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A human-centred review on maritime autonomous surfaces ships: impacts, responses, and future directions

Xue Li and Kum Fai Yuen

School of Civil and Environmental Engineering, Nanyang Technological University, Singapore, Singapore

ABSTRACT
Maritime autonomous surface ships (MASS) are transforming the future of maritime transport. They are expected to shoulder important roles in seaborne trade and maritime resilience. As the primary operator of traditional ships and a significant component of maritime transport, seafarers are inevitably directly and indirectly affected by levels of automation introduced into the shipping space. Therefore, in addition to increasing attention to automated system designs, a holistic understanding of human elements in MASS operations is necessary. The current research (1) reviews human-centred MASS research, (2) categorises MASS impacts on seafarers, and (3) summarises responses to prepare seafarers for this emerging technology. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses, a total of 101 articles were collected from Scopus. The systematic review reveals that MASS impacts seafarers from the following dimensions: employment, task contents, requisite skills, and human risks. Moreover, regulations and education frameworks can be adapted to respond to changes in seafarer demand and supply. Future research directions are also proposed and can serve as recommendations for future human-centred research on MASS. The research findings enhance the understanding of seafarer elements in MASS operations and provide policy implications for future seafarer management.

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1. Introduction

Technological advancement is transforming societies, cities, and especially human actors within the system, in many ways. Meanwhile, artificial intelligence is gradually penetrating into human life and challenging traditional human tasks in various industries, including the transport industry (Chinoracký & Čorejová, 2019; Frank et al., 2019). Albeit a relatively traditional industry, the maritime transport industry is being progressively revolutionised. The maritime autonomous surface ship (MASS) is a prominent concept that could reshape the current maritime market.

CONTACT Kum Fai Yuen kumfai.yuen@ntu.edu.sg School of Civil and Environmental Engineering, Nanyang Technological University, 50 Nanyang Ave, N1 01b-37, Singapore 639798, Singapore

MASS is defined as ships that can operate independently of seafarers with the assistance of artificial intelligence to various degrees (IMO, 2018). The level of dependency on seafarers and artificial intelligence varies with different levels of autonomy (LoA). There are several definitions of LoA. For instance, Bureau Veritas classifies MASS into six levels: systems operated by a human, systems directed by a human, systems delegated by a human, systems supervised by a human, and fully automated systems that only require human intervention (Marine&Offshore, 2024). Nevertheless, as the International Maritime Organisation (IMO) initiates MASS and serves as the global standard-setting authority of shipping, the regulatory system established by the IMO would be the universally acknowledged standard. IMO classifies four LoA: LoA one is defined as "*ships with automated processes and decision support*"; whereas automatic systems are available to assist ship operations, the seafarers are onboard and responsible for overall ship operations. LoA two is defined as "*remotely controlled ships with seafarers on board*" where MASS can be controlled by seafarers offshore; moreover, a small number of seafarers remain onboard and operate ship systems. LoA three is defined as "*remotely controlled ships without seafarers on board*" where MASS is controlled by seafarers in the remote-control centre without seafarers onboard. LoA four is defined as "*fully autonomous ships*' where the automation system can make decisions independent of the human operator.

As a huge vocational population including approximately 1.8 million seafarers and shouldering the responsibility of transporting goods up to 10.65 billion tons, seafarers are acknowledged as a significant component of the maritime transport (ICS, 2021a; UNCTAD, 2021). Conventionally, seafarers operate ships to transport goods worldwide safely with their sailing skills and sea experience. With the introduction of MASS and an increasing LoA, the roles of seafarers are evolving. Whilst certain traditional seafarer tasks can be replaced by shipping automation (e.g. the lookout on the bridge), seafarers can serve as reliable back-ups for automated system failures. Moreover, human roles will serve industry 5.0 in a different manner (Shahbakhsh et al., 2022).

Under these circumstances, in addition to focusing on MASS-related engineering projects, a human-perspective understanding of MASS is indispensable to better prepare the maritime industry to embrace foreseeable transformations. Nevertheless, a systematic review consolidating this stream of research is scarce. Therefore, the current research aims to systematically review this stream of literature from a human-centred perspective. In the current review, human-centred research is defined as research that discusses topics related to seafarers. This review provides a holistic summary of existing human-related topics of MASS. In addition, based on the research findings, critical research gaps and future research recommendations are provided.

2. Research design

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines were followed to systematically source peer-reviewed research articles and credible technical reports. To control the articles' quality, the articles were sourced from Scopus which is the largest peer-reviewed literature database. The research was conducted on 20th September 2023. Three-layer keywords are used to search articles. The first layer was composed of "autonomous' or "automation" or "digitalisation" or "unmanned"; the second layer was composed of "ship" or "vessel" or "maritime transport" or "sea shipping; the third layer was composed of "seafarer" or "human".

Then automatic screening and manual screening were conducted to screen out irrelevant articles. The eligibility criteria for the initial automatic screening were (1) articles that contain the abovementioned keywords in the title, abstract, or keywords; (2) articles that are written in English. A total of 3628 articles were found at this stage.

Next, manual screening was conducted by reviewing the abstract and contents to ascertain that the reviewed articles were consistent with the rationale of the current study. The exclusion criteria were articles that (1) do not investigate maritime autonomous surface ships (e.g. underwater autonomous ships); (2) have limited implications on human-relevant topics. After the manual screening and snowballing, a total of 123 articles and reports were screened out. 113 articles that meet the criteria remained for further analysis. As important findings can be obtained in the form of reports, a total of ten pieces of grey literature from the industry and public sector investigations (e.g. World Maritime University, International Chamber of Shipping, International Maritime Organisation) were included in the review.

3. Research outcomes

The research outcomes are presented following the results of two analyses: descriptive analysis and content analysis. The descriptive statistics are presented to provide an overview of the publication's characteristics. Next, the key research findings are summarised.

3.1. Descriptive analysis

The year and journal distribution of reviewed articles are presented in Figure 1. The majority of human-relevant MASS research was published in the recent four years (i.e. between 2020 and 2023), indicating that the human aspects of MASS are emerging topics and that they are gaining traction. Most outputs were published in journals related to maritime transport and safety. It is expected that with the development of MASS technologies and the growing interest in human roles in the automation era, human-related research is expected to proliferate in the future.

3.2. Content analysis

Adapting the classification process of Woo et al. (2012), the selected literature was grouped based on their research themes. An inductive approach was conducted to analyse the keywords and contents (Karjalainen & Juhola, 2021; Woo et al., 2012). The classification process was performed iteratively to avoid ambiguity between different categories.

The themes are identified and displayed with different colours as shown in Figure 2. The human-related contents are divided into two general topics: impacts and responses. The impacts are further analysed from three aspects: labour demand, labour supply, and safety performance. Regarding labour demands, three sub-topics are derived which are displayed in lighter blue blocks: employment, task contents, and requisite skills. Regarding the labour supply, occupational health and safety are discussed. Regarding safety

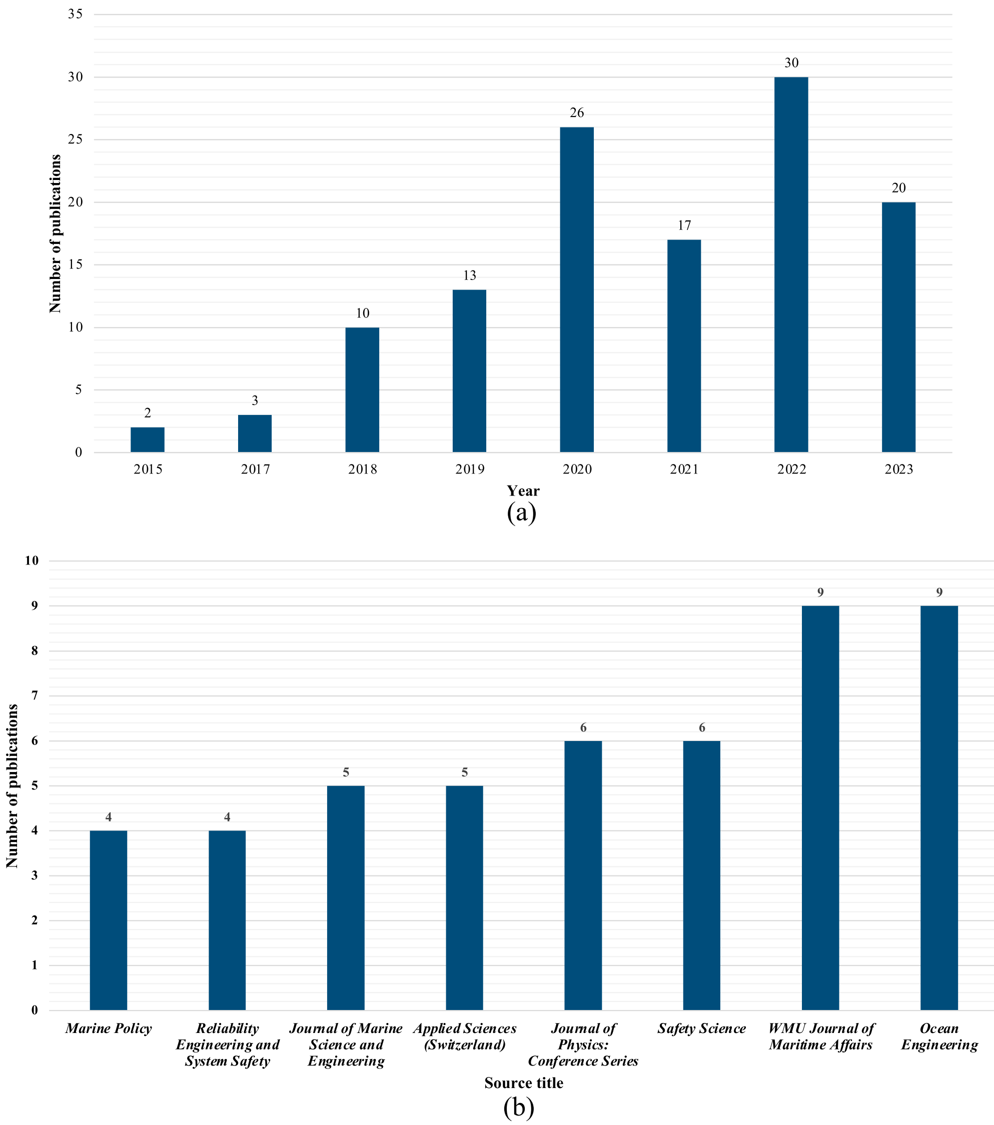

Figure 1. Statistical description: (a) Year distribution (b) Source distribution.
Note: Only sources that rank in top eight publications are listed.

performance, human risks are the primary concern. The responses, which are depicted using the orange block, concern the various strategies to respond to changes of labour demand and supply. Two sub-topics (i.e. education and training, regulation) are derived, which are displayed in lighter orange blocks.

3.2.1. MASS impacts on seafarers

This section explains the impacts of MASS on seafarers from different dimensions. As depicted in Figure 1, the impacts of MASS on seafarers can be analysed from the demand and supply perspective.

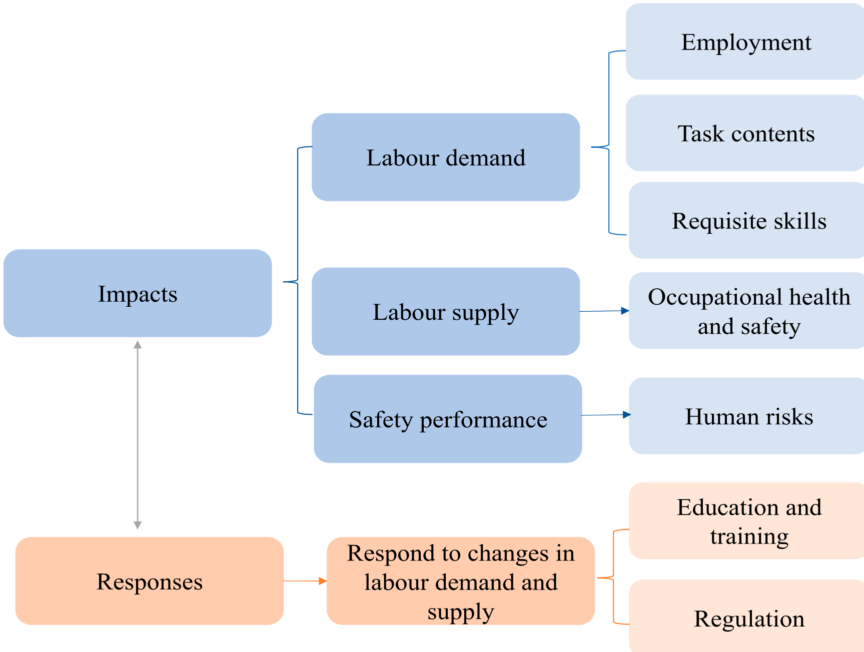

Figure 2. Research outcome framework.

3.2.1.1. MASS impact on seafarer employment. Automation has both displacement and reinstatement effects on employment. The former refers to the take-over of tasks by automation and the reduction of labour share whereas the latter refers to the increase of new labour share due to the creation of automation-complementary tasks (Acemoglu & Restrepo, 2019).

With the adoption of MASS and increasing LoA, onboard operational jobs will be gradually substituted by automated operation systems (Jo & D'agostini, 2020; S. Li & Fung, 2019). At LoA 2, a smaller number of onboard seafarers are required than manned ships; at LoAs 3 and 4, the demand for onboard crew will be removed. According to the forecast made by the ICS (2021b), the shortage of STCW-certified maritime officers is around 26,240. Consequently, the reduction or removal of onboard seafarers due to ship automation has the potential to offset seafarer supply shortage and relieve seafarer demand-supply imbalance (Lušić et al., 2019).

MASS could lead to the creation of complementary jobs and workforce shifts (Schröder-Hinrichs et al., 2019). The construction of the shore-based remote-control centres will lead to an increased demand for high-qualified seafarers as remote operators (Muslu, 2020). Complementary job positions would also include shipbuilding and infrastructure construction (Jo & D'agostini, 2020).

Despite the creation of complementary jobs, the reduction of the onboard crew may arouse fear about unemployment (Bogusławski et al., 2022). Whether unemployment can be a major problem depends on the actual size of displacement and reinstatement effects. Jo and D'agostini (2020) reported that the number of jobs created by the MASS-related industries, especially the shipbuilding sector, can largely surpass the number of jobs lost when MASS is fully introduced. However, due to limited research, more evidence is needed to support such forecast.

Moreover, consistent with the findings that automation supports gender equality, more opportunities for women seafarers could be expected in the future (Brussevich et al., 2019; Kim et al., 2019; Narayanan et al., 2023). As a culturally male-dominant industry, females face barriers such as harassment, stereotypes, excessive workload and poor working conditions; the new shore-based positions could resemble office-based jobs and therefore, encourage more female seafarers in the future (Kim et al., 2019).

3.2.1.2. MASS impact on seafarer task contents. The creation of seafarer positions onshore indicates a change in task contents compared to jobs onboard. Traditionally, a shipmaster holds the highest authority; the master is responsible for overall ship management and ensuring that everything is operated in accordance with existing regulations (Iordanoaia, 2010). The deck and the engine departments conduct ship operation tasks, including navigation, cargo maintenance, and machinery maintenance (Hannaford & Hassel, 2021). With the transition to MASS, traditional onboard operations will be gradually replaced by automated operation systems. The concept of remote control emerges and reinstates seafarers into new tasks. Onboard seafarers will be gradually shifted to offshore centres and it is hypothesised that the control centres are composed of remote operators, engineers, supervisors, and a captain (MacKinnon et al., 2015; Man et al., 2015).

Whilst comprehensive task contents have not been identified due to insufficient empirical tests on MASS, researchers have proposed several core tasks for remote operators (MacKinnon et al., 2015; Ramos et al., 2018b; Ramos et al., 2019). If the automated system is operating well and no human intervention is required, remote operators are assumed to shoulder the role of passive, continuous monitoring (Veitch & Alsos, 2022). Nevertheless, if there is a potential risk or a circumstance that the automated systems cannot handle, remote operators are anticipated to be actively involved in ship operations and provide assistance. They should continuously supervise MASS operations, be well aware of the current situation, detect alarm alerts and make responses (Veitch & Alsos, 2022). Situation awareness and fault recognition have been emphasised in the existing literature (Jevon Philip Chan et al., 2022b; Veitch et al., 2020). Remote operators should possess situation awareness with the automated maneuvering system, including the collection of information from the display, comprehending and analysing the information timely and accurately (Ramos et al., 2019). During the remote control of MASS, remote operators should communicate with other autonomous or manned ships to avoid collisions (van den Broek et al., 2020). If there is any emergency, remote operators should decide on the response strategy. The decision whether to take control of the ship and implement appropriate actions should be made wisely and quickly to ensure the operation's safety. Meanwhile, if human operators encounter difficulties, they can contact the supervisor or the team for assistance; after deciding on the strategy, operators should send commands to the automated maneuvering system correctly (Ramos et al., 2019).

A key issue related to task contents concerns the task distribution between human operators and the automated operation system. The task distribution requires effective collaboration between humans and machines. Human operators can implement different levels of interventions in the automated operation (Dellner, 1981). It is notable that human efficiency should be considered in different levels of human-machine collaboration; the design of interaction systems should be compatible with human cognitive processes and support human operators' decision-making and reactions (Bainbridge, 1983). To address this issue, the understanding of human operator behaviour in integrated systems is important. According to existing research (Aarsæther & Moan, 2010; Wu et al., 2021), the development of appropriate interaction design (e.g. display, alarm, human-centred artificial intelligence system) is necessary.

3.2.1.3. MASS impact on requisite seafarer skills. To exert comparable advantages of humans and take advantage of the interplay between automation and seafarers, the training of requisite skills is important and researchers are working on the identification of essential competencies for new task contents (Autor, 2015; Ceylani et al., 2022; Emad & Ghosh, 2023; Kennard et al., 2022; Y. Li et al., 2019). Due to the different task contents between offshore and onboard work, a mismatch between traditional skills and future requisite skills can happen. A categorisation of redundant and requisite skills for future seafarers is summarised in Figure 3.

With the replacement of onboard operations by the automated operation system, there are certain skills that are required for working in the remote-control centre (Bachari-Lafteh & Harati-Mokhtari, 2021). Nevertheless, the emphasis on emerging skills does not mean that traditional skills and sea experiences will be completely redundant; some traditional skills can be retained and transferred (Ceylani et al., 2022; Kennard et al., 2022). For example, human operators should have acute ship sense when they are geographically separated from ships and obtain information remotely from displays or with extra assistance from a few seafarers on board (i.e. under LoA2) (Dybvik et al., 2020; Zhu et al., 2019). In this case, seafarer experiences are expected to help operators make better judgments remotely (Kennard et al., 2022).

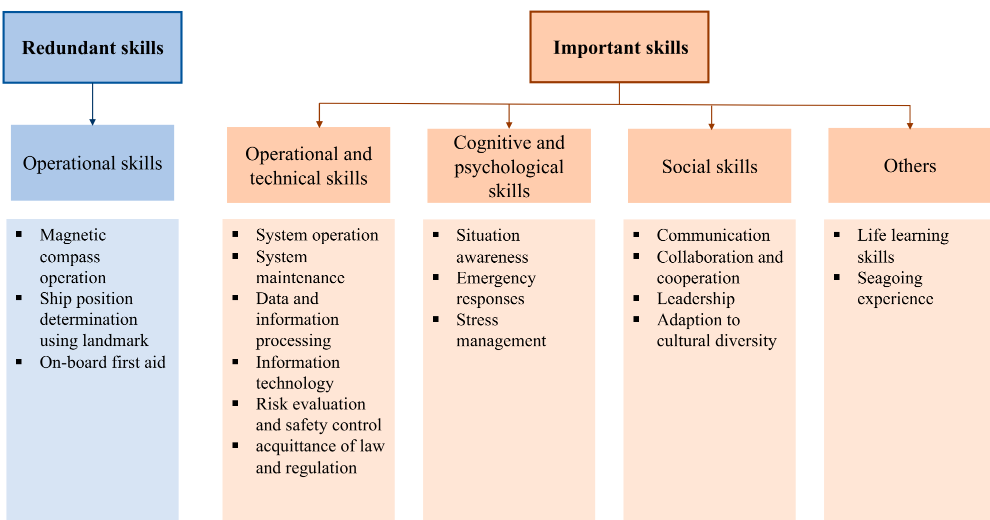

Figure 3. Redundant and critical skills for MASS.

In addition to the retention of critical skills, seafarers will need skill upgrading to adapt to different task contents. Working remotely and controlling MASS via the remote maneuvering support system requires more interactions with computers than working on manned ships. A hybrid of MASS-related technical (e.g. information technology skills, understanding of navigation-related technologies) and non-technical skills (e.g. cognitive skills, communication skills) would become increasingly important (Ceylani et al., 2022; Kennard et al., 2022; Sharma & Kim, 2021).

Limited research studies have concentrated on the skillsets of future marine engineers. Some key competencies such as the ability to operate automated control systems, as well as maintain and repair electric equipment have been identified by existing studies (Kidd & McCarthy, 2019; Lokuketagoda et al., 2018; Tusher et al., 2021).

3.2.1.4. MASS impact on seafarer occupational health and safety. Changes in future seafarers' working conditions can have impacts on their occupational health and safety (Li et al., 2022). On the one hand, onboard repetitive operational tasks can be replaced by automated systems, which theoretically can support seafarers and free seafarers from much physical work (Ölçer et al., 2023; Kim & Schröder-Hinrichs, 2021). On the other hand, new job demands indicate that seafarers can be exposed to occupational health risks related to office-like remote working, such as mental stress, computer-related injuries (e.g. motion sickness) and sedentary-related injuries (Ramos et al., 2018b; Wahlström et al., 2015). As stated by the technostress theory, if the technology creates demands exceeding employees' capabilities, employees may experience negative health outcomes such as stress and burnout (Maier, 2014). Seafarers shall adapt to new working environments; they will not have a direct observation of their surroundings when working ashore; the physical constraints and limited visibilities can reduce remote operators' confidence to correctly judge a situation (van den Broek et al., 2020; Yoshida et al., 2020). Moreover, human-automation communication is different from human-human communication in that the responses are usually generated based on predefined algorithms. When seafarers work with automated systems, they should be able to exhibit situation awareness, correctly understand an automated system's intention and deal with conflicts between human judgments and the system's decision-making (J. Choi & Lee, 2022; van den Broek et al., 2020). Therefore, if the design of the remote-control centre and automated systems are not sufficiently transparent, and seafarers lack enough emergency response capabilities, seafarers could be more stressed due to the complexities of conducting tasks (Yoshida et al., 2021).

Health and safety conditions have been recognised as an important consideration in seafarers' choice to enter or continue to stay in the maritime industry (Oldenburg et al., 2010). The demands created by automation-complementary job positions, the new working environments, and associated occupational health and safety could affect future seafarer supply. Therefore, preparations to support seafarer health and safety during the automation transition are needed.

3.2.1.5. MASS impacts on human risks. Human errors are commonly considered to be a main cause of accidents (Harrald et al., 1998). As traditional on-board operations will be gradually replaced by automated systems with the increase of LoA, a few traditional human risks (e.g. cargo mishandling, watchkeeping errors) will be a less significant concern for MASS. Therefore, understanding human risks under MASS operations is important for seafarer management and risk mitigation in the future.

Currently, several research has investigated potential causes or events of human failure and proposed potential measures to mitigate the risks (C. Fan, Wróbel, et al., 2020; Ramos et al., 2020). Potential human factors leading to the risks are summarised in Figure 4. These risk factors are categorised into functional aspects, which encompass operational risks, and non-functional aspects, which involve cognitive and social risks. Operational risks, particularly those related to data reading and information technology, deserve special attention due to the growing interaction with automated systems. Additionally, compared to conventional shipping, cognitive factors can play an increasingly critical role in human operator performance.

Existing research suggests that operators may need to monitor several autonomous ships simultaneously, necessitating multitasking (MacKinnon et al., 2015). This aligns with the cognitive load theory, which asserts that the design of automated systems and the flow of information can impact a person's cognitive load, with information overload being identified as a potential trigger for human errors (Plass et al., 2010; Ramos et al., 2018a). Another significant cognitive concern discussed in the previous literature is automation bias, where seafarers may become overly complacent or reliant on automated systems (Jevon P Chan et al., 2022a). Complacency towards automation can lead to the degradation of human capabilities, resulting in lower situation awareness due to overreliance on automated systems. Consequently, seafarers may not react quickly enough when they need to take over system control or may lack confidence in their decision-making abilities. In addition, the changes in human risks call upon the consideration of critical risk factors under the risk assessment for human reliability. For instance, a notable research trend is the incorporation of human psychological factors into risk assessment and machine learning-related methods (Cheng et al., 2023; S. Fan et al., 2023; S. Fan & Yang, 2023).

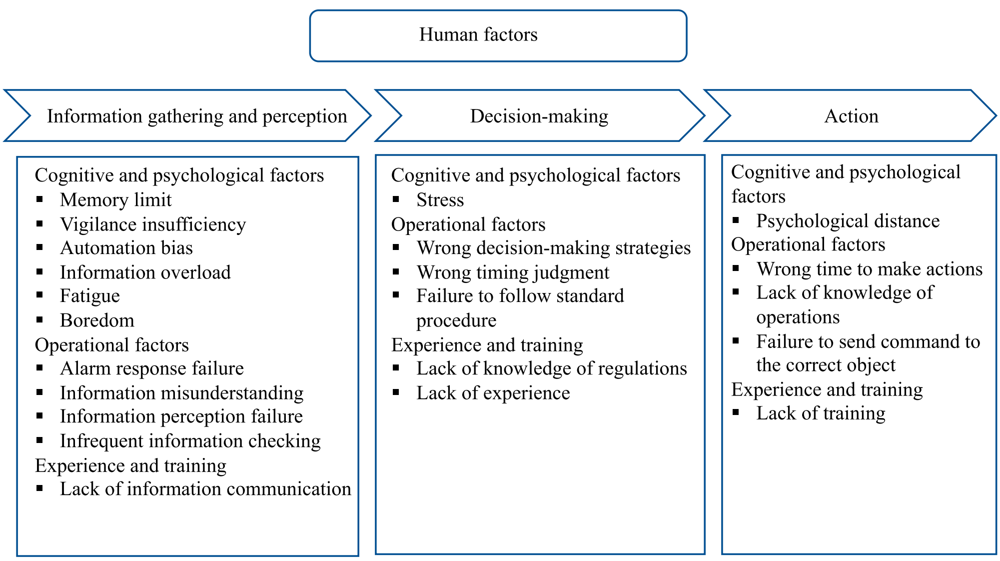

Figure 4. Summary of potential human factors.

It is essential to recognise that human risks will not be entirely eradicated with the introduction of automation (Ramos et al., 2020; M. Zhang, 2020). The automation does not completely eliminate humans from the operation; seafarers are likely to support MASS by working on board, remotely controlling ships at remote control centres, and performing monitoring duties (Bainbridge, 1983; Rødseth et al., 2023). For instance, human operators shoulder important responsibilities during tasks related to remote control, such as information gathering, processing, decision-making, and action execution. Therefore, humans can be considered as a “contributer” rather than a complete “threat” to maritime safety by identifying and controlling adverse conditions (Bainbridge, 1983). In this light, based on the understanding of risk factors that can lead to human errors, researchers can take a further step by exploring ways to encourage human operators to make appropriate decisions under complex conditions.

3.2.2. Educational and regulatory responses

This section describes the responses to MASS impacts on seafarer structural changes from education and regulation perspectives.

3.2.2.1. Maritime education and training. Primarily, the education and training of seafarers are realised from two channels: (1) formal university education and education provided by international organisations (e.g. IMO); (2) practice and training throughout seafarers’ careers (Lušić et al., 2019).

The content of standardised IMO Maritime Education and Training courses, such as modules on navigation, should be revamped to include requisite skills of MASS. For instance, the module provided by IMO (e.g. module 7.03 which introduces officers’ watchkeeping duties and principles at the operational level) should fit with the skill upgradation and different task contents (Belev et al., 2021; Lušić et al., 2019). In addition, technology-centric training such as simulation, virtual realities, and computer-based e-learning can be a powerful pedagogical tool to help seafarers achieve requisite technical skill and cognitive skills efficiently.

Simulation training has been designed to train seafarers to react to different scenarios with excellent situation awareness (Hwang & Youn, 2022; Kataria & Emad, 2022; Lokuketagoda et al., 2018; Saastamoinen et al., 2019). The benefits of simulation include the ability to attain a deeper understanding of accidents safely in controlled environment, the ease of replicating events numerous times, economic efficiency, the ease of generating various scenarios, and the ability to store relevant data in databases for record and learning purposes (Jevon P Chan et al., 2022a; Young & Lenné, 2017). Nevertheless, simulation-based training has disadvantages. For example, the cost can be huge to create simulated environments; simulated motion sickness can harm seafarers (Jevon P Chan et al., 2022a; Young & Lenné, 2017). It is suggested that more scenario-based simulation training and other appropriate pedagogical methods be proposed and tested to effectively train seafarers’ technical and non-technical skills to handle remote operations safely.

3.2.2.2. Regulation adaptation. From a legal perspective, it is important to develop regulations to support MASS operations. Rooted on the understanding of the MASS operation, task contents and requisite skills of future seafarers, a series of necessary regulatory revisions are suggested, such as navigation, liability and responsibility, and competencies from the International Regulations for Preventing Collisions at Sea (COLREGs) and Standards of Training, Certification, and Watchkeeping (STCW) (S. Li & Fung, 2019; Luchenko et al., 2023; Miyoshi et al., 2022; Porathe, 2019a).

As navigation control systems should be able to make sensible decisions based on algorithms, key terms in regulations are suggested to be quantified when incorporated into the navigation systems (Miyoshi et al., 2022). The quantification of responses in different conditions specified by regulations can make MASS's decision predictable by human operators and therefore, beneficial to achieve consistency and foster trust between humans and automated control systems (Perera & Batalden, 2019).

In addition, the adaptation of key definitions to MASS is another focus of existing research. For example, the traditional concept of "seamanship" might not apply to remote operators (Sharma & Kim, 2021). Furthermore, the STCW should be adapted to cater to emerging seafarer competency needs. Consistent with the changes in seafarer competencies, STCW can be revised to give a clear baseline for seafarer education and training (Yoshida et al., 2020).

4. Discussions and future directions

In the above section, the contents of reviewed articles are categorised and discussed from two themes: impacts and responses. This section synthesises the limitations of previous research and proposes future research directions.

4.1. Direction 1: Skill structure and educational framework

The adoption of MASS within maritime transport unquestionably necessitates a significant advancement in skill sets. This transformation has prompted numerous researchers to proactively propose critical competencies to accommodate the evolving job demands on seafarers (Sharma & Kim, 2021). However, it is crucial to acknowledge that a comprehensive competency framework is not something that can be swiftly modified. Hence, it is recommended that an evolving skill shift structure be established through continuous research. Such a structure can yield far-reaching implications, not only for the revision of the STCW but also for maritime education and training as a whole.

Moreover, it is noteworthy that there has been an oversight regarding the specific skill sets required for marine engineers. The maritime landscape is poised for a significant shift, with marine engineers transitioning to shore-based personnel, where they will be entrusted with a diverse set of responsibilities (Lokuketagoda et al., 2018). Hence, it is imperative to extend the focus beyond navigation operators and delve into the competencies required for other crucial personnel stationed at the remote-control centre, including engineers and supervisors.

To respond to changes in seafarer job demands and prepare seafarers so that they can successfully interact with automation, it is suggested that a dynamic and forward-thinking pedagogical framework be designed to develop required technical and non-technical skills. The changes in LoA and automated technologies would bring challenges to the established pedagogical systems. Based on the updated understanding of task contents, requisite skills, and potential human risks, the need for education and training should be continuously assessed. Furthermore, the detailed pedagogical framework can be discussed from both technology-centric and non-technology-centric perspectives. Discussion on technology-centric education such as simulation has been discussed (Hwang & Youn, 2022; Lokuketagoda et al., 2018). This stream of research can be further extended by experimenting and designing effective simulations, virtual realities, and e-learning education. It should be emphasised that educational tools such as simulation cannot train human operators on events with low probabilities or are not known thus far (Bainbridge, 1983). Therefore, training to make human operators resilient and adaptable to unpredictable situations is important. Moreover, pedagogical tools such as role-playing exercises, team-building activities, collaborative problem-solving exercises, case studies and disruptive scenario planning can be utilised to develop remote operators' non-technical skills (e.g. communication, problem solving and leadership skills).

4.2. Direction 2: Human welfare

Seafarers' welfare with the introduction of MASS is an essential topic. The analysis can be conducted for two types of seafarers: those working on conventional ships and those whose tasks have evolved remotely due to the increasing achievements of LoA.

In the report published by ICS (2018), eighty percent of surveyed seafarers expressed anxiety about the introduction of MASS; this can be triggered by worries about the loss of employment. Regarding seafarer employment, it cannot be overlooked that the gradual replacement of seafarer work on board will be accompanied by the creation of employment in autonomous ship-complementary fields (Acemoglu & Restrepo, 2019). This effect has been observed in other industries such as the financial industry (Autor, 2015). Nevertheless, the size of displacement and reinstatement effects associated with the introduction of MASS in the short run and the long run is yet to be accurately predicted, which deserves more exploration from the economic perspective. In addition, the influence of autonomous shipping on seafarer wages is worth investigating. The introduction of MASS is predicted to lower the operational costs of maritime transport, but discussions on whether there will be an increased wage due to skill upgradation and the effects of automation on the wage for existing seafarers on conventional ships are lacking in the existing academic research.

In the context of MASS, the cognitive, psychological, and physiological states of seafarers are subjected to the dynamic effects of novel task content. The implementation of automation, in theory, promises a reduction in fatigue and workload, replacing mundane tasks (Lee et al., 2020). However, the change in the work nature indicates that seafarers are anticipated to conduct more cognitively demanding tasks. They may also face time pressure during complex situations. The extent to which operating computers remotely and engaging in communication with other vessels may impose additional stress on seafarers necessitates deeper scrutiny. Therefore, in the transition from conventional ships to autonomous ships, additional insights into ways to physically and mentally prepare seafarers for employment structural changes are necessary.

4.3. Direction 3: Human safety performance

Safe and efficient interactions between remote operators and the automated operation system are important components of operational safety. At the current stage, most research is based on conventional expectations of automated technologies. With the development of automated technologies and the achievement of higher levels of LoAs, the task contents and required skills of operators could be continuously reflected and investigated. An updated understanding of the characteristics of automated technologies and training requirements could facilitate efficient task distribution between seafarers and the automated operation system, enhancing safe human-autonomous systems interaction.

Nevertheless, it is inevitable that seafarers will need to adapt to the new working environment when operating MASS. Their tasks may be more cognitively demanding, and their performance may vary under different conditions (Bainbridge, 1983; Hollnagel, 2018). Therefore, studies on the promotion of safety performance and the reduction in variability of remote operator performance are of great importance.

Currently, research on human risks and performance within the context of MASS is at the initial stage. There is a limited amount of both exploratory and empirical studies on the human performance research (Allal et al., 2017; Ramos et al., 2018a; Ramos et al., 2018b; Ramos et al., 2019; D. Zhang et al., 2022). In risk analysis research, a common approach is to identify, assess, and control risk factors to mitigate adverse situations. At the current stage, there are no available accident reports for analysis, and the research is focused on predicting potential risk factors based on existing assumptions about MASS operations. For instance, human reliability analysis has served as a solid foundation for analysing potential human errors that can occur under remote control based on the current understanding of MASS (Allal et al., 2017). In addition, Bayesian networks have been used to analyse the causality between potential risk factors, and expert judgment is used in tandem to quantitatively evaluate the priority of risks using probability theory (Fan, Blanco-Davis, et al., 2020). This method can be further applied in the autonomous shipping context to provide a better understanding of the factors that may lead to unsafe events and generate strategies to mitigate the risks.

It is worth noting that, due to resource limitations, the assessment of risks can serve as a reference for effective resources allocation (Hollnagel, 2018). This provides implications for maritime managers to improve safety efficiently. In addition, MASS is being developed and its LoA will be gradually evolving in the future. It is expected that seafarers' working conditions can be more complicated with the development of such systems, the increase of LoA, and the co-existence of ships of different LoAs during the process. There is a high probability that seafarers would deal with both autonomous ships and conventional ships when performing remote control operations. As seafarers serve as an important resource to support MASS safety through monitoring and supervising, these complicated cognitive-demanding situations require seafarers to be more flexible in responding to different events at sea and at the remote-control centre. Under these circumstances, a categorical view of a good system leads to safety and a malfunction leads to accidents or incidents may not be sufficient (Hollnagel, 2018). Hence, it is suggested that in addition to the causal analysis between risk factors and failures and the constraints on non-normative behaviour, the perspectives of what adjustments remote operators can make to assist in the safety of MASS operation can be examined. In other words, researchers are suggested to consider the underlying mechanisms that shape seafarers' dynamic decision-making and propose strategies to motivate seafarers to take appropriate actions (Leveson, 2002).

In addition, it is necessary to support human performance via the design of interaction systems (Bainbridge, 1983). The autonomous behaviour of systems would influence the interaction between operators and the autonomous systems (Porathe, 2019b). A challenge in designing automated systems is to make the decisions of artificial intelligence transparent and explainable to operators and stakeholders (Alsos et al., 2022). Therefore, researchers are suggested to investigate automation transparency, or artificial intelligence transparency, to facilitate a better understanding, confident and efficient control, and take-over between operators and machines.

Overall, by understanding how remote operators' performance may vary in collaborating with automated systems as well as social and organisational conditions, strategies can be formulated to train operators to be skilled at making adjustments based on their states and anticipations (Leveson, 2002). Thereafter, seafarers can be conditioned to be responsive to the changing conditions (e.g. the compensation behaviour for missing information or mental model flaws) and proactively support maritime safety.

Another consideration is related to the data issues in human performance analysis. It should be admitted that currently, the primary data sources are from experiments, trials and subjective judgments. Given the time required for the development of MASS and the current lack of real-world data, expert judgment can serve as a valuable source for seafarer risk management. Nevertheless, limitations associated with subjective judgements and a lack of data for the application machine-learning-related techniques remain. To address this issue, future researchers can ethically leverage real digital information for the analysis of remote operator human risks. For example, companies such as MagellanX are actively working on utilising real-time situational data of seafarers' health conditions which can then be used to understand human operators' reactions in different scenarios and conduct safety-related analyses (Snyder, 2023). Furthermore, when accident reports become available, more objective data can be gathered and utilised.

4.4. Direction 4: Regulatory adjustments

To respond to changes in task contents, adapted international, national, and industrial preparedness should be revised. With regard to international regulations, previous research has discussed the revisions of CORLEGs in detail. Whilst the International Convention for the Safety of Life at Sea is also mentioned, the detailed contents are relatively less discussed. Moreover, consistent with the ample research on requisite skills, STCW code modification corresponding to seafarers' competencies, applicable simulation designs, and other training updates are worth further investigation. Therefore, discussion on regulations that can be modified to accommodate MASS should continue. Furthermore, researchers posited that different countries possess their own unique characteristics and pace in implementing national regulatory changes; some can be faster than international legislation (de Klerk et al., 2021). Therefore, more research on national responses can be conducted based on the special characteristics of different regions.

5. Conclusions

Seafarers can undertake different yet important roles in future MASS operations. With increasing research and tests on MASS, the way automation technology impacts seafarers and prepares seafarers to work in an automated era are essential for the shipping industry. Therefore, the current research consolidates previous human-related MASS research, categorises the main findings and proposes future research recommendations.

Based on the reviewed research articles and reports, a systematic review of MASS impacts on seafarers from demands, supply, and safety performance perspectives, as well as responses to the potential impacts is provided. It was found that from a labour demand perspective, the introduction of MASS could both gradually displace onboard crew and create complementary onshore and other supplementary job positions; the structural change of employment leads to different task contents and demands, which require different working skills. Moreover, the changing working demands can influence occupational health which may further influence seafarers' employment choices. Furthermore, the influence of automation on the safety performance of seafarers is a critical concern for maritime transport. The responses to MASS impacts are discussed from educational and regulatory perspectives. Education serves as the foundation for building seafarer knowledge and competencies. Therefore, a state-of-the-art pedagogical framework should be adapted to support MASS operational requirements. Moreover, regulatory preparedness can be developed both internationally and nationally. Overall, the amount of existing research on the topic of the human elements of MASS is limited. Research papers on the topic have only started growing in the past three years. Despite the growth, research on the topic remains limited and more research can be conducted in the future.

The current review contributes to the existing literature by presenting significant findings and highlighting the roles of seafarers in automated maritime transport. The findings provide policy implications on seafarers' management. Firstly, to enhance preparedness for the impacts of MASS on seafarers' employment, labour policies can focus on adapting seafarers' skills to the changing demands of the industry. This may involve providing training programmes and educational resources to help seafarers acquire the requisite technical and non-technical skills needed for remote operations and automation-related jobs. Moreover, the potential for increased opportunities for women in the maritime industry due to the shift towards remote-based positions should be acknowledged and supported. Policies promoting gender equality in the maritime industry, such as addressing issues of harassment and improving working conditions for female seafarers, could be encouraged. Secondly, given the changing nature of seafarer tasks and the introduction of remote control centres, occupational health and safety policies should address potential mental and physical problems associated with office-like remote working and provide seafarers with a safe and healthy working environment, both onboard and at remote control centres. In addition, policies should encourage comprehensive training programs that equip seafarers with the skills and knowledge required to handle the complexities of remote operations and automated systems. This includes training in human-automation communication, situation awareness, and emergency response capabilities. Thirdly, policymakers at the international level should work on establishing clear and updated regulations specific to MASS operations, including those related to navigation, liability, and competencies. These regulations should consider the evolving nature of seafarer roles and responsibilities. National governments should also be prepared to make regulatory adjustments that may be required at a national level, as regulations related to the maritime industry can vary from one country to another. Fourthly, policymakers should encourage research and practices related to risk assessment in MASS operations, considering both operational risks and cognitive risks associated with human-automation interaction. Strategies for managing human performance from a combined Safety I and Safety II can be developed. Policies should also encourage research optimising human-centred artificial intelligence systems that enhance collaboration between remote operators and automated systems.

In the future, researchers can continue to collect articles and grey literature from other databases and enrich human-centred MASS research based on the current research findings. Furthermore, lessons from other developed industries (e.g. the aviation and road transport industries) can be drawn. For example, there has been a lot of human factor research in the autonomous vehicle field. Similarities can be found when comparing the research between maritime and road transport. The topics relevant to human elements are similar to a certain degree, such as the creation of trust (J. K. Choi & Ji, 2015), human–computer interaction in system designs (J. Zhang et al., 2021), and liability issues (Inners & Kun, 2017). Experiences from other transport sectors can be applied to the maritime transport industry (Wahlström et al., 2015).

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