user only. Crew training and navigation technologies do not need to be consider training crews to operate MASS systems from all manufacturers.

Figure 6 presents the cause-and-effect relationships among the six criteria of Construct A. Criteria A1 (ship space design) and A3 (modular design of MASS) were in Quadrant I, A4 (sailing safety planning) and A6 (logistics and maintenance planning) were in Quadrant IV, A2 (cargo gear design) were in Quadrant II, and A5 (security

Table 9. Centrality and causality of respective criteria

Criteria Code	d i	r i	Centrality d i + r i	Rank	Causality d i – r i	Rank	Cluster
A1	16.520	15.083	31.603	2	1.438	1	Cause cluster
A2	13.819	13.357	27.176	5	0.462	3	Cause cluster
A3	16.195	15.781	31.976	1	0.414	2	Cause cluster
A4	14.039	15.776	29.816	4	–1.737	6	Effect cluster
A5	13.353	13.743	27.095	6	–0.390	5	Effect cluster
A6	15.249	15.436	30.685	3	–0.187	4	Effect cluster
B1	13.154	11.702	24.856	2	1.452	1	Cause cluster
B2	11.973	12.246	24.219	4	–0.273	3	Effect cluster
B3	12.634	12.873	25.507	1	–0.238	2	Effect cluster
B4	11.809	12.750	24.559	3	–0.940	4	Effect cluster
C1	11.988	11.527	23.516	2	0.461	2	Cause cluster
C2	11.885	11.171	23.056	4	0.714	1	Cause cluster
C3	11.653	12.477	24.130	1	–0.823	4	Effect cluster
C4	11.390	11.741	23.131	3	–0.352	3	Effect cluster
D1	8.250	7.530	15.780	2	0.720	1	Cause cluster
D2	6.815	6.745	13.560	4	0.071	2	Cause cluster
D3	7.807	7.966	15.773	3	–0.159	3	Effect cluster
D4	7.829	8.461	16.290	1	–0.632	4	Effect cluster

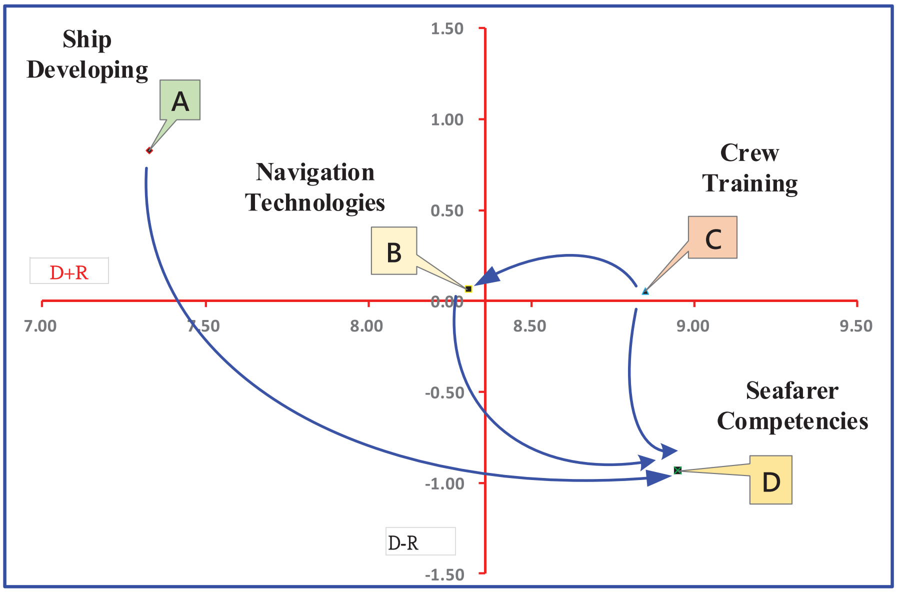

Figure 5. Causality and correlation analysis for the main constructs

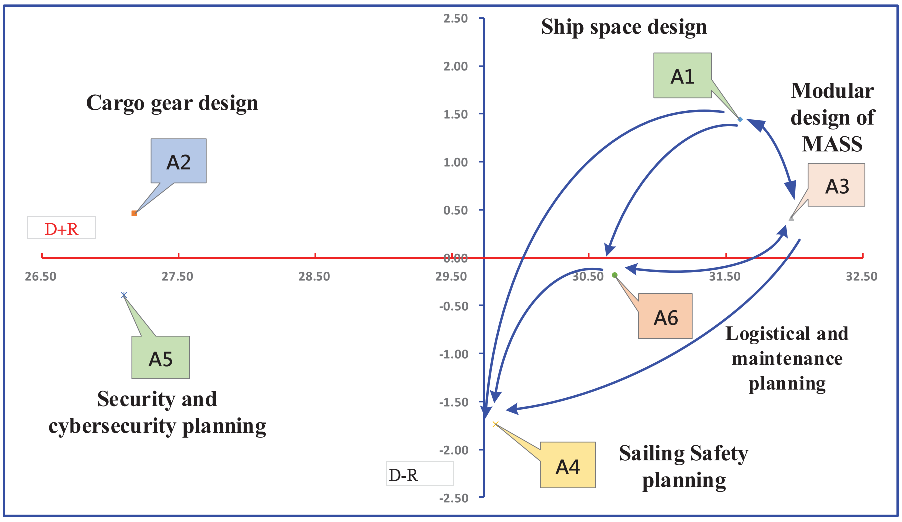

Figure 6. Ship developing criteria

and cybersecurity planning) were in Quadrant III. This implies that sailing safety planning is influenced by ship space design, MASS modular design, and logistics and maintenance planning. Ship space design and MASS modular design had a mutually influencing relationship; cargo gear design was independent and did not affect other criteria. Security and cybersecurity planning was entirely independent and unrelated to the other criteria.

Figure 7 presents the cause-and-effect relationships of the four criteria of Construct B. Criterion B1 (reform of nautical education) affected other criteria and was identified as the best target for resource allocation. Although Criterion B3 (AI input data) required the most management, it was influenced by B1. This suggests that a rational reform of nautical education should be prioritized. Crews with adequate nautical education can receive enhanced practical training to improve their collaboration with AI on MASS vessels, ensuring maximum safety. Criterion B4 (route monitoring) is influenced by both B1 and B3. Therefore, addressing B1 and B3 effectively addresses B4. Well-trained crew members and MASS AI can achieve easy monitoring of MASS decision-making and operations during voyages. In low traffic or absence of sensor alerts, crew members can relax from their vigilance and duty, trusting in the reliability of their MASS AI.

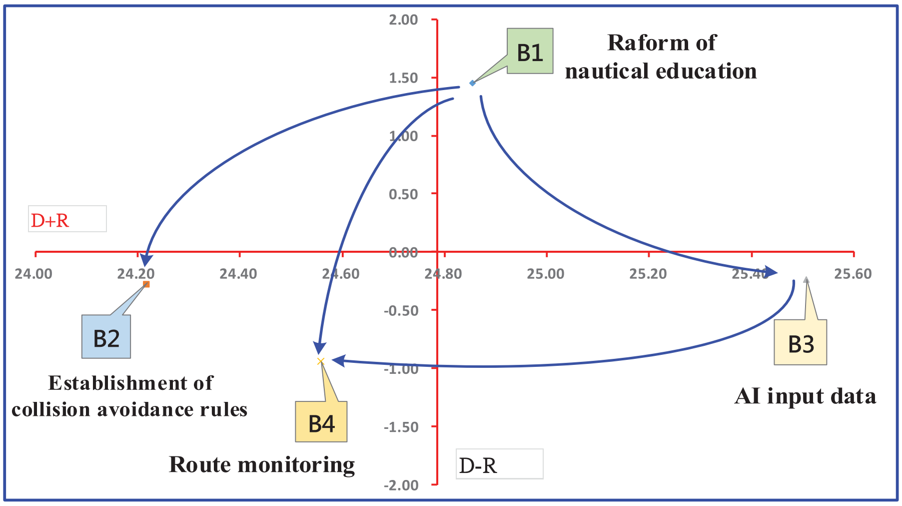

Figure 7. Navigation technologies criteria

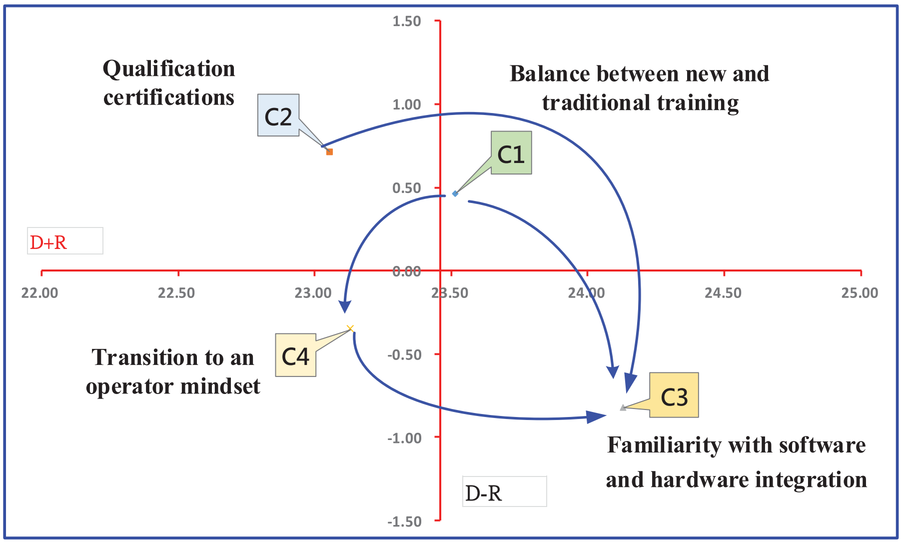

Figure 8. Crew training criteria

Figure 8 displays the cause-and-effect relationships of the four criteria of Construct C. Criterion C3 (familiarity with software and hardware integration) was influenced by the other three criteria. Hence, improving this criterion can be achieved by directing resources and effort towards C1 (balance between new and traditional training), followed by C2 (qualification certifications). This suggests that traditional teaching remains crucial for cultivating excellent ship crews, but new technology courses should be added to the traditional curriculum. Criterion C4 (transition to an operator mindset) is an independent criterion. Although it affects C3, this issue can be addressed by allowing ship crews more time to gradually adapt to MASS vessels.

Figure 9 depicts the cause-and-effect relationships of the four criteria of Construct D. Two criteria, D3 (ability of modular maintenance) and D4 (ability of monitoring AI decision-making), were influenced by D1 (ability of human–machine collaboration), which is therefore the highest priority and most crucial criterion requiring resource investment. MASS vessels must operate in all weather conditions, like traditional ships. Seafarers, whether on board MASS vessels or in ROCs, must possess the ability to cooperate with AI or remote technical specialists. Meanwhile, D2 (ability of traditional repair) also needs continued resource investment. However, because it is unrelated to other criteria, maintaining the current state suffices. Presently, seafarers are trained to

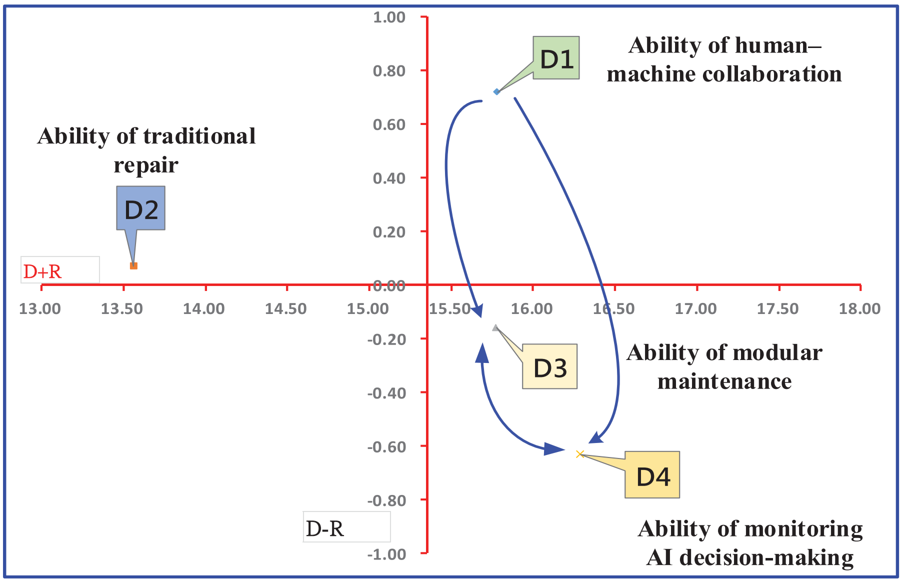

Figure 9. Seafarer competencies criteria

satisfy the maintenance and repair needs of ships, and this skill will also be applicable in the future for necessary hardware or module repairs on MASS vessels.

4.4 DISCUSSION ON THE WEIGHT OF ANP RESULTS

The ANP weight values of the constructs and criteria, respectively, are listed in Table 10. Criteria C3 (0.265), D3 (0.259), D4 (0.275), and B3 (0.260) were determined to be the most crucial effect clusters and should be should be prioritized for crew training resources. Combining the weight values with the DEMATEL results indicates that five criteria, A1, A3, B1, C1, and D1, should be prioritized when modifying crew training plans. After the above criteria are improved, this will affect whether the criteria in the quadrant IV are effective.

Furthermore, A2, C2, and D2 were identified as less important criteria, suggesting that less resources should be allocated then others. The development of new MASS vessels should be prioritized before any adjustments or improvements to cargo gear. Similarly, revisions to course content, teaching materials, teaching aids, and instructor qualifications should be considered before certification planning, particularly for establishing uniform international standards by the IMO, such as the Safety of Life at Sea Convention; MASS Code; the Standards of Training, Certification, and Watchkeeping for Seafarers (STCW); and model courses. Maintenance and repair skills are included in current training, and the experts believed that no modifications were necessary.

Table 11 summarizes the research findings. Criteria outside of Quadrant I, such as A5, B2, B4, C4 may not have the lowest weights. For example, cybersecurity is critical but is not a typical skill of ship crews. The ability of systems to thwart hackers should be a risk considered during the design phase, not a burden for ship crews to bear or a problem solved by training ship crews to code. Similarly, changes to collision avoidance rules cannot be directly implemented by ship crews or educational institutions; the IMO must make relevant decisions. Shifts in crew mind sets will requires time. The new training content will teach ship crews about their future roles on MASS vessels. The Table 12 presents the criteria weights categorized by the backgrounds of the experts.

In Table 12, the differences among experts are clearly and sensitively identified. Specifically, A1 shows simultaneous changes in both weight and causality cluster among government experts and is marked in blue. For the rest, if only one of either weight or causality changes, a light yellow highlight is applied.

Table 10. Weights of main construct and criteria

A 0.197				C 0.264			
B 0.264				D 0.293			
A1	0.169	B1	0.237	C1	0.245	D1	0.246
A2	0.150	B2	0.247	C2	0.240	D2	0.220
A3	0.177	B3	0.260	C3	0.265	D3	0.259
A4	0.177	B4	0.257	C4	0.249	D4	0.275
A5	0.154						
A6	0.173						

Table 11. DANP weights and ranking

Constructs	Weights	Code	Criterion	Overall Weights	Ranking	Cluster
A (Ship Developing)	0.197 (Cause cluster)	A1	Ship space design	0.169	4	Cause cluster
		A2	Cargo gear design	0.150	6	Cause cluster
		A3	Modular design of MASS	0.177	1	Cause cluster
		A4	Sailing Safety planning	0.177	2	Effect cluster
		A5	Security and cybersecurity planning	0.154	5	Effect cluster
		A6	Logistics and maintenance planning	0.173	3	Effect cluster
B (Navigation Technologies)	0.247 (Cause cluster)	B1	Reform of nautical education	0.237	4	Cause cluster
		B2	Establishment of collision avoidance rules	0.247	3	Effect cluster
		B3	AI input data	0.260	1	Effect cluster
		B4	Route monitoring	0.257	2	Effect cluster
C (Crew Training)	0.264 (Cause cluster)	C1	Balance between new and traditional training	0.245	3	Cause cluster
		C2	Qualification certifications	0.240	4	Cause cluster
		C3	Familiarity with software and hardware integration	0.265	1	Effect cluster
		C4	Transition to an operator mindset	0.249	2	Effect cluster
D (Crew Competencies)	0.293 (Effect cluster)	D1	Ability of human–machine collaboration	0.246	3	Cause cluster
		D2	Ability of traditional repair	0.220	4	Cause cluster
		D3	Ability of modular maintenance	0.259	2	Effect cluster
		D4	Ability of monitoring AI decision-making	0.275	1	Effect cluster

Therefore, Experts with different backgrounds had notable differences in perspective. Especially, for constructs A, experts from government agencies that regulate MASS prioritized its development with a focus on avoiding an excess of models or significant differences that could complicate regulations. They expected the IMO to establish unified mandatory standards. By contrast, industry experts focused on route monitoring, modular design of MASS, and logistics and maintenance planning. Given their role as operators and future adaptors of MASS vessels, this focus was logical. With fewer crew members on future MASS vessels and a streamlined manpower pool, reliable AI decision-making during navigation and modular software and hardware systems are vital to enable the replacement faulty modules without substantial cross-disciplinary training, enabling them to focus on logistics, supply, maintenance, and emergency measures. Therefore, the industry experts foresaw MASS technologies reducing the workload of ship crews. Academic experts, particularly those involved in seafarer education, were concerned with various criteria under the navigation technologies construct. They considered the reform of nautical education, the establishment of collision avoidance rules, and feeding knowledge to AI as interconnected. They considered route monitoring as least important, a view that contradicts that of industry experts. This is because academic teachers are not actual crew members on MASS vessels or operators in ROCs. However, they are still responsible for the nautical education of new seafarers suitable for MASS vessels. The categorization by expert backgrounds illustrates patterns that suggest the need for collaboration across various fields in future research on this topic. This study supports this view, aligning with the majority opinion in the literature.

Table 12. DANP weights and categorization for experts with different backgrounds

Constructs & Criterion	Weights & Ranking	Expert Backgrounds		
		Government	Shipping Business	Academic Institution
A	C: 0.197 (4)	C: 0.187 (4)	C: 0.204 (4)	C: 0.202 (4)
B	C: 0.247 (3)	E: 0.260 (3)	C: 0.209 (3)	E: 0.263 (2)
C	C: 0.264 (2)	C: 0.262 (2)	E: 0.281 (2)	C: 0.252 (3)
D	**E: 0.293 (1)**	**E: 0.291 (1)**	**E: 0.306 (1)**	**E: 0.284 (1)**
A1	C: 0.169 (4)	**E: 0.210 (1)**	C: 0.156 (4)	C: 0.149 (6)
A2	C: 0.150 (6)	E: 0.147 (6)	C: 0.145 (6)	C: 0.155 (5)
A3	**C: 0.177 (1)**	C: 0.155 (4)	**E: 0.204 (1)**	C: 0.174 (2)
A4	E: 0.177 (2)	C: 0.169 (3)	E: 0.165 (3)	**E: 0.191 (1)**
A5	E: 0.154 (5)	C: 0.149 (5)	E: 0.146 (5)	E: 0.163 (4)
A6	E: 0.173 (3)	C: 0.170 (2)	E: 0.185 (2)	E: 0.167 (3)
B1	C: 0.237 (4)	C: 0.207 (4)	C: 0.242 (3)	E: 0.254 (3)
B2	E: 0.247 (3)	E: 0.237 (3)	C: 0.226 (4)	**E: 0.270 (1)**
B3	**E: 0.260 (1)**	E: 0.275 (2)	C: 0.251 (2)	E: 0.258 (2)
B4	E: 0.257 (2)	**E: 0.281 (1)**	**E: 0.282 (1)**	C: 0.218 (4)
C1	C: 0.245 (3)	C: 0.250 (3)	C: 0.233 (4)	**C: 0.252 (2)**
C2	C: 0.240 (4)	C: 0.232 (4)	C: 0.242 (3)	C: 0.246 (4)
C3	**E: 0.265 (1)**	**E: 0.268 (1)**	**E: 0.280 (1)**	E: 0.251 (3)
C4	E: 0.249 (2)	E: 0.250 (2)	E: 0.245 (2)	**C: 0.252 (1)**
D1	C: 0.246 (3)	C: 0.248 (3)	C: 0.246 (3)	C: 0.245 (3)
D2	C: 0.220 (4)	C: 0.202 (4)	C: 0.210 (4)	E: 0.237 (4)
D3	E: 0.259 (2)	C: 0.249 (2)	E: 0.267 (2)	**E: 0.262 (1)**
D4	**E: 0.275 (1)**	**E: 0.301 (1)**	**E: 0.277 (1)**	C: 0.256 (2)

* The highest weights are highlighted in bold. C and E represent cause and effect clusters, respectively.

5. CONCLUSION AND SUGGESTIONS

5.1 CONCLUSION

This study explored the future roles of ship crews during the transition to Level 2 MASS technologies. Crews remain key players whose value increases as new technologies are introduced. The required technical skills and capabilities of future MASS crews are expected to surpass those of crews on traditional vessels. Currently, amid uncertainties related to international conventions, regulations, national laws, trust issues, and research and development outcomes, experts unanimously agree on the need for competent crews capable of serving on MASS vessels to ensure maritime safety as MASS technologies advance to Level 2. This is the primary requirement. Therefore, reforming crew training to align with the adaptation to new MASS technologies is crucial. Future research and development efforts should consider the scenario where MASS vessels still require crews on board after transitioning to Level 2. This includes considering crew training, skill development, and adaptability. Future research should focus on modular approaches, integrating the practical experiences of seafarers, developing more robust and reliable AI systems, simplifying operation software, and enhancing cybersecurity.

Through this study, the key factors with the highest weights were identified. Among them, Construct D (Crew Competencies) is the most important, with a standardized weight of 0.293. Among which Within the detailed criteria, D4 has the highest standardized weight of 0.275, indicating that future focus should be placed on the supervision issues of AI decision-making in MASS. Additionally, new MASS designs need to adopt modularization (A3 weight 0.177), in navigation technologies, appropriate ship control training data should be pre-inputted into the AI (B3 weight 0.260), and crew training should familiarize personnel with the integrated operation of future MASS software and hardware (C3 weight 0.265). Therefore, after transitioning to Level 2 MASS technologies, the most critical aspect to address in crew training adjustments is the crews' ability to monitor AI decision-making. However, this must first be addressed through the three constructs of Ship Developing, Navigation Technologies, and Crew Training.

This study contributes significantly by addressing the gap in MASS research, specifically the deficiencies in future training improvements and planning for ship crews. By analysing the cause and effect relationships and priorities of various criteria, this study provides planning recommendations from the perspective of all necessary participants, such as ship crews, regulatory authorities, shipping operators, academics, and research and development personnel. These suggestions serve as a reference for future efforts, facilitating the arrangement of crew training and the establishment of relevant schools, training institutions, or delegation to ship inspection organizations. This preplanning of subsequent strategies aims for mutual cooperation and learning. In a future of technological maritime operations, this helps gain a competitive edge while enabling seafarers to adeptly serve on technologically advanced MASS vessels. This approach prioritizes maritime safety and aims to alleviate regulatory doubts and safety concerns, fostering trust. The ultimate goal is to ensure that technology serves humanity rather than replacing us.

5.2 SUGGESTION

Navigational safety remains the primary requirement for MASS vessels. This core priority, upheld throughout this study, applies uniformly to the IMO, any country, and individuals in any role. The study offers the following suggestions to regulatory bodies like the IMO, policy makers of various countries, shipping companies and ship crews, and educational institutions:

1. The IMO has the authority to establish unified international standards. Currently, various research and development organizations, as well as related groups, are awaiting the revision of the MASS Code and corresponding regulations. Without established regulations for ships, similar to the already approved circular MSC.1/Circ.1638 concerning the regulatory framework for MASS vessels, the applicability of personnel is uncertain. The establishment of standards is the first key step, and some literature criticizes the inefficiency of IMO's approach (Stepien, 2023). Therefore, the IMO, the MSC, and the Joint Working Group should broadly incorporate opinions from the academic community, industry professionals, and regulatory authorities from various countries with different conditions to properly establish future unified international standards.
2. From a national perspective, referring to the criteria, causality, and importance identified in this study is advisable. Before the IMO sets a unified standard, proactive steps should be taken, such as inviting experts from various fields to contribute ideas, planning new crew training programs, establishing simulators, and making plans for certifications, teaching resources, seed instructors, international collaborations, and technical support from nationally commissioned accrediting organizations. Attention should also be given to colleges and universities involved in nautical education. Additionally, domestic laws should be reviewed and relaxed to facilitate the adaptation to new MASS technologies. Government agencies have a responsibility; a lack of proactive action will deny the country's seafarers the knowledge of future technologies, resulting in loss of employment opportunities due to insufficient technical competency. This is a consequence of national negligence and a lack of emphasis on maritime affairs. In addition, future research can include more discussions on the differences between national training standards and international standards, which will enhance international comparability.
3. For shipping companies, the full-scale deployment of MASS vessels in large-scale operations is premature. Existing vessels should be used for research and development, and a cautious management strategy should be adopted to benefit from these efforts. MASS technologies should further mature and companies should evaluate suitable operational routes before significantly investing in MASS.
4. Ship crews may be forced to adapt by taking new courses, learning new skills, and facing new competency assessments, but these can enhance their employment competitiveness. Even with the development of Level 3 or Level 4 MASS technologies, crews who are willing to learn and adapt, especially those with prior Level 2 experience, will remain vital in the shipping industry for remote monitoring and emergency intervention in AI decision-making. They need not fear being replaced by new technologies.
5. From an academic perspective, the recommendation that revised DEMATEL can be used in the future to replace DEMATEL, effectively addressing the issue of the initial direct-relation matrix in DEMATEL failing to converge. In addition, MASS vessels will require crews even after the introduction of Level 2 technologies. Crews on MASS vessels should have traditional nautical education, and schools should gradually incorporate basic courses related to MASS technologies in accordance with updates to the MASS Code, the STCW, and model courses. In the coming years, maritime academies and training institutions should assess whether their faculty are capable of cross-disciplinary teaching. It not, schools may consider hiring new teachers from fields such as systems engineering, computer science, information technology, AI, and control.

5.3 FUTURE RESEARCH SUGGESTION

For future follow-up studies, different methods can be attempted, if statistical approaches are used, sensitivity analyses should be included in the results section.

Additionally, the discussion and research methods on this topic can also attempt to conduct predictive analysis within the framework of more advanced levels of autonomy (levels 3 or 4).

Finally, the IMO and individual countries should begin preparing for the practical verification of adding specialized MASS training programs for crew, or the development of standardized AI monitoring protocols.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

1. AHMED, Y. A., THEOTOKATOS, G., MASLOV, I., WENNERSBERG, L. A. L. and NESHEIM, D. A. (2023). Towards autonomous inland waterway vessels - a comprehensive analysis of regulatory, liability and insurance frameworks. *WMU Journal of Maritime Affairs*. 23: 73–101.
2. ASPLUND, F. and ULFVENGREN, P. (2022). *Engineer-Centred Design Factors and Methodological Approach for Maritime Autonomy Emergency Response Systems*. Safety 8(54): 1–26.
3. BELLINGMO, P. R., WILLE, E., NORDAHL, H., MORKRID, O. E. and HOLTE, E. A. (2023). Analyzing the feasibility of an unmanned cargo ship for different operational phases. *International Journal on Marine Navigation and Safety of Sea Transportation*. 17(2): 397–404.
4. BLINDHEIM, S., JOHANSEN, T. A. and UTNE, I. B. (2023). Risk-based supervisory control for autonomous ship navigation. *Journal of Marine Science and Technology*. 28: 624–648.
5. CHANG, C. H., KONTOVAS, C., YU, Q. and YAN, Z. (2020). Risk assessment of the operations of maritime autonomous surface ships. *Reliability Engineering & System Safety*. 207: 1–24.
6. CHANG, E. W. and Tai, H. H. (2021). An investigation into switching vessel sizes for efficient container terminal operations: A case study of kaohsiung port. *International Journal of Maritime Engineering*. 163(A1): 101–118.
7. CHAN J. P., PAZOUKI, K. and NORMAN, R. A. (2023). An experimental study into the fault recognition of onboard systems by navigational officers. *Journal of Marine Engineering & Technology*. 22(2): 101–110.
8. CHEN, S. J., XIONG, X., WEN, Y. Q., JIAN, J. X. and HUANG, Y. M. (2023). State compensation for maritime autonomous surface ships' remote control. *Journal of Marine Science and Engineering*. 11(2): 1–15.
9. DITTMANN, K., HANSEN, P. N., PAPAGEORGIOU, D., JENSEN, S., LUTAEN, M. and BLANKE, M. (2021). *Autonomous Surface Vessel with Remote Human on the Loop: System Design for STCW Compliance*. IFAC-Papers On Line. 54(16): 224–231.
10. EMAD, G. R. and GHOSH, S. (2023). Identifying essential skills and competencies towards building a training framework for future operators of autonomous ships: a qualitative study. *WMU Journal of Maritime Affairs*. 22(4): 427–445.
11. FAN, C. L., WROBEL, K., MONTEWKA, J., GIL, M., WAN, C. P., and ZHANG, D. (2020). A framework to identify factors influencing navigational risk for maritime autonomous surface ships. *Ocean Engineering*. 202: 1–15.
12. FAN, S. Q. and YANG, Z. L. (2023). Analysing seafarer competencies in a dynamic human-machine system. *Ocean & Coastal Management*. 240: 1–9.
13. FENTON, A. J. and CHAPSOS, I. (2023). Ships without crews: IMO and UK responses to cybersecurity, technology, law and regulation of maritime autonomous surface ships (MASS). *Frontiers in Computer Science*. 5: 1–14.
14. HEFFNER, K. and RODSETH, Ø. J. (2019). Enabling Technologies for Maritime Autonomous Surface Ships. *Journal of Physics: Conference Series*. 1357. 242nd The Electrochemical Society, Trondheim, Norway, Oct 9–13: 1–12.
15. HOEM, A. S. (2023). *Risk Assessment in the Design phase of Maritime Autonomous Ships*. Ph.D. Thesis, Norwegian University of Science and Technology, Norway.
16. HWANG, T. M. and YOUN, I. H. (2022). *Navigation Scenario Permutation Model for Training of Maritime Autonomous Surface Ship Remote Operators*. Applied Sciences. 12: 1–11.
17. HWANG, T. W. and YOUN, I. H. (2022). Collision Risk Situation Clustering to Design Collision Avoidance *Algorithms for Maritime Autonomous Surface Ships*. Journal of Marine Science and Engineering. 10(10): 1–17.
18. ILLIASHENKO, O., KHARCHENKO, V., BABESHKO, I., FESENKO, H. and GIANDOMENICO, F. D. (2023). *Security-Informed Safety Analysis of Autonomous Transport Systems Considering AI-Powered Cyberattacks and Protection*. Entropy. 25(8): 1–35.

19. IMO (2021). *MSC.1/Circ.1638 Outcome of The Regulatory Scoping Exercise For The Use Of Maritime Autonomous Surface Ships (MASS)*. https://docs.imo.org/Category.aspx?cid=106 (Accessed 12 January 2024).
20. IMO (2023). *Resolution MEPC.377(80) 2023 IMO Strategy on Reduction of GHG Emissions from Ships*. https://wwwcdn.imo.org/localresources/en/MediaCentre/PressBriefings/Documents/Clean%20version%20of%20Annex%201.pdf (Accessed 12 January 2024).
21. iMoor System For any specific integrated berthing and mooring requirement Mampaey Offshore Industries offers the most complete suite of products and services (2023). https://www.mampaey.com/imoor-system/ (Accessed 12 January 2024).
22. INO, A., ENDO, N., FUJIMOTO, S. and IWANAGA, T. (2023). *A Study of Difficulties Surrounding Developing a Pattern to Fit the "the ordinary practice of seaman" as Autonomous Vessels Complicate Existing Navigation Rules*. Transactions of Navigation. 8(1): 1–9.
23. ISSA, M., ILINCA, A., IBRAHIM, H. and RIZK, P. (2022). *Maritime Autonomous Surface Ships: Problems and Challenges Facing the Regulatory Process*. Sustainability. 14: 1–13.
24. KARATUG, C., ARSLANOGLU, Y. and SOARES, C. G. (2022). *Determination of a maintenance strategy for machinery systems of autonomous ships*. Ocean Engineering. 266(3): 1–9.
25. KIM, T. E. and SCHRODER-HINRICHS, J. U. (2021). *Research developments and debates regarding Maritime Autonomous Surface Ship (MASS): Status, Challenges and Perspectives*. New Maritime Business. WMU Studies in Maritime Affairs. 10: 175–197.
26. KOO, H. H., CHAE, J. H. and KIM W. S. (2023). *Design and Experiment of Satellite-Terrestrial Integrated Gateway with Dynamic Traffic Steering Capabilities for Maritime Communication*. Sensors. 23(3): 1–19.
27. KURT, I. and AYMELEK, M. (2022). *Operational and economic advantages of autonomous ships and their perceived impacts on port operations*. Maritime Economics & Logistics. 24(1): 1–26.
28. LEE, G. J., LEE, D., CHOI, J. and KANG, H. J. (2023). *A Concept Study on Design Alternatives for Minimizing Accident Consequences in Maritime Autonomous Surface Ships*. Journal of Marine Science and Engineering. 11(5): 1–14.
29. LEE, H. T. and CHOI, H. M. (2023). *Passage Planning in Coastal Waters for Maritime Autonomous Surface Ships using the D Algorithm*. Journal of the Korean Society of Marine Environment & Safety. 29(3): 281–287.
30. LEE, P., THEOTOKATOS, G., BOULOUGOURIS, E. and BOLBOT, V. (2023). *Risk-informed collision avoidance system design for maritime autonomous surface ships*. Ocean Engineering. 279: 1–20.
31. LEVENE, M. and WOOLDRIDGE, J. (2023). *Certification of Machine Learning Applications in the Context of Trustworthy AI with Reference to the Standardisation of AI Systems.* NPL Report MS 45. NPL Management Limited, Middlesex, UK. ISSN:1754-2960.
32. LI, S. and FUNG, K. S. (2019). *Maritime autonomous surface ships (MASS): implementation and legal issues*. Maritime Business Review. 4(4): 330–339.
33. LI, Z. H., ZHANG, D., HAN, B. and WAN, C. P. (2023). *Risk and reliability analysis for maritime autonomous surface ship: A bibliometric review of literature from 2015 to 2022*. Accident Analysis & Prevention. 187: 1–16.
34. LIU, C. G., CHU, X. M., WU, W. X., LI, S. L., HE, Z. B., ZHENG, M., ZHOU, H. M. and LI, Z. X. (2022). *Human - machine cooperation research for navigation of maritime autonomous surface ships: A review and consideration*. Ocean Engineering. 246: 1–18.
35. LUCHENKO, D., GEORGIIEVSKYI, I. and BIELIKOVA, M. (2023). *Challenges and Developments in the Public Administration of Autonomous Shipping*. LEX PORTUS. 9(1): 20–36.
36. LYNCH, K. M., BANKS, V. A., ROBERTS. A. P. J., RADCLIFFE, S. and PLANT, K. L. (2022). *What factors may influence decision-making in the operation of Maritime autonomous surface ships? A systematic review*. Theoretical Issues in Ergonomics Science. 25(1): 1–45.
37. LYNCH, K. M., BANKS, V. A., ROBERTS, A. P. J., DOWNES, J., RADCLIFFE, S. and PLANT, K. L. (2023). *The application of a system-based risk management framework and social network analysis to the Maritime Autonomous Surface Ship system: Who are the decision-makers in the wider system?* Human Factors and Ergonomics in Manufacturing & Service Industries. 33(5): 395–429.
38. MILLEFIORI, L. M., BRACA, P., ZISSIS, D., SPILIOPOULOS, G., MARANO, S., WILLETT, P. K. and CARNIEL, S. (2021). *COVID-19 impact on global maritime mobility. Nature*. Scientific Reports. 11: 1–16.
39. MIYOSHI, T., FUJIMOTO, S., MATTHEW, R., KONISHI, T. and SUZUKI, R. (2022). *Rules required for operating maritime autonomous surface ships from the viewpoint of seafarers*. The Journal of Navigation. 75(2): 384–399.
40. MUNIM, Z. H. and HARALAMBIDES, H. (2022). *Advances in maritime autonomous*

surface ships (MASS) in merchant shipping. Maritime Economics & Logistics. 24: 181–188.

41. NARAYANAN, S. C., EMAD, G. R. and FEI, J. G. (2023). *Theorizing seafarers' participation and learning in an evolving maritime workplace: an activity theory perspective*. WMU Journal of Maritime Affairs. 22:165–180.
42. NAVARRO, A. P. (2023). *Ships of the future. Autonomous and intelligent.* Journal of Maritime Research. 20(2): 89–96.
43. OSALONIL, O. S. and AYENI, V. O. (2022). *The Development of Maritime Autonomous Surface Ships: Regulatory Challenges and the Way Forward*. Beijing Law Review. 13: 544–554.
44. PORATHE, T. (2022). *Remote Monitoring of Autonomous Ships: A Quickly Getting into the Loop Display (QGILD)*. Advances in Transportation. 60: 691–697.
45. SHAHBAKHSHA, M., EMADA, G. R. and CAHOONB, S. (2021). *Industrial revolutions and transition of the maritime industry: The case of Seafarer's role in autonomous shipping*. The Asian Journal of Shipping and Logistics. 38(1): 10–18.
46. SINOHARA, H. T. and TANNURI, E. A. (2022). *Port's technologies for autonomous ships in restricted waters*. Maritime Business Review. 7(1): 5–23.
47. STEPIEN, B. (2023). *Can a ship be its own captain? Safe manning of autonomous and uncrewed vessels.* Marine Policy. 148: 1–7.
48. TAKUYA, N., MOSER, B. and KAZUO, H. (2023). *Accelerated adoption of maritime autonomous vessels by simulating the interplay of stakeholder decisions and learning*. Technological Forecasting & Social Change. 194: 1–13.
49. TALMOR, P. B. and KITADA, M. (2022). *Industry 4.0 in shipping: Implications to seafarer's skills and training*. Transportation Research Interdisciplinary Perspectives. 13: 1–9.
50. THEOTOKATO, G., DANTAS, J. L. D., POLYCHRONIDI, G., RENTIF, G. and COLELLA, M. M. (2023). *Autonomous shipping - an analysis of the maritime stakeholder perspectives*. WMU Journal of Maritime Affairs. 22: 5–35.
51. TORBEN, T. R., SMOGELI, Ø., GLOMSRUD, J. A., UTNE, I. B. and SORENSEN, A. J. (2023). *Towards contract-based verification for autonomous vessels*. Ocean Engineering. 270: 1–17.
52. TZENG, G. H., CHIANG, C. H. and LI, C. W. (2007). *Evaluating intertwined effects in e-learning programs: A novel hybrid MCDM model based on factor analysis and DEMATEL*. Expert Systems with Applications. 32(4): 1028–1044.
53. UTNE, I. B., ROKSETH, B., SORENSEN, A. J. and VINNEM, J. E. (2020). *Towards supervisory risk control of autonomous ships*. Reliability Engineering & System Safety. 196: 1–15.
54. VEITCH, E. and ALSOS, O. A. (2022). *A systematic review of human-AI interaction in autonomous ship systems*. Safety Science. 152: 1–23.
55. WANG, D. L., WU, D. K., HUANG, C. G. and Wu, C. Y. (2020). *Marine Autonomous Surface Ship - A Great Challenge to Maritime Education and Training*. American Journal of Water Science and Engineering. 6(1): 10–16.
56. WANG, S. B., ZHANG, Y. J., ZHANG, X. G. and GAO, Z. J. (2023). *A novel maritime autonomous navigation decision-making system: Modelling, integration, and real ship trial*. Expert Systems With Applications. 222: 1–27.
57. WEN, Y. Q., HAHN, A., BANDA, O. V. and HUANG, Y. M. (2023). *Data/Knowledge-Driven Behaviour Analysis for Maritime Autonomous Surface Ships*. Journal of Marine Science and Engineering. 11(3): 1–4.
58. WONG, C. P. (2021). *Impact of the COVID-19 pandemic on the well-being of the stranded seafarers*. Maritime Business Review. 8(2): 156–169.
59. WU, C. B., YU, W. N., LI, G. Z. and LIAO, W. Q. (2023). *Deep reinforcement learning with dynamic window approach based collision avoidance path planning for maritime autonomous surface ships*. Ocean Engineering. 284: 1–16.
60. WU, G. X., LI, D. B., DING, H., Shi, D. D. and HAN, B. (2023). *An overview of developments and challenges for unmanned surface vehicle autonomous berthing*. Complex & Intelligent Systems. 10: 981–1003.
61. XU, H. T. and SOARES, C. G. (2023). *Review of Path-following Control Systems for Maritime Autonomous Surface Ships*. Journal of Marine Science and Application. 22: 153–171.
62. ZHAO, Z., TANG, L. J. and WU, Y. Y. (2023). *Fatigue during the COVID-19 pandemic: The experiences of Chinese seafarers.* Marine Policy. 153: 1–7.