

Transformation of Maritime Industry through Autonomous Ship: A Systematic Review of Operational Landscapes

Ashari Fitra Rachmannullah¹, Afifah Nurrosyidah², Adel Gohari¹

Maritime Autonomous Surface Ships (MASS) is reshaping maritime industry by introducing automation, affecting port infrastructure, workforce, and regulatory frameworks. This study aims to systematically review the current state of research on MASS and assess its transformative impacts on maritime industry. A systematic analysis was conducted of 45 articles that were selected from 524 articles on the Web of Science (WoS) database through PRISMA process. Emerging keywords such as *model*, *system*, and *bibliometric* suggest a growing interest in technological integration and meta-analytical approaches. Moreover, the analysis highlights the need for greater attention to port integration, regulatory compliance, workforce transformation, and infrastructure readiness to support the adoption of MASS. This review highlights the importance of interdisciplinary collaboration and policy adaptation to ensure the effective and responsible integration of MASS into maritime operations.

KEY WORDS

- ~ MASS
- ~ Autonomous ship
- ~ Systematic literature review
- ~ Maritime industry

¹ Universiti Malaysia Terengganu, Faculty of Maritime Studies, Kuala Terengganu, Malaysia

² Independent Researcher, Titik Jeda Global, Surabaya, Indonesia

e-mail: ashari.fitra@umt.edu.my

doi: 10.7225/toms.v15.n02.w02

Received: 1 Aug 2025 / Revised: 27 Feb 2026 / Accepted: 10 May 2026 / Published: 20 May 2026

This work is licensed under



1. INTRODUCTION

Nowadays, technology is reshaping the roles of humans across various sectors, including transportation (Frank *et al.*, 2019). In this context, maritime transportation is also being transformed by new technologies. This is especially important because global economy depends heavily on shipping, with more than 80% of goods around the world being transported by sea (The World Bank, 2023). In recent years, the emergence of autonomous ships has gained significant attention, driven by their potential to transform maritime operations that have traditionally relied on human crews (Chaal *et al.*, 2023; Munim & Haralambides, 2022a; Osaloni & Ayeni, 2022; Yanchin & Petrov, 2020). Autonomous and unmanned ships promise to enhance efficiency, reduce operational costs, and improve safety, particularly in complex or hazardous maritime environments (Gantiva Osorio *et al.*, 2024; Negenborn *et al.*, 2023). Therefore, autonomous shipping has attracted growing attention from both industry and academia. This growing work highlights the transformative potential of autonomous ships and signals a significant shift in the future of maritime transportation.

Research and development related to maritime autonomous surface ship (MASS) operations has experienced significant growth over the past decade. The technical aspects of MASS have dominated studies, particularly in areas such as collision avoidance (Cui *et al.*, 2025; He *et al.*, 2024; F. Zhu *et al.*, 2025) and cybersecurity (Kouroupis & Sotiropoulos, 2024; Peng *et al.*, 2025; Smacki *et al.*, 2024; Symes *et al.*, 2024). Economic discussions have largely centered on the cost-saving potential of MASS, including reduced operational and voyage expenses (Kooij & Hekkenberg, 2022). In the context of maritime industry adaptation, much of the existing literature has focused on sustainability-related outcomes, such as reducing carbon emissions (Xing, 2024) and promoting environmental responsibility (Acciaro *et al.*, 2014). While MASS offers numerous advantages, its implementation also brings significant challenges. For example, in the supply chain context, the integration of autonomous ships may lead to job displacement (Shahbakhsh *et al.*, 2022) and increased complexity in coordination between traditional and automated systems (Zhou *et al.*, 2025). These unintended consequences highlight the double-edged side of automation, offering benefits on one hand while generating new risks and gaps on the other. While all the above-mentioned studies addressed various aspects of MASS, there is a lack of study to systematically review the academic literature in regard to how the maritime industry is structurally and operationally adapting to the emergence of MASS. Conducting such a review is important since it enables us to determine how effectively MASS technologies can be implemented, particularly in the operational areas such as supply chain, business structure, and workforce management.

Therefore, it is essential to conduct a comprehensive literature review that captures the transformative impact of MASS on the maritime industry. This study specifically examines how autonomous ships have reshaped industrial practices, with particular attention to the processes of transformation and the challenges associated with adaptation. Unlike previous reviews, which primarily emphasize technological developments, regulatory frameworks, or safety dimensions (Özkan & Sevgili, 2025; Chaal *et al.*, 2023; Belabyad *et al.*, 2025a), this study improves the discussion by integrating bibliometric analysis with a systematic thematic synthesis to examine autonomous shipping from an industrial transformation perspective. By bridging quantitative bibliometric mapping with qualitative systematic review, this study provides a multidimensional understanding of how MASS drives structural transformation. Methodologically, this study integrates the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework for systematic screening with bibliometric document co-citation analysis and thematic synthesis. This approach enables both structural mapping of the intellectual landscape and in-depth interpretation of industrial transformation patterns. In other words, it examines how autonomous ships reshape operational models, business ecosystems, workforce structures, and maritime value chains, rather than concentrating solely on technical dimensions.

This review examines the extent to which autonomous ships have influenced maritime industry, with a specific focus on industrial transformation and the challenges associated with adaptation. This also explores potential future research directions from an industry-centered perspective in the era of autonomous maritime transportation. The focus is on examining the extent to which maritime industry has been influenced, transformed, and redefined by increasing levels of automation. Accordingly, the research questions guiding this review are the following:

RQ 1. What are the research trends related to industry-centered view in autonomous ship over the past decade?

RQ2. What is the operational transformation introduced by autonomous ships in maritime industry?

RQ3. What are the potential future directions for research of autonomous ship in the maritime industry perspectives?

The remaining study is structured as follows: Section 2 elaborates on the research methodology; Section 3 presents the research findings by visualizing the top research and trends; in Section 4, a comprehensive discussion is provided along with the implications; Section 5 concludes the study and points to the limitations of the research.

2. METHODOLOGY

The article selection for analysis was conducted in accordance with the PRISMA framework, which provides standardized guidelines for conducting systematic literature reviews (Page *et al.*, 2021). Figure 1 illustrates the PRISMA-flowchart process employed in this systematic review.

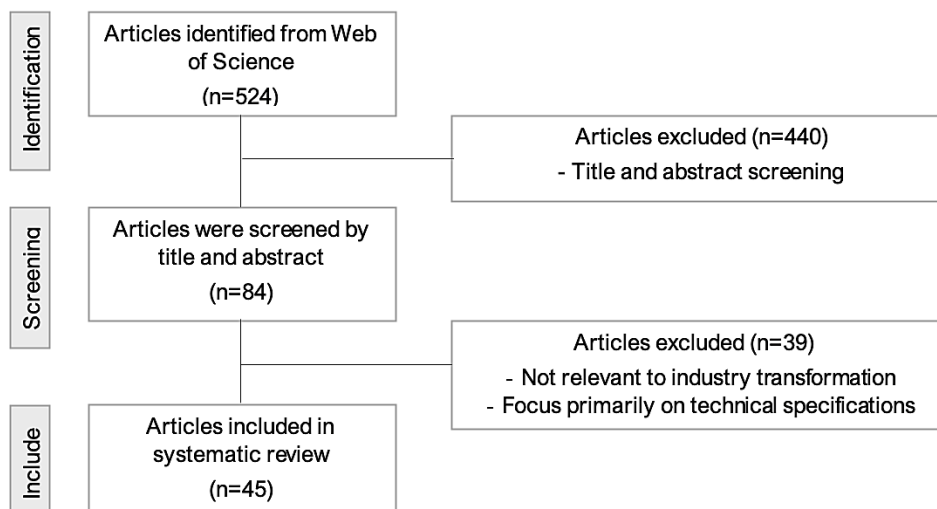


Figure 1. PRISMA framework

We used specific inclusion (IN) and exclusion (EX) criteria. In the identification stage, the Web of Science (WoS) Core Collection was selected as the primary data source for the literature search as it encompasses high-quality academic journals and conference proceedings across diverse disciplines (IN 1). The search conducted on 30 June 2025 using the terms *MASS*, *industry* and *maritime* as the core search keywords. Publications between 2010 and 2025 were selected (IN 2) using the English language (IN 3). This was applied using structured search formulas within the WoS Core Collection to ensure precision and comprehensiveness in the retrieval process: $TS=(autonomous\ ships\ OR\ maritime\ autonomous\ surface\ ships\ OR\ MASS\ OR\ autonomous\ vessel^*)\ AND\ TS=(logistics\ OR\ supply\ chain\ OR\ industry\ 4.0\ OR\ industry\ OR\ supply\ chain\ resilience\ OR\ green\ logistics\ OR\ automated\ logistics\ OR\ industrial\ automation)\ AND\ ALL=(marine\ OR\ maritime)$. Conference proceedings were included in the dataset due to the emerging nature of MASS-related studies, which are frequently presented at academic conferences prior to journal publication. In addition, non-English publications (EX 1), editorial materials, book reviews, abstract-only papers, and duplicate records were excluded (EX 2). The search strings used in this study yielded a total of 524 results. In the screening stage, the inclusion and exclusion criteria for this study were established to ensure relevance and quality of the selected literature. Each article's title and abstract were examined to confirm its relevance to MASS. Studies were included if they explicitly focused on MASS as a primary research subject and examined its implications within industrial, operational, organizational, or systemic maritime contexts (IN 4). Studies were excluded if they only focused on technical or engineering specifications, such as navigation algorithms, control systems, hardware design, or sensor optimization, without linking these developments to broader industrial or operational transformation (EX 3). To ensure the relevance and quality of the selected database in the systematic review, a thorough article-by-article screening of the search results was conducted, considering the contextual relevance. The study had to include content related to the maritime industry or industrial applications of MASS, as indicated in the introduction or background sections. The primary aim of this screening process was to identify a specific literature that analyzed MASS within industrial contexts such as operations and logistics. Only the studies with a clear focus on MASS were considered for inclusion. Then, the remaining 84 records have been selected for further processing in the next step.

Thus, the scope of the selected studies was restricted to those that directly align with the specified thematic areas. Several sources were eliminated as they contained advanced technical content not aligned with the research objective. Following this manual review process, a final set of 45 papers was retained. These constitute the core dataset used in the systematic literature review in the study.

Additionally, we also included the quantitative analysis to map the research trends, influential publications, and key contributors by examining citation networks and keyword patterns (Öztürk *et al.*, 2024). The quantitative bibliometric analysis will identify document co-citation analysis (DCA) and qualitative thematic synthesis through silhouette values and the Log-Likelihood Ratio (LLR) cluster labeling to provide both structural and interpretative insights into the MASS research. This DCA analysis will enable the identification of intellectual structures, knowledge clusters, and thematic evolution within the field (Chen *et al.*, 2010). The integration of bibliometric mapping with thematic analysis is particularly appropriate for

examining industrial transformation as it allows the study to move beyond isolated technological discussions and, instead, capture systemic shifts in operations, governance, safety frameworks, and port–ship ecosystems. This methodological design therefore enhances both analytical depth and conceptual clarity, making the study’s contribution distinct from prior reviews that focus primarily on technological or regulatory dimensions. CiteSpace Version 6.4.R2 was utilized as a tool for data visualization to map research trends and structures. Therefore, this meticulous review process helps identify gaps in the existing literature and supports a focused thematic discussion, ensuring that key topics related to MASS in the maritime industry are thoroughly addressed.

3. RESULTS

3.1. RQ1: Top article and research trends

The result highlights the foundational studies and research categories. Table 1 presents the leading countries contributing to research on autonomous vessels. Notably, regions such as China, various European nations, South Korea, and the United States have already initiated efforts toward the commercialization of autonomous shipping technologies (Chen *et al.*, 2025). In recent years, China has emerged as a prominent global maritime power, with the development of unmanned vessels poised to significantly impact the nation's maritime industry.

No	Country	Record count
1	China	163
2	Norway	78
3	South Korea	50
4	England	47
5	Finland	46
6	Netherlands	38
7	Poland	27
8	Russia	22
9	USA	22
10	Germany	20

Table 1. Top productive countries

Table 2 offers the findings regarding the most productive journals covering MASS research in the industry. The leading journal is *Journal of Marine and Engineering*, with 61 articles among 524 eligible articles. Engineering journals dominate the publication landscape in this field, reflecting the highly technical nature of research on MASS.

No	Journal	Record count
1	<i>Journal of Marine and Engineering</i>	61
2	<i>Ocean Engineering</i>	51
3	<i>Reliability Engineering System Safety</i>	16
4	<i>Marine Intellectual Technology</i>	15
5	<i>Safety Science</i>	13
6	<i>IEEE Access</i>	11
7	<i>Journal of Marine Engineering and Technology</i>	11
8	<i>Marine Policy</i>	11
9	<i>WMU Journal of Maritime Affairs</i>	11
10	<i>Maritime Economics Logistics</i>	7

Table 2. Top productive journals

In addition, examining the WoS subject categories is essential for identifying the disciplinary trends. As shown in Table 3, *Engineering marine* emerges as the leading category, with a total of 199 publications. Interestingly, several non-maritime disciplines (such as *Electrical and Electronic Engineering*, *Telecommunications*, and *Computer Science*) also exhibit a significant number of contributions, indicating the interdisciplinary nature of research on MASS.

No	WoS Category	Record count
1	<i>Engineering marine</i>	199
2	<i>Oceanography</i>	141
3	<i>Engineering ocean</i>	132
4	<i>Operation research management</i>	69
5	<i>Transportation</i>	48
6	<i>Engineering electrical electronic</i>	47
7	<i>Telecommunications</i>	46
8	<i>Computer science</i>	44
9	<i>Information systems</i>	38
10	<i>Artificial intelligence</i>	29

Table 3. Top WoS categories

The 442 publications were published by 524 institutions. Table 4 shows the ten most productive institutes in MASS research. Three of these are based in China, while the others are located in Europe, Hong Kong, and Singapore. As a university specializing in maritime studies, Dalian Maritime University ranks second among the most productive institutions with 37 publications.

No	Institution	Record count
1	Wuhan University of Technology	59
2	Dalian Maritime University	37
3	Aalto University	31
4	Delft University of Technology	28
5	Norwegian University of Science Technology	25
6	Liverpool John Mores University	22
7	Shanghai Maritime University	21
8	Korea Maritime Ocean University	18
9	Hong Kong Polytechnic University	12
10	Nanyang Technological University	9

Table 4. Top institutions

To explore recent research trends on how MASS affects maritime industry, we looked at keywords with strong bursts of activity, shown in Table 5. In more recent years, keywords such as *model*, *system*, and *bibliometric analysis* have emerged with citation bursts extending into 2025, suggesting a shift toward system modeling, and technology optimization. These trends indicate a progression from feasibility studies to efforts aimed at improving operational performance through advanced simulations and decision-support systems. These two topics highlight the main directions in the current MASS research. Significantly, *bibliometric analysis* appears as a citation burst starting in 2024 and extending into 2025. This suggests that bibliometric methods are becoming increasingly popular in synthesizing existing literature and identifying strategic research gaps in the evolving MASS landscape.

Top 10 Keywords with the Strongest Citation Bursts					
Keywords	Year	Strength	Begin	End	2017 - 2025
<i>maritime safety</i>	2020	2.07	2020	2021	
<i>safety assessment</i>	2020	1.18	2020	2020	
<i>human factor issue</i>	2020	1.18	2020	2020	
<i>maritime autonomous surface ships</i>	2021	1.76	2021	2023	
<i>impact</i>	2022	1.98	2022	2023	
<i>model</i>	2021	1.41	2023	2025	
<i>system</i>	2023	1.4	2023	2025	
<i>optimization</i>	2023	1.38	2023	2023	
<i>design</i>	2023	1.37	2023	2023	
<i>bibliometric analysis</i>	2023	1.15	2024	2025	

Table 5. Top keywords

In this study, we also applied DCA, which identifies groups of closely related articles based on their citations. This method reveals thematic linkages and structural patterns among the cited literature (Chen *et al.*, 2010). The network construction and visualization were performed using CiteSpace. The citation network was visualized in Figure 2, with each node representing an article from our dataset. The clusters were ordered by size, from the largest (#0) to the smallest (#3). To label each cluster, we employed the LLR algorithm, which identifies the most representative term based on the keyword (Chen, 2014; Gaggero *et al.*, 2020). The resulting clusters are as follows: Cluster #0 as *Autonomous Ship System*, Cluster #1 as *Port Operation*, Cluster #2 as *Autonomous Surface Ship* and Cluster #3 as *Safety Acceptance Principle*.

Cluster #0: Autonomous ship system

This is the largest cluster, which contains 43 articles with a silhouette value of 0.78. The cluster mainly explores the development progress, risk analysis, and broader implications of autonomous ships. It reflects growing academic attention to the technological readiness, regulatory concerns, and the operational impact of these vessels. One of the key contributions in this cluster is Chaal *et al.* (2023) entitled *Research on risk, safety, and reliability of autonomous ships: a bibliometric review*.

Cluster #1: Port operation adaptation

The second-largest cluster, which consists of 32 articles with a silhouette value of 0.813, is labeled port operation and focuses on the challenges ports face in adapting to autonomous shipping operation (Ghaderi, 2019; Munim & Haralambides, 2022a; Tsvetkova & Hellström, 2022). Topics include infrastructure upgrades, digital integration, and changes required in port management to accommodate MASS. For instance, the articles by Kurt & Aymelek (2022, 2024) are prominent in this cluster to identify the MASS impact on port operations.

Cluster #2: Autonomous surface ship

This cluster includes 25 articles with a silhouette value of 0.821 and shares similarities with Cluster #0 but emphasizes surface ship applications specifically. A key example is the highly cited article by Jovanović *et al.* (2024), titled *Review of Research Progress of Autonomous and Unmanned Shipping and Identification of Future Research Directions*, which provides a comprehensive overview of existing studies and future directions in autonomous surface shipping.

Cluster #3: Safety acceptance principle

The smallest cluster, with 15 articles, stands out with a high silhouette value of 0.875. This group focuses on safety issues related to autonomous ships, including risk assessment frameworks, accident prevention strategies, and the human-machine interface in safety-critical scenarios. The most cited articles include Bolbot *et al.* (2025), which investigates safety acceptance principles for autonomous ships, and Corsi *et al.* (2025), which explores certification requirements for maritime autonomous surface ship operation.

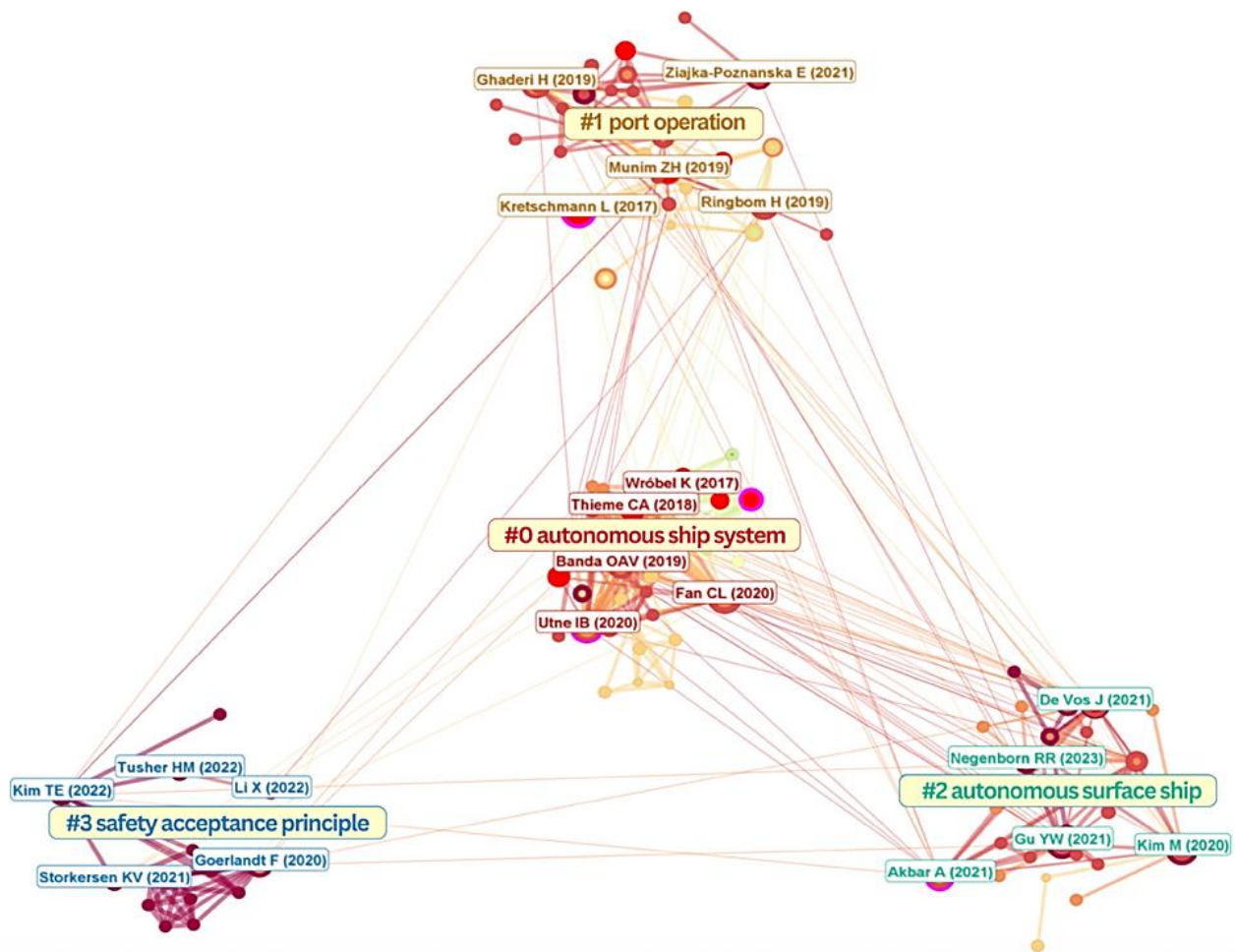


Figure 2. Cluster visualization

Although the clusters appear as distinct thematic domains, they collectively reflect interconnected dimensions of maritime industrial transformation driven by autonomous shipping. Cluster #0 (*Autonomous ship system*) and Cluster #2 (*Autonomous surface ship*) both represent the technological and systemic foundation of MASS development, focusing on technical readiness, regulatory considerations, and operational implications. However, the deployment of autonomous ship systems directly necessitates structural adjustments within ports (Kurt & Aymelek, 2024; Karatvuo *et al.*, 2022), as reflected in Cluster #1 (*Port Operation Adaptation*). Port digitalization, infrastructure upgrades, and operational reconfiguration are not independent developments but adaptive responses to the technological maturity outlined in Cluster #0. Furthermore, safety and acceptance issues identified in Cluster #3 intersect closely with both technological development and port adaptation. The introduction of autonomous vessels requires new risk assessment frameworks, certification mechanisms, and human–machine interface standards, which influence both shipboard systems and port operational protocols (Bolbot *et al.*, 2025; Chaal *et al.*, 2023; Chang *et al.*, 2021). Workforce training and role redefinition, implicitly embedded within port adaptation and safety discussions, emerge as a cross-cutting theme linking these clusters. Overall, the clusters illustrate that MASS transformation is not purely technological but systemic. In this case, technological innovation (Cluster #0) triggers operational restructuring in ports (Cluster #1), which must be stabilized through safety governance and acceptance frameworks (Cluster #3), while being synthesized conceptually within broader maritime discourse (Cluster #2).

3.2. RQ2: Transformation of maritime industry driven by MASS

MASS offer not only economic advantages but also logistical benefits for shipping companies and their stakeholders (Abudu & Bridgelall, 2024; Ghaderi, 2019; Goerlandt, 2020; Symes *et al.*, 2024; Wu *et al.*, 2024). However, the impact of MASS extends far beyond cost reduction, it constitutes a system-level innovation with the potential to fundamentally reshape global supply and logistics chains (J. Chen *et al.*, 2019; Kurt & Aymelek, 2022; Tsvetkova & Hellström, 2022). Following this, MASS adoption may require structural realignment to accommodate new modes of operation (Ghaderi, 2019; Munim & Haralambides, 2022a; Tsvetkova & Hellström, 2022). As the logistics ecosystem adapts to automation, traditional models of coordination and control are likely to evolve. For instance, shippers may be affected over cargo movement through highly automated and transparent supply chains that integrate MASS, smart ports, and other digital innovations. Moreover, the

operational flexibility introduced by autonomous technologies enhance service coverage and goods distribution, especially during the transitional phase from conventional vessels to autonomous ships (Gu *et al.*, 2021).

Maritime industry is adopting innovative advanced technologies to promote more sustainable, energy-efficient, and cost-effective operations, aligning with the sustainability objectives outlined by the United Nations. Ongoing investments and pilot projects clearly show that autonomous vessels are becoming more integrated into the shipping industry (Toni, 2024). The goals such as achieving net-zero emissions by 2050, with the integration of artificial intelligence and large-scale automation, are not only reshaping logistics and service delivery but also redefining the roles, interests, and dynamics among industry stakeholders (Zhang, 2025). The implementation of MASS challenges the sustainability of traditional business models within maritime supply chains (Bălan, 2020). These developments signal a broader transformation in the logistics landscape, one in which automation not only enhances efficiency but also redefines the roles, relationships, and value flows within the maritime supply chain. As a result, further research is needed to examine how MASS affects information visibility and sharing across different stages of the supply chain, as well as to identify potential challenges to achieving seamless integration. Drawing from the systematic literature review conducted in this study, two primary areas within the maritime industry emerge as undergoing substantial transformation:

Port digitalization

Alongside benefits such as reduced costs, enhanced safety, and greater revenue potential, MASS has the capacity to contribute significant value to the broader logistics ecosystem. However, this potential requires the development of smart port infrastructure as foundational prerequisites (Munim & Haralambides, 2022b). The integration of port infrastructure, digital information networks, and transportation systems is becoming increasingly important, reflecting a broader shift of maritime operations (J. Chen *et al.*, 2019; Corsi *et al.*, 2025; Heikkilä *et al.*, 2024; Ho & Lee, 2024). This evolution highlights the growing operational demands placed on ports, which must adapt to accommodate the technological and logistical requirements of autonomous vessels (Burciu & Abramowicz-Gerigk, 2023; Chou *et al.*, 2022; Ghaderi, 2019; Kurt & Aymelek, 2022; W. Zhang & Wang, 2020). As MASS technology evolves, shipping companies, port authorities, and maritime regulatory agencies must develop a comprehensive understanding of its navigational requirements to effectively plan port infrastructure and establish appropriate safety regulations for future operations (Chou *et al.*, 2022; Zhu & Xing, 2022).

However, from an operational aspect, cybersecurity has emerged as a critical challenge in the implementation of advanced technologies across maritime industry (Bogusławski *et al.*, 2022; Chang *et al.*, 2021; Kouroupis & Sotiropoulos, 2024; Peng *et al.*, 2025; Symes *et al.*, 2024). The maritime sector's heavy dependence on interconnected digital infrastructures, such as navigation, communication, cargo tracking, and ship management systems, further increase the exposure to cyberattacks. These systems are often integrated with external networks, creating potential entry points for malicious actors. Additionally, the complexity of the maritime supply chain, which involves diverse stakeholders including shipbuilders, shipping company, and other operators, further exposes it to cyber threats. Specifically, MASS have been identified as easy-to-breach security systems (Munim *et al.*, 2025; Symes *et al.*, 2024). The consequences of successful cyberattacks can be severe, ranging from financial impact, cargo loss, to escalate in extreme cases to military conflict.

As MASS moves toward higher degrees of autonomy, including fully unmanned vessels, the lack of onboard supervision will require continuous and secure communication between ships and ports. Ensuring uninterrupted digital connectivity and operational alignment presents one of the most significant challenges for sustainable MASS-port integration (Kurt & Aymelek, 2022). Several challenges remain in implementing MASS within port operations, including autonomous navigation in port areas (e.g., avoiding collisions), establishing effective ship-port communication, and enabling remote control access for cargo handling operations. Additionally, there are concerns regarding the adequacy of onshore crew in monitoring the content of cargo being handled. This includes the need for proper testing, verification, and validation of cargo characteristics, such as quantity and type.

Additionally, with the emergence of MASS, the management, operation, and maintenance of unmanned vessels differ significantly from conventional ships, it is necessary to update the domestic laws and regulations (Issa *et al.*, 2022; Shao *et al.*, 2024). Clarifying the legal status of unmanned ships is essential for effective governance, alongside revising existing maritime rules and developing specific technical regulations aligned with the MASS operational characteristics.

Skills gaps and required workforce training

MASS leads to a shift in operational responsibilities, requiring ports to reconfigure their governance structures and upgrade workforce competencies to effectively manage autonomous operations. Port-based crews must take over key functions previously performed at sea, including ship operational management (safe navigation, berthing, and maneuvering), technical management (maintenance and repair), and cargo operations management (stability assessment and cargo handling). While MASS may reduce the number of seafarers required onboard, they simultaneously increase the need for

skilled port-based labor, infrastructure modernization, and revised operational protocols. Finally, the shipowners, positioned as the final adopters of MASS, play a crucial role in facilitating the transition. Their engagement not only supports the enhancement of system reliability but also promotes interoperability between autonomous vessels and essential support systems such as ports and maritime corridors (Yiteng & Ling, 2024).

The human–automation relationship is also critical to the success of maritime autonomy, so if MASS and their supporting infrastructure are properly managed, automated systems can enhance and support the operational aspects (Chan *et al.*, 2023; Veitch & Andreas Alsos, 2022; M. Zhang *et al.*, 2020). Traditionally, crew members have played a critical role in various port activities such as cargo handling, routine maintenance, and vessel preparation. However, as the maritime industry transitions toward autonomy, many of these responsibilities are expected to shift from shipboard personnel to port-based staff, particularly during berthing and turnaround operations. Despite design efforts aimed at enabling fully autonomous vessel functions, shore-based control crews remain vital for managing essential port operations, including berthing, bunkering, and cargo transfer (Jan Rødseth & Burmeister, 2012; Kretschmann *et al.*, 2017). The logistical transfer of personnel for these tasks may require specialized infrastructures, underlining the need for ports to upgrade both technological capacity and physical facilities.

Significant skill gaps are emerging as the maritime industry transitions to greater automation. Ensuring the safe operation of a MASS voyage requires a high degree of situational awareness and technical skills, allowing operators to anticipate potential hazards (Abramowicz-Gerigk & Burciu, 2024; Bolbot *et al.*, 2025; Polemis *et al.*, 2022; Stępień, 2023). The integration of advanced technologies demands higher levels of digital literacy and the ability to manage complex automated systems. Previous research already highlighted that it is essential to manage both technological readiness and stakeholder preparedness for the successful implementation of MASS (de Klerk *et al.*, 2021; Li & Yuen, 2022). Weintrit (2024) emphasizes the importance of balancing conventional maritime training with modern competencies. They highlight four key areas to support workforce adaptation: (1) soft skills, including leadership, teamwork, and decision-making; (2) technical expertise, involving proficiency in both traditional and digital navigation systems; (3) practical experience, facilitated through simulators and technology-driven training environments; and (4) integration of theory and practice, ensuring that training programs remain relevant and comprehensive in preparing seafarers for evolving industry demands. M. Zhang & Yu (2025) evaluated the extent to which China's maritime legal education is aligned with emerging demands associated with sustainable shipping, digitalization, and artificial intelligence. Their findings underscore the broader need for maritime education and training systems to proactively evolve in support of MASS integration.

Belabyad *et al.*, (2025a) and Karahalios (2025) emphasize that maritime education must align with industry expectations and technological advancements. Belabyad *et al.*, (2025b) identifies three core competency areas crucial for MASS operations: operational skills, digital skills, and maritime-specific knowledge. Complementing this, Karahalios (2025) argues that statistical literacy, programming, and cybersecurity should be the top priority to prepare students for future maritime careers. Similarly, some prior research also highlights that AI is critical for the effective operation of MASS systems (Belabyad *et al.*, 2025b; Simion *et al.*, 2024). Their study maps global technological trends to define future maritime competencies, emphasizing the growing importance of AI and automation, cybersecurity awareness, and problem-solving abilities. Overall, these findings point to the urgent need for a workforce capable of navigating the intersection of traditional seafaring and advanced automation.

Figure 3 shows the summary of key elements in maritime industry transformation in port digitalization, grouped into three main areas: digital information networks, cybersecurity enhancements, and vessel preparation. Additionally, to support the transformation and integration of ports, future workforce development must focus on enhancing competencies in key areas: digital literacy, operational skills, change management, and regulatory and maritime domain knowledge.

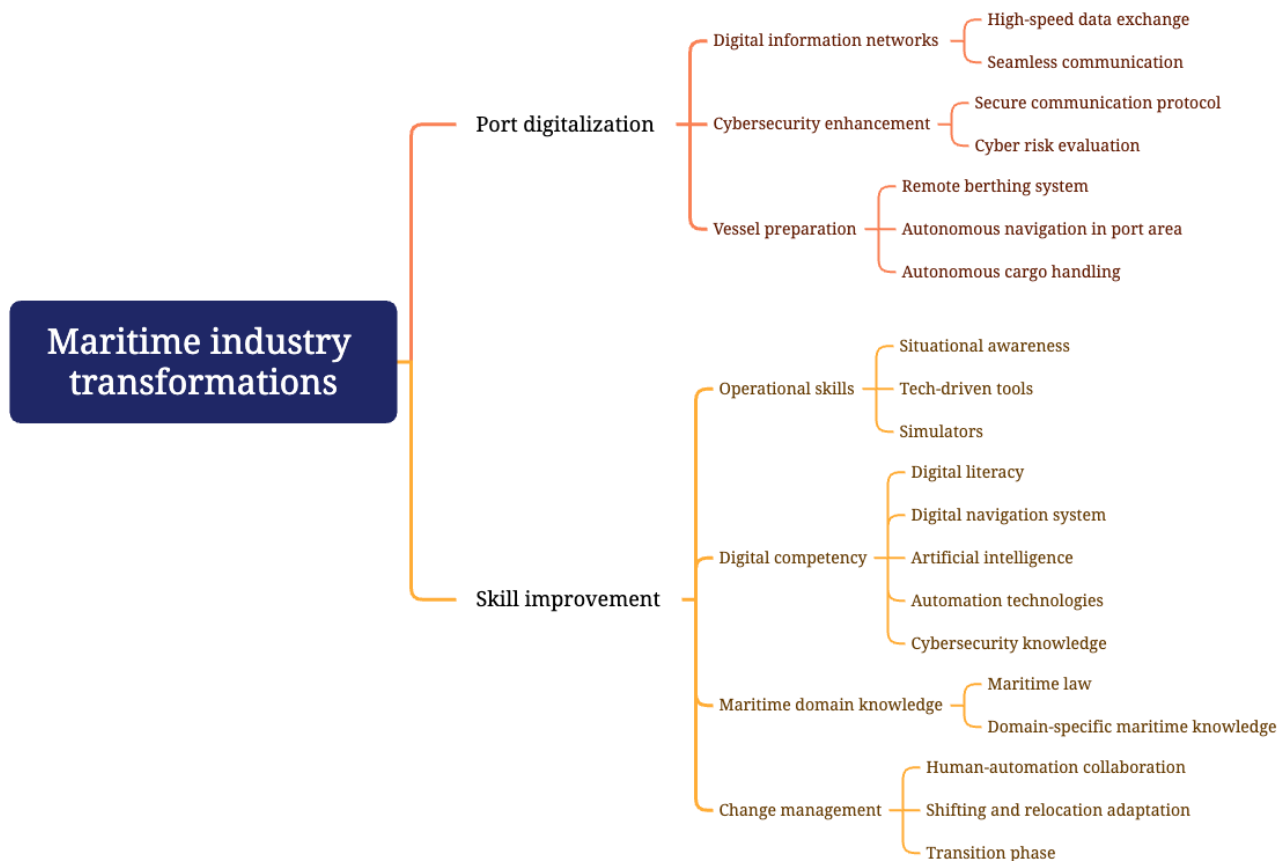


Figure 3. Key transformation for MASS adoption

3.3. RQ3: Future research direction

This study presents a systematic analysis of the impacts MASS on maritime industry performance, along with industry responses to these emerging challenges. The findings reveal that MASS significantly affects key sectors such as the supply and logistics chain, as well as port integration. The rise of MASS demands accelerated cross-sectoral collaboration within the maritime domain, such as shipbuilding, vessel maintenance, shipping operations, and port management, in terms of physical infrastructure and digital information systems. To address these evolving needs, future research should further explore infrastructure-specific challenges, with a particular emphasis on assessing the technological and operational feasibility of supporting MASS deployment. The bibliometric results also indicate that the largest clusters are centered around autonomous ships and port operations. This finding reinforces the need for further research on port integration in the MASS context.

From the workforce perspective, the implementation of MASS is expected to gradually reduce the demand for traditional onboard crew, while simultaneously creating new roles in shore-based operations and related support services. This transition highlights the critical need for workforce transformation and strategic labor planning to ensure a balanced and sustainable shift toward autonomous maritime systems. Future research should focus on identifying standardized training requirements for operators and assessing the practical impact of such training. Moreover, given the limited discussion on regulatory frameworks in current literature, further studies should examine the regulatory implications of MASS.

Finally, based on the results of the keyword burst, future research should investigate the integration of MASS into operational models, such as optimizing MASS systems to enhance port efficiency. Optimization research could focus on developing intelligent routing algorithms, real-time decision-making frameworks, and resource allocation models that can improve operational efficiency. As system modeling and optimization have become dominant research trends, reflected by the continued burst of keywords like *model* and *system* through 2025, there is a clear need for interdisciplinary studies that combine engineering, data science, and maritime logistics. Additionally, the appearance of *bibliometric* as a burst keyword until 2025 indicates a growing recognition of bibliometric analysis as a valuable tool to map emerging themes, monitor research evolution, and guide future inquiry in the autonomous maritime domain. This underscores the importance of meta-analytical approaches in shaping the direction of MASS-related research.

4. CONCLUSION

This study contributes to the growing body of knowledge on MASS and their impact on the maritime industry. Through a systematic review of 45 selected articles, the research identifies key aspects in port operations and skill improvements. These aspects are important in preparing the maritime industry on receiving MASS as a new mode of transportation. This study offers valuable insights for researchers, policymakers, and industry stakeholders seeking to navigate the operational transformation brought about by MASS.

Among the findings, the *Journal of Marine and Engineering* was identified as the leading journal in the field, particularly within the marine engineering category. China emerged as a key contributor, reflecting its growing academic and industrial engagement with MASS-related research. Additionally, keyword burst analysis revealed a progression in research focus, from initial concerns on maritime safety to more recent emphases on system development and optimization. The finding also highlights the transformation of the maritime industry centers on two primary domains: port operations and workforce development.

Port digitalization necessitates advancements in infrastructure, including robust digital networks, enhanced cybersecurity, and the integration of autonomous technologies, alongside adherence to both international and domestic regulatory frameworks. Concurrently, workforce development must prioritize the cultivation of digital proficiency, operational expertise, change management capabilities, and a comprehensive understanding of maritime regulatory contexts to effectively support this transition. The analysis also points to research gaps in key areas such as port infrastructure integration operations, human-automation collaboration, and critical elements for the successful deployment of MASS to provide valuable direction for future studies to explore the readiness and strategies. Therefore, the collaboration of interdisciplinary collaboration among fields such as engineering, computer science, maritime logistics, and regulatory studies to develop interoperable MASS solutions are needed.

It is important to mention that the findings of this review research are based on multiple limitations. The analysis was based only on data from the WoS database, which may exclude relevant studies indexed in other databases. Future study should consider expanding the journal's databases, such as Scopus or IEEE to leverage the source. Lastly, the interpretation of co-citation clusters involves a degree of subjectivity, which may influence thematic categorization.

REFERENCES

- Abramowicz-Gerigk, T. and Burciu, Z. (2024). Situational awareness in autonomous shipping – ship domain in remote MASS operation. *TransNav*, 18(4), pp. 889–893. Available at: <https://doi.org/10.12716/1001.18.04.15>
- Abudu, R. and Bridgelall, R. (2024). Autonomous ships: A thematic review. *World*, 5(2), pp. 276–292. Available at: <https://doi.org/10.3390/world5020015>
- Acciaro, M. et al. (2014). Environmental sustainability in seaports: A framework for successful innovation. *Maritime Policy & Management*, 41(5), pp. 480–500. Available at: <https://doi.org/10.1080/03088839.2014.932926>
- Bălan, C. (2020). The disruptive impact of future advanced ICTs on maritime transport: A systematic review. *Supply Chain Management*, 25(2), pp. 157–175. Available at: <https://doi.org/10.1108/SCM-03-2018-0133>
- Belabyad, M. et al. (2025). Skills and competencies for operating maritime autonomous surface ships (MASS): A systematic review and bibliometric analysis. *Maritime Policy & Management*. Available at: <https://doi.org/10.1080/03088839.2025.2475177>
- Belabyad, M. et al. (2025). The human element in autonomous shipping: A study on skills and competency requirements. *WMU Journal of Maritime Affairs*. Available at: <https://doi.org/10.1007/s13437-025-00366-9>
- Bogusławski, K. et al. (2022). Implications of autonomous shipping for maritime education and training: The cadet's perspective. *Maritime Economics & Logistics*, 24(2), pp. 327–343. Available at: <https://doi.org/10.1057/s41278-022-00217-x>
- Bolbot, V. et al. (2025). Investigation into safety acceptance principles for autonomous ships. *Reliability Engineering and System Safety*, 257. Available at: <https://doi.org/10.1016/j.ress.2025.110810>
- Burciu, Z. and Abramowicz-Gerigk, T. (2023). Autonomous shipping: A stochastic model describing MASS operational safety. *Zeszyty Naukowe Politechniki Morskiej w Szczecinie*, 76(148), pp. 57–64. Available at: <https://doi.org/10.17402/586>
- Chaal, M. et al. (2023). Research on risk, safety, and reliability of autonomous ships: A bibliometric review. *Safety Science*, 167, 106256. Available at: <https://doi.org/10.1016/j.ssci.2023.106256>
- Chan, J. et al. (2023). Perception of autonomy and the role of experience within the maritime industry. *Journal of Marine Science and Engineering*, 11(2). Available at: <https://doi.org/10.3390/jmse11020258>
- Chang, C.H. et al. (2021). Risk assessment of the operations of maritime autonomous surface ships. *Reliability Engineering and System Safety*, 207. Available at: <https://doi.org/10.1016/j.ress.2020.107324>

- Chen, C. et al. (2010). The structure and dynamics of cocitation clusters: A multiple-perspective cocitation analysis. *Journal of the American Society for Information Science and Technology*, 61(7), pp. 1386–1409. Available at: <https://doi.org/10.1002/asi.21309>
- Chen, H. et al. (2025). Inland waterway autonomous transportation: System architecture, infrastructure and key technologies. *Journal of Industrial Information Integration*, 46. Available at: <https://doi.org/10.1016/j.jii.2025.100858>
- Chen, J. et al. (2019). Constructing governance framework of a green and smart port. *Journal of Marine Science and Engineering*, 7(4), p. 83. Available at: <https://doi.org/10.3390/jmse7040083>
- Chou, C.C., Wang, C.N. and Hsu, H.P. (2022). A novel quantitative and qualitative model for forecasting navigational risks of maritime autonomous surface ships. *Ocean Engineering*, 248. Available at: <https://doi.org/10.1016/j.oceaneng.2022.110852>
- Corsi, P. et al. (2025). Analysis and definition of certification requirements for maritime autonomous surface ship operation. *Journal of Marine Science and Engineering*, 13(4). Available at: <https://doi.org/10.3390/jmse13040751>
- Cui, Z., Guan, W. and Zhang, X. (2025). Gated transformer-based proximal policy optimization for multiple maritime autonomous surface ships collision avoidance decision-making. *Engineering Applications of Artificial Intelligence*, 156, 111242. Available at: <https://doi.org/10.1016/j.engappai.2025.111242>
- de Klerk, Y., Manuel, M.E. and Kitada, M. (2021). Scenario planning for an autonomous future: A comparative analysis of national preparedness. *Marine Policy*, 127, 104428. Available at: <https://doi.org/10.1016/j.marpol.2021.104428>
- Frank, M.R. et al. (2019). Toward understanding the impact of artificial intelligence on labor. *Proceedings of the National Academy of Sciences*, 116(14), pp. 6531–6539. Available at: <https://doi.org/10.1073/pnas.1900949116>
- Gantiva Osorio, M. et al. (2024). Coordinated control of multiple autonomous surface vehicles: A systematic review. *Ocean Engineering*, 312, 119160. Available at: <https://doi.org/10.1016/j.oceaneng.2024.119160>
- Ghaderi, H. (2019). Autonomous technologies in short sea shipping: Trends, feasibility and implications. *Transport Reviews*, 39(1), pp. 152–173. Available at: <https://doi.org/10.1080/01441647.2018.1502834>
- Goerlandt, F. (2020). Maritime autonomous surface ships from a risk governance perspective. *Safety Science*, 128. Available at: <https://doi.org/10.1016/j.ssci.2020.104758>
- Gu, Y. et al. (2021). Autonomous vessels: State of the art and opportunities in logistics. *International Transactions in Operational Research*, 28(4), pp. 1706–1739. Available at: <https://doi.org/10.1111/itor.12785>
- He, Z. et al. (2024). Dynamic domain-based collision avoidance system for autonomous ships. *Expert Systems with Applications*, 255, 124805. Available at: <https://doi.org/10.1016/j.eswa.2024.124805>
- Heikkilä, M. et al. (2024). Navigating the future: Developing smart fairways for enhanced maritime safety and efficiency. *Journal of Marine Science and Engineering*, 12(2). Available at: <https://doi.org/10.3390/jmse12020324>
- Ho, T.C. and Lee, H.S. (2024). Key factors influencing autonomous ship adoption by shipping companies. *Journal of Marine Science and Engineering*, 12(12). Available at: <https://doi.org/10.3390/jmse12122153>
- Issa, M. et al. (2022). Maritime autonomous surface ships: Problems and challenges facing regulation. *Sustainability*, 14(23). Available at: <https://doi.org/10.3390/su142315630>
- Jan Rødseth, Ø. and Burmeister, H.-C. (2012). Developments toward the unmanned ship. Available at: <http://www.unmanned-ship.org>
- Jovanović, I. et al. (2024). Review of research progress of autonomous and unmanned shipping. *Journal of Marine Engineering & Technology*, 23(2), pp. 82–97. Available at: <https://doi.org/10.1080/20464177.2024.2302249>
- Karahalios, H. (2025). Enhancing maritime education for digital sustainability. *International Journal of Innovation Science*. Available at: <https://doi.org/10.1108/IJIS-06-2024-0156>
- Karatvuo, H. et al. (2022). Improved climate change adaptation in Port of Brisbane using a digital twin cloud-based modelling approach. *Proceedings of the ASME 2022 41st International Conference on Ocean, Offshore and Arctic Engineering*. Available at: <https://doi.org/10.1115/OMAE2022-79613>
- Kooij, C. and Hekkenberg, R. (2022). Identification of a task-based implementation path for unmanned autonomous ships. *Maritime Policy & Management*, 49(7), pp. 954–970. Available at: <https://doi.org/10.1080/03088839.2021.1914878>
- Kouroupis, K. and Sotiropoulos, L. (2024). Cyber challenges amid the digital revolution in maritime transport. *Juridical Tribune*, 14(2), pp. 321–340. Available at: <https://doi.org/10.62768/TBJ/2024/14/2/09>
- Kretschmann, L. et al. (2017). Economic benefits of unmanned autonomous ships. *Research in Transportation Business & Management*, 25, pp. 76–86. Available at: <https://doi.org/10.1016/j.rtbm.2017.06.002>
- Kurt, I. and Aymelek, M. (2022). Operational and economic advantages of autonomous ships. *Maritime Economics & Logistics*, 24(2), pp. 302–326. Available at: <https://doi.org/10.1057/s41278-022-00213-1>
- Kurt, I. and Aymelek, M. (2024). Operational adaptation of ports with maritime autonomous surface ships. *Transport Policy*, 145, pp. 1–10. Available at: <https://doi.org/10.1016/j.tranpol.2023.09.023>
- Li, X. and Yuen, K.F. (2022). Autonomous ships: A study of critical success factors. *Maritime Economics & Logistics*, 24(2), pp. 228–254. Available at: <https://doi.org/10.1057/s41278-022-00212-2>

- Marzi, G. et al. (2024). Guidelines for bibliometric-systematic literature reviews. *International Journal of Management Reviews*. Available at: <https://doi.org/10.1111/ijmr.12381>
- Munim, Z.H. and Haralambides, H. (2022). Advances in maritime autonomous surface ships (MASS) in merchant shipping. *Maritime Economics & Logistics*, 24(2), pp. 181–188. Available at: <https://doi.org/10.1057/s41278-022-00232-y>
- Munim, Z.H. et al. (2025). Key determinants for the commercial feasibility of maritime autonomous surface ships (MASS). *Marine Policy*, 172. Available at: <https://doi.org/10.1016/j.marpol.2024.106482>
- Negenborn, R.R. et al. (2023). Autonomous ships are on the horizon: Here's what we need to know. *Nature*, 615(7950), pp. 30–33. Available at: <https://doi.org/10.1038/d41586-023-00557-5>
- Osaloni, O.S. and Ayeeni, V.O. (2022). The development of maritime autonomous surface ships: Regulatory challenges and the way forward. *Beijing Law Review*, 13(3), pp. 544–554. Available at: <https://doi.org/10.4236/blr.2022.133035>
- Özkan, E.D. and Sevgili, C. (2025). Future horizons: A bibliometric analysis of autonomous shipping technologies. *Ships and Offshore Structures*, pp. 1–15. Available at: <https://doi.org/10.1080/17445302.2025.2454306>
- Öztürk, O., Kocaman, R. and Kanbach, D.K. (2024). How to design bibliometric research: An overview and a framework proposal. *Review of Managerial Science*, 18(11), pp. 3333–3361. Available at: <https://doi.org/10.1007/s11846-024-00738-0>
- Page, M.J. et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, n71. Available at: <https://doi.org/10.1136/bmj.n71>
- Peng, P. et al. (2025). Bibliometric analysis of maritime cybersecurity: Research status, focus and perspectives. *Transportation Research Part E: Logistics and Transportation Review*, 195. Available at: <https://doi.org/10.1016/j.tre.2025.103971>
- Polemis, D., Darousos, E.F. and Boviatsis, M. (2022). A theoretical analysis of contemporary vessel navigational systems: Assessing the future role of the human element for unmanned vessels. *TransNav*, 16(4), pp. 637–646. Available at: <https://doi.org/10.12716/1001.16.04.05>
- Shahbakhsh, M., Emad, G.R. and Cahoon, S. (2022). Industrial revolutions and transition of the maritime industry: The case of seafarers' role in autonomous shipping. *The Asian Journal of Shipping and Logistics*, 38(1), pp. 10–18. Available at: <https://doi.org/10.1016/j.ajsl.2021.11.004>
- Shao, Y., Yu, Y. and Ma, Y. (2024). The challenge of safe and sustainable development of the unmanned ship: Seeking effective legal responses. *Frontiers in Marine Science*, 11. Available at: <https://doi.org/10.3389/fmars.2024.1385082>
- Simion, D. et al. (2024). AI-driven predictive maintenance in modern maritime transport: Enhancing operational efficiency and reliability. *Applied Sciences*, 14(20), 9439. Available at: <https://doi.org/10.3390/app14209439>
- Smacki, A. et al. (2024). Cybersecurity of autonomous ships in offshore wind farms. *Procedia Computer Science*, 246, pp. 5525–5534. Available at: <https://doi.org/10.1016/j.procs.2024.09.703>
- Stępień, B. (2023). Can a ship be its own captain? Safe manning of autonomous and uncrewed vessels. *Marine Policy*, 148. Available at: <https://doi.org/10.1016/j.marpol.2022.105451>
- Symes, S. et al. (2024). Cyberattacks on the maritime sector: A literature review. *Journal of Marine Science and Application*. Available at: <https://doi.org/10.1007/s11804-024-00443-0>
- The World Bank (2023). Sustainable development in shipping and ports. Available at: <https://www.worldbank.org/en/topic/transport/brief/sustainable-development-in-shipping-and-ports>
- Tsvetkova, A. and Hellström, M. (2022). Creating value through autonomous shipping: An ecosystem perspective. *Maritime Economics & Logistics*, 24(2), pp. 255–277. Available at: <https://doi.org/10.1057/s41278-022-00216-y>
- Veitch, E. and Andreas Alsos, O. (2022). A systematic review of human–AI interaction in autonomous ship systems. *Safety Science*, 152. Available at: <https://doi.org/10.1016/j.ssci.2022.105778>
- Weintrit, A. (2024). Sustainable reaction of the maritime education sector to marine technology development including autonomous surface shipping. *TransNav*, 18(4), pp. 927–933. Available at: <https://doi.org/10.12716/1001.18.04.20>
- Wu, Y., Wang, T. and Liu, S. (2024). A review of path planning methods for marine autonomous surface vehicles. *Journal of Marine Science and Engineering*, 12(5). Available at: <https://doi.org/10.3390/jmse12050833>
- Xing, W. (2024). Contemplating maritime autonomous surface ships (MASS) under international law on ship-source pollution. *Marine Pollution Bulletin*, 207, 116884. Available at: <https://doi.org/10.1016/j.marpolbul.2024.116884>
- Yanchin, I. and Petrov, O. (2020). Towards autonomous shipping: Benefits and challenges in information technology and telecommunications. *TransNav*, 14(3), pp. 611–619. Available at: <https://doi.org/10.12716/1001.14.03.12>
- Yiteng, L. and Ling, Z. (2024). Exploring industry acceptance of maritime autonomous surface ships: A grounded theory approach. *Research in Transportation Business & Management*, 57, 101221. Available at: <https://doi.org/10.1016/j.rtbm.2024.101221>
- Zhang, C. et al. (2025). Towards autonomous inland shipping: A manoeuvring model in confined waterways. *Ships and Offshore Structures*, 20(6), pp. 767–779. Available at: <https://doi.org/10.1080/17445302.2024.2358284>

- Zhang, M. and Yu, S. (2025). A review on the preparedness of Chinese maritime law education for emerging industry and technology trends: Sustainable net-zero shipping, maritime digitalization and artificial intelligence technologies. *Sustainable Futures*, 9. Available at: <https://doi.org/10.1016/j.sfr.2025.100752>
- Zhang, M. et al. (2020). A probabilistic model of human error assessment for autonomous cargo ships focusing on human–autonomy collaboration. *Safety Science*, 130. Available at: <https://doi.org/10.1016/j.ssci.2020.104838>
- Zhang, W. and Wang, S.A. (2020). Autonomous vessel scheduling. *Journal of the Operations Research Society of China*, 8(3), pp. 391–414. Available at: <https://doi.org/10.1007/s40305-018-0218-2>
- Zhou, X.-Y. et al. (2025). A framework to assess the operational state of autonomous ships with multi-component degrading systems. *Ocean Engineering*, 327, 121000. Available at: <https://doi.org/10.1016/j.oceaneng.2025.121000>
- Zhu, F. et al. (2025). A high-risk test scenario adaptive generation algorithm for ship autonomous collision avoidance decision-making based on reinforcement learning. *Ocean Engineering*, 320, 120344. Available at: <https://doi.org/10.1016/j.oceaneng.2025.120344>
- Zhu, L. and Xing, W. (2022). Policy-oriented analysis on the navigational rights of unmanned merchant ships. *Maritime Policy & Management*, 49(3), pp. 447–462. Available at: <https://doi.org/10.1080/03088839.2021.1914877>