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Evaluating Business Models in Autonomous Shipping: A Systematic Literature Review

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Abstract. This paper presents a systematic literature review of academic contributions related to business models for Maritime Autonomous Surface Ships (MASS). A total of 43 peer-reviewed publications, spanning from 2016 to 2025, were analysed using a structured coding and segmentation approach. The review distinguishes between two main perspectives: models centred on the autonomous vessel as a technological innovation, and those embedding MASS within broader logistics and port systems. Two dominant thematic areas emerge: vessel-centric models, which prioritise cost savings and operational efficiency, and logistics-integrated models, which highlight multimodal coordination and stakeholder collaboration. The review identifies persistent challenges such as high capital costs, regulatory uncertainty, and the absence of validated return-on-investment frameworks. Nonetheless, promising opportunities are found in short sea shipping, inland navigation, and offshore operations—particularly in predictable routes where labour savings improve viability. Overall, the findings stress the need for collaborative, service-based business strategies, underpinned by empirical evidence, cross-sectoral approaches, and public–private investment. This review offers a foundation for understanding how MASS can evolve from technological concept to commercially scalable solution within modern maritime ecosystems. Further research should focus on testing these models in real-world conditions.

Keywords: MASS, Business Models, Autonomous Shipping, Market Adoption, Logistics, Commercial Feasibility, Investment Barriers, Market Uptake.

1. Introduction and Propose of the Paper

1.1 Rationale for exploring business models in autonomous shipping.

The maritime sector is undergoing a profound transformation, driven by digitalisation, automation, and decarbonisation pressures. One of the most disruptive innovations is the emergence of Maritime Autonomous Surface Ships (MASS), which promise improvements in safety, operating costs, vessel design, and logistics—particularly in short sea and inland waterway transport.

As recently noted in Nature by Negenborn et al. (2023), the expected rise of autonomous ships is accompanied by critical questions around safety, governance, and societal impact—highlighting the urgency of exploring not only their technological readiness, but also the business models that will enable real-world deployment.

To date, most academic and industry debates have focused on technical and regulatory issues such as navigation autonomy, collision avoidance, cybersecurity, and compliance. However, understanding the economic viability and commercial scalability of MASS is still a critical research gap.

Business models serve as the bridge between technological innovation and market adoption. Without clear value propositions, cost structures, and revenue mechanisms, even advanced technologies risk market failure. Additionally, MASS introduce new stakeholder dynamics and cost allocations that challenge traditional shipping models.

The risk-averse nature of the maritime sector, combined with the absence of proven return-on-investment (ROI) scenarios, demands a clearer understanding of how MASS can integrate into current and future maritime value chains. A systematic literature review on business models for MASS is therefore essential to inform future research, policymaking, and investment decisions.

1.2 Scope of the analysis

This review focuses on academic contributions that examine autonomous vessels from a business model perspective, particularly in relation to port systems and broader logistics integration. The goal is to explore how business models respond to the operational, regulatory, and technological challenges associated with MASS deployment.

The scope is limited to peer-reviewed publications in English, accessed via major academic databases. As such, the review may exclude valuable grey literature or non-English sources. Additionally, while environmental and legal dimensions are acknowledged as critical, they fall outside the primary focus of this review, which centres on technological integration and business feasibility.

1.3 Structure of the paper

The paper is organised as follows. Section 2 details the methodological approach, including the selection criteria and analytical framework. Section 3 presents the core findings, both qualitative and quantitative, and distinguishes between vessel-centric and logistics-integrated business models. Section 4 summarises the conclusions and proposes directions for future research.

2. Methodology and Analytical Framework

2.1 Literature review design and objectives

This study adopts a systematic literature review (SLR) approach to explore how business models for Maritime Autonomous Surface Ships (MASS) are being conceptualised, analysed, and debated within the scientific literature. The aim is to synthesise contributions that not only describe the technological and regulatory landscape of MASS, but also examine their commercial viability, value generation potential, and integration into broader port and logistics systems.

Our review is designed to respond to four research questions concerning (i) the typologies of business models proposed for autonomous shipping, (ii) the structural elements of those models, (iii) the barriers and opportunities to their implementation, and (iv) the influence of contextual factors such as regulation, operational environments, and stakeholder roles.

A distinctive aspect of this review is its collaborative methodology. Unlike generic keyword searches or automatic reviews, the selection process benefited from the involvement of a professional documental analyst within the Fundación Valenciaport (CEDIPORT), which ensured a curated, rigorous and thematically relevant set of sources. This definition of scope was carried out in coordination with the CEDIPORT documentation unit through an initial alignment meeting, following its established methodology for precise and targeted scientific searches. Furthermore, the review seeks to balance comprehensiveness with thematic coherence: although MASS is a cross-cutting topic, only contributions explicitly dealing with business models or commercial logic were retained.

Rather than focusing solely on technical innovations, this study frames autonomy as a business and ecosystem innovation. Our goal is to provide a foundation for understanding how MASS may transition from technological prototype to commercially scalable service models within the maritime industry.

2.2 Search strategy and selection process

The initial phase of the review involved a targeted bibliographic search carried out in March and May 2025, with the support of the documentation unit at Fundación Valenciaport (CEDIPORT). The objective was to identify scientific publications addressing MASS from a business model perspective, with special emphasis on their interaction with port environments and logistic chains.

The search was conducted using Google Scholar as the primary database, due to its wide academic coverage and versatility in exploratory queries. Additional searches were also performed in Scopus and ScienceDirect. The search queries applied across these platforms were built using Boolean operators and included the following specific combinations:

- “autonomous ship” OR “autonomous vessel” OR “remote ship” OR “uncrewed ship”, combined with
- “business model”, “cost-benefit”, “financial”, “investment”, “market uptake”, “revenue”, “ROI”, “value proposition”, “commercialisation”, “canvas”, “customers”, “final product”.

In line with the CEDIPORT methodology, the keywords were also translated into other relevant languages, primarily English and Spanish, to account for linguistic and terminological variations in the literature. These combinations were adjusted iteratively to balance precision and coverage. In some cases, filters were added to limit results by year or document type. While the core focus remained on the business and economic aspects of MASS, papers with purely technical or regulatory scope were excluded unless they explicitly addressed commercial strategies. Differences in platform indexing were also considered during the screening phase.

Publications from 2015 to May 2025 were considered, allowing us to trace the evolution of research from initial theoretical approaches to recent applied studies. This first round yielded a total of 254 records, which were reviewed based on titles, abstracts, and availability of full text. To ensure a high level of scientific quality, only peer-reviewed documents (journal articles, conference papers, institutional reports) were considered. Non-scientific sources such as promotional documents, student theses or commercial presentations were excluded from the main corpus.

Following this screening phase, 40 publications were retained based on relevance, thematic alignment, and accessibility. These formed the basis for further refinement and bibliographic expansion, as described in the following section.

2.3 Iterative refinement and bibliographic expansion

Once the initial selection of 40 publications was established, the review process was further reinforced through two complementary strategies aimed at improving coverage and identifying potentially overlooked contributions.

First, a backward reference analysis was conducted. This involved a manual review of the bibliographic references contained in each of the selected articles. The purpose was to trace foundational works or closely related studies that might not have appeared in the initial keyword-based search. This process helped to identify relevant papers that were either indexed under different metadata, published in less prominent journals, or referenced within broader studies on digitalisation, automation, or maritime innovation.

Second, a forward-looking monitoring mechanism was activated by setting up automated alerts through Google Scholar. These alerts were configured using the same combination of keywords employed in the initial search and allowed the team to remain updated on newly published works. This led to the incorporation of three additional scientific contributions and a broader contextualisation of the existing corpus through citation chaining.

The selected references were systematically stored in a shared digital repository, ensuring consistent access, traceability, and the possibility of updating the corpus in future review cycles. Both mechanisms reflect a commitment to methodological transparency and thematic consistency. While the review is not exhaustive by design, this iterative expansion phase ensures that the dataset reflects not only the most cited publications, but also recent and emerging perspectives in the academic discourse on autonomous shipping. After this refinement phase, and following a thorough quality check and relevance validation, the final corpus was consolidated into a set of 43 scientific publications.

Moreover, this approach supports the replicability of the study by documenting how the corpus evolved over time and on what basis new documents were included. As of the latest update, plans are in place to maintain this process on a quarterly basis, to support follow-up work and future revisions.

To provide temporal context to the growing academic interest in the topic, Figure 1 presents the distribution of the 43 reviewed publications across time. It illustrates a notable increase in research output from 2019 onwards, peaking in 2021 and maintaining a steady rhythm through 2024.

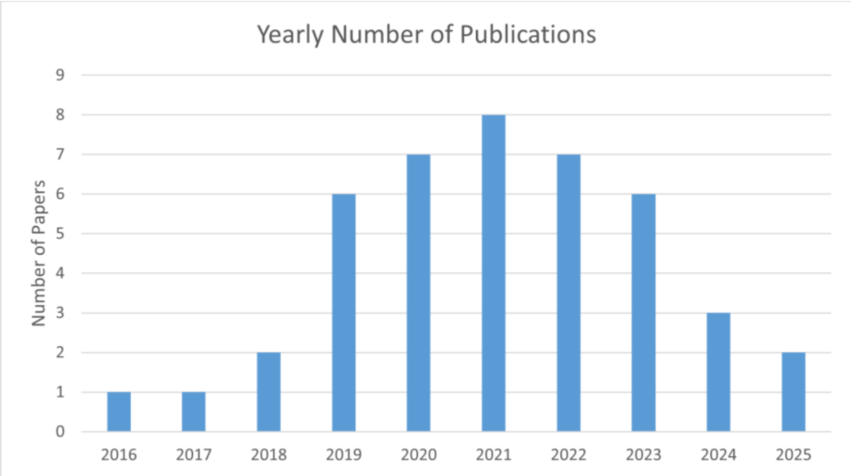

Figure 1. Number of publications per year related to autonomous shipping business models.

2.4 Corpus refinement and analytical dimensions

Once the final corpus of 43 publications was consolidated, a refinement and coding process was undertaken to organise the material systematically and extract relevant insights. This phase served two main purposes: first, to ensure thematic consistency by confirming that all selected papers aligned with the scope of the review; and second, to enable comparative analysis through a shared analytical framework.

To achieve this, a set of inclusion and exclusion criteria was applied, as summarised in Table 1 below:

Table 1. Criteria used in the selection phase.

Inclusion criteria	Exclusion Criteria
Peer-reviewed journal articles, conference proceedings, or institutional reports	Undergraduate or Master's theses, even if relevant
Focus on business models, economic strategies, or commercial feasibility of MASS	Grey literature lacking scientific validation (e.g., newsletters, white papers)
Published between 2015 and May 2025	Publications focused solely on legal, educational or safety-related aspects
Available full text or sufficient metadata (title, abstract, keywords)	
Primarily in English, with selective inclusion of non-English papers via abstract	
Indexed in academic repositories such as Google Scholar	

While the review aimed to be as comprehensive as possible within its defined scope, the authors acknowledge that some potentially relevant publications may have been omitted due to metadata inconsistencies, lack of access, or ambiguity in thematic focus.

Although the primary language of the review is English, a limited number of non-English publications were included. These cases were justified by (i) relevance indicated in translated abstracts or (ii) direct recommendations by international project partners. All non-English entries were evaluated with the same rigour as the rest of the corpus.

This balanced approach helps safeguard scientific quality while accounting for the interdisciplinary and international character of the topic under study.

2.5 Thematic overview

The structured analysis of the reviewed literature revealed two dominant thematic perspectives on how business models for Maritime Autonomous Surface Ships (MASS) are conceived and discussed:

1. Technology Unit Models, which treat the autonomous vessel as a self-contained technological innovation. These studies tend to focus on ship design, crew reduction, automation infrastructure, and return on investment (ROI) through operational efficiency (Munim, 2019; Ziajka-Poznanska & Montewka, 2021; Adland & Strandenes, 2021; Runde, 2024).
2. Logistics Integrated Models, which view MASS as elements within a wider logistics ecosystem. These works emphasise digital coordination with ports, intermodal connectivity, shared infrastructures, and stakeholder collaboration (Tsvetkova et al., 2021; Bolbot et al., 2020; Nesheim et al., 2022; Akbar et al., 2021).

This classification highlights a fundamental distinction between models centred on the ship itself, and those that explore systemic integration with broader value chains. While both approaches contribute to understanding MASS feasibility, their assumptions, priorities and implications differ significantly.

3. Analysis and evaluation of the state of the art

3.1 Qualitative analysis: typologies, approaches and theoretical frameworks

The literature on business models for MASS presents a diverse mix of conceptual frameworks, case studies, and empirical insights. Collectively, these contributions offer a multidimensional understanding of how autonomy can reshape maritime transport.

Early conceptual work (e.g. Rødseth, 2017) highlighted that cutting onboard crew enables not only cost reductions but also fundamental redesigns in ship structure. Similarly, Komianos (2018) pointed to early prototypes like DNV-GL's ReVolt to underline the regulatory and maintenance challenges linked to such shifts.

Surveys also provide valuable perspectives. Ahn et al. (2022), based on input from 74 maritime stakeholders, stressed that viable business models must extend beyond the vessel to include supporting digital infrastructure and logistics integration.

The literature reflects a range of methodologies—simulations, interviews, mixed-methods, cost modelling—which together strengthen the analysis of MASS viability. Authors such as Munim et al. (2019) and Adland & Strandenes (2021) combine economic and operational lenses to assess feasibility.

Several theoretical frameworks have been proposed. Lambrou et al. (2019) developed a maritime digitalisation framework that links value creation to data-sharing, partnerships, and efficiency gains. Makitie et al. (2023) introduced the idea of "innovation couplings", finding whether MASS business models drive incremental or radical digital-sustainability transitions.

Some authors also contextualise autonomy within broader industry dynamics. Askari & Hossain (2022) framed MASS within the Fourth Industrial Revolution, highlighting benefits beyond cost, such as resilience and safety. Others, like Nordahl et al. (2022), examined collaborative models, where shared infrastructure—like control centres or platforms—enables new service-based business logic.

In sum, qualitative contributions agree that MASS are not just a technological breakthrough but a redefinition of the shipping business. The dominant view is that successful models will need to integrate autonomy into digital, collaborative, and logistics-oriented strategies.

3.2 Quantitative analysis: concept frequency, dominant categories and observed relationships.

The analysis of the 43 selected publications revealed frequent references to concepts such as "cost reduction", "crew elimination", "control centres", "value propositions", and "short sea shipping". Recurring categories were:

- Cost structure analysis:
  A key theme is the trade-off between high capital investment in automation and potential operating cost reductions—especially in crew-related expenses, which can stand for up to 45% of OPEX (Adland & Strandenes, 2021). While automation may reduce crew costs, studies also highlight new expenses such as remote operations, maintenance, and system redundancies (Veitch et al., 2023).
- Revenue mechanisms:
  MASS can enable new monetisation strategies such as "vessel-as-a-service", flexible leasing, and subscription or pay-per-use pricing (Munim, 2019; Nordahl et al., 2022). Digital platforms with dynamic pricing, like airlines or ride-hailing apps, could optimise utilisation and profitability (Ahn et al., 2022). These models suggest a shift from static freight contracts to more adaptive, service-oriented revenue streams.
- Logistics integration:
  Autonomous ships must connect smoothly with ports and intermodal systems to realise efficiency gains. Compatibility with smart terminals, remote pilotage, and hinterland coordination are critical (Chae et al., 2020). V2I communication and standardised protocols are central to avoiding bottlenecks. As a result, business models often include port partnerships to ensure seamless cargo transfer.
- Stakeholder impact:
  Autonomy redistributes roles across the maritime ecosystem. Regulators influence deployment through legal frameworks (Osinuga, 2020), while insurers affect cost through risk assessments (Max Johns, 2018). Technology providers gain importance through systems provision and service contracts. The crew is partially replaced by remote operators, leading to new entities like third-party control centres (Veitch et al., 2020). Clear risk-sharing and collaboration are crucial to practical business models.
- Economic feasibility and ROI:
  Economic viability is context-dependent and most promising in short-sea, inland, or offshore segments where routes are stable and labour costs high (Munim, 2019; Akbar et al., 2021). Savings in crew costs and added cargo capacity can improve profitability, but sensitivity to fuel prices, tech costs, and financing remains high. Studies like Munim et al. (2025) use multi-criteria analysis to find possible

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configurations—pointing to Degree 2 remote-controlled feeders as currently the most viable.

The review also revealed a lack of detailed market segmentation or robust modelling of how MASS might be deployed beyond pilot-scale operations in specific shipping segments.

3.3 Presentation of results according to the thematic areas

Table 2 presents key information from each paper, categorized under the two main thematic areas: business models focused on the autonomous ship as a technological unit, and business models addressing interaction with the logistics environment. Table 2 includes insights from 15 papers and highlights the diversity of approaches and perspectives found in the literature.

Table 2. Summary of key publications for each category

Thematic Category of Business model	Author(s)	Year	Insights
Technology Unit Model	Ornulf J.	2017	The study focuses on how the elimination of crew may enable the redesign of ship systems, creating new types of shipping systems.
	Chong Ju et al.	2020	The study examines the current state of technologies for autonomous ships, highlights key components, and proposes improvements across six major research areas related to MASS.
	Havard Nordalh	2022	The study proposes a method that uses key performance indicators (KPIs) to assess both competitiveness and societal impact
	Pakkanen P. and Henttinen E.	2016	The study outlines key areas of data analytics application in the maritime industry, with a particular focus on NAPA's role—a Finnish maritime software company specialised in vessel performance, simulation, and operational analytics—in supporting these efforts and their relevance to autonomous vessels.
	Humayun R. et al.	2022	The study proposed a possible and sustainable strategy for container shipping and suggested innovative applications of autonomous shipping in the shipping industry and for the extreme and challenging situations as well.
	Yuki I. et al.	2022	This study reviews the digitalization strategies of leading maritime companies, based on publicly available action plans, to uncover key characteristics of their future orientation and industry vision.

	Yongwon know et al.	2019	This study focuses on the implementation of the Smart K-Yard Project, emphasizing safety, reliability, and efficiency for small and medium-sized vessels.
	Nitin Agarwala	2023	The study specifically examines the core technologies currently available for uncrewed and autonomous vessels.
	Tukkaa Makitie et al.	2023	The study introduces a typology of innovation couplings, ranging from incremental to radical, highlighting the interplay between digital and sustainable transitions.
Logistics Integrated Model	Young Gyun Ahn et al.	2022	The study is based on 74 surveys conducted with officials from both domestic and international shipping sectors, including representatives from shipping companies, brokers, and government agencies.
	Changhee Lee et al.	2021	The study investigates data-activating digital platforms in terms of their design, transactional mechanisms, and role in enabling commercial operations of maritime autonomous surface ships.
	Max Johns	2018	The study finds key developments in ship digitization, digital transformation of operations, increasing autonomy, and the growing collaboration between Remote Operating Centers (ROCs) and onboard systems.
	E. Veitch et al.	2020	The study focuses on the contribution to design methodologies for development of Shore Control Centres (SCCs), where remote monitoring, supervision, and intervention of autonomous ships are coordinated via human operators.
	Maria Lambrou et al.	2019	The study adopts a qualitative case study approach to develop a theoretical model that organizes the key components of shipping digitalization.
	van den Berg, R. & Notteboom	2023	Proposes collaborative business models between shipping lines, ports, and terminals. Focus on CAPEX sharing, long-term contracting, and logistics integration.

3.3.1 Technology Unit Model

This thematic category focuses on business models that conceptualize the autonomous vessel as a self-contained innovation. Key features include the elimination of onboard crew, redesigned ship structures, and technology-based service models such as leasing or "vessel-as-a-service" (Munim, 2019; Nordahl et al., 2022). Studies highlight CAPEX–OPEX trade-offs, integration of advanced control systems, and sustainability-linked design strategies (Ornulf, 2017; Humayun et al., 2022).

Technological readiness plays a significant role, with initiatives like the Smart K-Yard project (Yongwon et al., 2019) illustrating how shipyards are digitising construction and enabling automation. Innovation typologies (Makitie et al., 2023) also suggest that these models may support both incremental and radical transitions depending on their coupling with sustainability goals.

3.3.2 Logistics Integrated Model

This category highlights business models that frame MASS as part of a connected logistics network rather than standalone assets. Emphasis is placed on digital coordination, smart port integration, and stakeholder collaboration (Bolbot et al., 2020; Nesheim et al., 2022). Platforms that offer real-time booking, adaptive pricing, and intermodal coordination are central features (Ahn et al., 2022; Lee et al., 2021).

Automation at terminals, blockchain-based tracking, and port–vessel synchronisation is seen as critical enablers. Human factors are still key: the role of Shore Control Centre (SCC) operators, task distribution, and skill retention are ongoing concerns (Veitch et al., 2020).

These models often assume shared governance, data interoperability, and joint investment strategies to overcome fragmented operational environments and regulatory uncertainty.

3.4 Impact of the analysis on the understanding of MASS integration in the logistic chain

The review shows that integrating MASS into logistics chains is not only a technological challenge, but also an organisational and institutional one. While much of the literature focuses on ship autonomy, real-world deployment depends on the maturity of supporting infrastructure, coordination mechanisms, and market readiness.

A system-level perspective is essential: MASS must work in synchrony with smart ports, remote operation centres, and intermodal networks. Without such alignment, the benefits of autonomy—cost savings, efficiency, safety—may be undermined.

In this context, the literature highlights three interrelated domains that shape the viability of MASS integration.

- Technological domain:
  Many studies detail the technical capabilities needed for MASS: autonomous navigation, collision avoidance, remote diagnostics, and reliable communications (e.g., satellite, 5G). Success depends not only on onboard systems, but also on digital port infrastructure and real-time data exchange (Chae et al., 2020; Rødseth, 2017). Pilot implementations are most practical in controlled routes—e.g., inland waterways or geofenced coastal corridors—where the digital ecosystem is already in place.
- Regulatory and institutional domain:
  Technology outpaces regulation. Current maritime conventions, such as the International Convention for the Safety of Life at Sea (SOLAS), the Collision Regulations Convention (COLREGs), or the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW)), were designed for crewed ships. Legal uncertainty persists around certification, liability, insurance, and

operator roles (Joukes et al., 2025; Osinuga, 2020). New governance models, sandbox trials, and updated standards are needed. SCC operators, for instance, require new training and certification pathways, which current frameworks do not cover.

- Market and stakeholder domain:
  Economic feasibility is influenced by route type, labour costs, and technology price. Short-sea and feeder services are commonly seen as early adopters. However, stakeholder confidence is still a barrier: risk aversion among shipowners, customers, and insurers slows adoption (Munim et al., 2025). Collaborative models—e.g., shared SCCs or tech-provider-operated fleets—can reduce costs and risk. Market uptake also hinges on social acceptance, job transition strategies, and clearly defined value propositions.

In summary, MASS integration is shaped by the co-evolution of technology, regulation, and market forces. Business models that recognise this interdependence and adopt a systemic, multi-actor approach are more likely to succeed.

4. Conclusions and future research recommendations

This systematic literature review has examined how Maritime Autonomous Surface Ships (MASS) are being addressed from a business model perspective, revealing two main conceptual approaches. On the one hand, vessel-centric models focus on the autonomous ship as a self-contained innovation, emphasising cost savings through crew reduction, automation, and optimised vessel design. On the other, logistics-integrated models view MASS as part of a broader transport ecosystem, requiring alignment with port operations, digital infrastructures, and stakeholder coordination mechanisms.

These perspectives reflect not only different priorities, but also diverse levels of system complexity. While technological models often highlight operational efficiency and return on investment, logistics-oriented approaches underline the importance of compatibility, interoperability, and multi-actor collaboration. The analysis suggests that treating MASS as isolated technologies risks overlooking key barriers to real-world implementation.

Although the literature has evolved in recent years, it still is largely conceptual. There is a lack of empirical studies that evaluate business models under actual operating conditions, and many publications focus on general frameworks without adapting them to specific market niches or regulatory environments. Similarly, important agents such as port authorities, classification societies, and insurers are often underrepresented in the models analysed.

Nevertheless, promising opportunities exist in short sea shipping, inland navigation, and offshore services—sectors where voyage patterns are predictable and crew-related costs are high. These environments could offer favourable conditions for pilot deployments and gradual scaling.

To unlock the commercial potential of MASS, future research should move beyond the vessel and adopt a systemic perspective that considers both technological and organisational readiness. Addressing the integration of MASS into existing value chains, exploring real-world feasibility, and fostering collaboration across the maritime sector will be essential steps to transform these innovations into commercially practical solutions.

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References

1. Abudu, R., & Bridgelall, R. (2024). Autonomous ships: A thematic review. World, 5(2), 276–292.
2. Adland, R., & Strandenes, S. P. (2021). Autonomous deep-sea shipping – The economist's view. IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), 1584–1587.
3. Agarwala, N. (2024). The potential of uncrewed and autonomous ships. Australian Journal of Maritime & Ocean Affairs, 16(1), 39-58.
4. Ahn, Y. G., Kim, T., Kim, B. R., & Lee, M. K. (2022). A Study on the Development Priority of Smart Shipping Items—Focusing on the Expert Survey. Sustainability, 14, 6892.
5. Ahn, J., Joung, T.-H., Kang, S.-G., & Lee, J. (2019). Changes in container shipping industry: Autonomous ship, environmental regulation, and reshoring. Journal of International Maritime Safety, Environmental Affairs, and Shipping, 3(3–4), 21–27.
6. Akbar, A., Aasen, A. K. A., Msakni, M. K., Fagerholt, K., Lindstad, E., & Meisel, F. (2021). An economic analysis of introducing autonomous ships in a short-sea liner shipping network. International Transactions in Operational Research, 28(4), 1740–1764.
7. Askari, H. R., & Hossain, M. N. (2022). Towards utilizing autonomous ships: A viable advance in industry 4.0. Journal of International Maritime Safety, Environmental Affairs, and Shipping, 6(1), 39-49.
8. Bolbot, V., Theotokatos, G., Boulougouris, E., Wennersberg, L. A. L., Nordahl, H., Rødseth, Ø. J., Faivre, J., & Molica Colella, M. (2020). Paving the way toward autonomous shipping development for European waters – The AUTOSHIP project. Royal Institution of Naval Architects.
9. Burmeister, H.-C., Weisheit, J., Küchle, J., Bluhm, L.-F., Mönicke, D., & Schwarze, A. (2023). Analyse, Auswertung und Ausblick des zukünftigen Marktes Autonomer Maritimer Systeme (AMS). Fraunhofer CML.
10. Chae, C. J., Kim, M., & Kim, H. J. (2020). A study on identification of development status of MASS technologies and directions of improvement. Applied sciences, 10(13), 4564.
11. Chesneau, A. (2017). Les "navires autonomes". Enjeux et impacts d'une navigation sans équipage dans le monde maritime. Université d'Aix-Marseille.
12. Felski, A., & Zwolak, K. (2020). The ocean-going autonomous ship—Challenges and threats. Journal of Marine Science and Engineering, 8(1), 41.
13. Gurevitch, J.; Koricheva, J.; Nakagawa, S.; Stewart, G. (2018). Meta-analysis and the science of research synthesis. Nature, 555, 175–182.
14. Ichimura, Y., Dalaklis, D., Kitada, M., & Christodoulou, A. (2022). Shipping in the era of digitalization: Mapping the future strategic plans of major maritime commercial actors. Digital Business, 2(1), 100022.
15. Koilo, V. (2021). Developing new business models: Logic of network value or cross-industry approach. Problems and Perspectives in Management, 19(2).
16. Komianos, A. (2018). The autonomous shipping era. Operational, regulatory, and quality challenges. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 12(2).
17. Kurtinaitis Joukes, M., Ortt, R., de Bruijne, M., & Kamp, L. M. (2025). How to analyse the introduction strategies for radically new technological innovations? The case of autonomous shipping. Journal of Engineering Research and Sciences, 4(1), 16–30.
18. Kwon, Y., Jeong, Y. K., Woo, J. H., Oh, D., Kim, H., Shin, I. S. & Jung, C. (2019, September). Korean technical innovation: toward autonomous ship and smart shipbuilding to ensure safety. In Proceedings of the International Seminar on Safety and Security of Autonomous Vessels (ISSAV) and European STAMP Workshop and Conference (ESWC) (pp. 83-94).
19. Lambrou, M., Watanabe, D., & Iida, J. (2019). Shipping digitalization management: conceptualization, typology and antecedents. Journal of Shipping and Trade, 4(1), 1-17.
20. Lambrou, M., Watanabe, D., & Iida, J. (2019). A tripartite model of shipping digitalization: Findings from a multi-case study. In Proceedings of the World Conference on Transport Research – WCTR 2019 Mumbai, 26–31 May 2019.
21. Lee, C.; Kim, Y.; Shin, Y. (2021). Data Usage and the Legal Stability of Transactions for the Commercial Operation of Autonomous Vessels Based on Digital Ownership in Korean Civil Law. Sustainability, 13, 8134.
22. Max Johns, (2018). Seafarers and digital disruption. Study for International Chamber of Shipping.

23. Meersman, H., Moschouli, E., NanwayBoukani, L., Sys, C., van Hassel, E., Vanelslander, T., & Van de Voorde, E. (2020). Evaluating the performance of the vessel train concept. European Transport Research Review, 12, 1–11.
24. Munim, Z. H. (2019). Autonomous ships: A review, innovative applications and future maritime business models. Supply Chain Forum: An International Journal, 20(4), 266–279.
25. Munim, Z. H., Notteboom, T., Haralambides, H., & Schøyen, H. (2025). Key determinants for the commercial feasibility of maritime autonomous surface ships (MASS). Marine Policy, 172, 106482.
26. Mäkitie, T., Hanson, J., Damman, S., & Wardeberg, M. (2023). Digital innovation's contribution to sustainability transitions. Technology in Society, 73, 102255.
27. Nesheim, D. A., Kristiansen, J. N., Raakjær, J., & Mørkrid, O. E. (2022). The need for collaborative business models in autonomous vessel ecosystems. ICMASS Conference Proceedings.
28. Nguyen-Luong, D., & Cariou, P. (2020). Technological change and seafarers' employment: Impact of autonomous ships. Transport Policy, 92, 1–9.
29. Nordahl, H., Nesheim, D. A., & Lindstad, E. (2022, July). Autonomous ship concept evaluation–Quantification of competitiveness and societal impact. In Journal of Physics: Conference Series (Vol. 2311, No. 1, p. 012020). IOP Publishing.
30. Oksavik, A., Hildre, H. P., Pan, Y., Jenkinson, I., Kelly, B., Paraskevadakis, D., & Pyne, R. (2021). Future skills and competence needs. SkillSea Deliverable 1.1.3, version 5.0.
31. Osinuga, D. (2020). Unmanned ships: Coping in the murky waters of traditional maritime law. European Transport Research Review, 12, 1–11.
32. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. Int. J. Surg. 88, 105906.
33. Pakkanen, P., & Henttinen, E. (2016). How data is shaping the future of vessel design, navigation and operation. RINA Smart Ship Technology.
34. Rodseth, O. J. (2017). From concept to reality: Unmanned merchant ship research in Norway. IEEE Underwater Technology (UT), 1-10.
35. Runde, J. (2024). Impact of autonomous shipping on the business model of commercial shipping companies. European Business University of Luxembourg.
36. Saha, R., Lundh, M., & MacKinnon, S. N. (2023). The shift toward autonomous European inland waterway shipping: Identifying the gaps in the emerging socio-technical system. Journal of Physics: Conference Series, 2618(1), 012016.
37. San Francisco, M. (2022). Le développement de la navigation autonome pour le transport fluvial de marchandises en petit gabarit : Redéfinition d'un modèle économique vieillissant. Voies Navigables de France, Direction Territoriale du Bassin de la Seine.
38. Sencila, V. (2019). Industry 4.0: Autonomous shipping and new challenges for maritime education and training. In Transport Means – Proceedings of the 23rd International Scientific Conference. Recuperado de https://www.scopus.com/inward/record.uri
39. Shahbakhsh, M., Emada, G. R., & Cahoon, S. (2021). Industrial revolutions and transition of the maritime industry: The case of seafarer's role in autonomous shipping. The Asian Journal of Shipping and Logistics.
40. Theotokas, I. N., Lagoudis, I. N., & Raftopoulou, K. (2024). Challenges of maritime human resource management for the transition to shipping digitalization. Journal of Shipping and Trade, 9(1), 6.
41. Tsvetkova, A., Hellström, M., & Ringbom, H. (2021). Creating value through product-service-software systems in institutionalised ecosystems – The case of autonomous ships. Industrial Marketing Management, 99, 16–27.
42. Veitch, C., Mallam, S., Porathe, T., & Lützhöft, M. (2023). Human-centred perspectives on remote ship operation: Design considerations for maritime autonomous surface ships. WMU Journal of Maritime Affairs, 22, 45–64.
43. Veitch, E., Hynnekleiv, A., & Lützhöft, M. (2020, February). The operator's stake in shore control centre design: A stakeholder analysis for autonomous ships. In Proceedings of the RINA, Royal Institution of Naval Architects—International Conference on Human Factors (pp. 23-30).
44. Wang, W., Wang, S., Zhen, L., & Laporte, G. (2023). The impact of autonomous ships in regional waterways. Transportation Research Part B: Methodological, 178, 102851.
45. Ziajka-Poznanska, E., & Montewka, J. (2021). Costs and benefits of autonomous shipping: A literature review. Applied Sciences, 11(10), 4553.