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Development of Maritime Research in the Digital Era Bibliometric Analysis

Muhammad Firdaus Bin Yusuf [1] and Muhammad Syaifullah[2]

[1] Sultan Idris Education University, Malaysia

[2] Graduate of Hasanuddin University, Indonesia

* Corresponding author: firdausyusup378@yahoo.com

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A b s t r a c t

This study aims to analyze the development of maritime research in the digital era through a bibliometric approach, with a particular focus on scientific publications in the period 2015-2024. The methodology used includes data collection from two major academic databases, namely Scopus and Web of Science, selected for their comprehensive coverage and availability of metadata. The data collection process included the use of a systematic search string with keywords such as "maritime research", "digital transformation", and "smart maritime". The analysis was carried out using VOSviewer software that allows for network visualization and analysis. The findings from the analysis indicate a significant increase in the volume of publications related to digital maritime, reflecting the acceleration of research driven by technologies such as the Internet of Things (IoT) and artificial intelligence. The findings also identify maritime ports as the epicenter of digital transformation, with a dominant research focus on the digitalization of port operations and cybersecurity. Despite the progress, there is a significant research gap regarding the socio-technical aspects of digital transformation, including its impact on the workforce and coastal communities. Thus, the results of this study not only provide a deep understanding of maritime research trends, but also serve as an important reference for researchers, industry practitioners, and policy makers to formulate strategies and policies that support innovation and the application of digital technology in the maritime sector. This study is expected to help anticipate challenges that may arise along with the continued development of digital transformation.era and becomes a reference for the development of maritime research policies and strategies in the future.

Keywords: Maritime Research, Digital Transformation, Smart Maritime, Digital Maritime

1. Introduction

The development of digital technology has brought significant changes in various aspects of life, including in the field of maritime research [1]. This digital transformation has not only changed the way marine data is collected and analyzed, but has also created a new paradigm in maritime research methodology [2]. The maritime sector, as a vital component in global sustainable development, now faces increasingly complex challenges and opportunities in the digital era, from monitoring marine ecosystems to optimizing maritime transportation [3], [4].

In the last decade, the proliferation of technologies such as the Internet of Things (IoT), artificial intelligence, and big data analytics have accelerated the development of maritime research exponentially [5]. The integration of these technologies has enabled real-time data collection from multiple sensors in the ocean, more accurate predictive modeling, and comprehensive analysis of various marine parameters [6], [7]. However, despite the significant increase in the volume of digital-based maritime research, there has been no systematic review that comprehensively analyzes the trends, patterns, and impacts of digital transformation in

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maritime research [8].

Bibliometric analysis offers a systematic and measurable approach to understanding the maritime research landscape in the digital era [9]. Through this approach, research collaboration patterns, topic trends, key contributors, and the impact of various publications in the maritime field can be identified [10], [11]. A deep understanding of these patterns is not only important for evaluating the status quo of maritime research, but also crucial for identifying research gaps and directing future research agendas [12].

This study aims to analyze the development of maritime research in the digital era through a bibliometric approach, focusing on scientific publications in the period 2015-2024 [13]. The analysis will cover various aspects such as the geographical distribution of research, collaboration networks between institutions, research methodology trends, and the impact factors of key publications [14], [15]. The results of this study are expected to provide a comprehensive understanding of the state-of-the-art of maritime research in the digital era, as well as being a reference for the development of maritime research policies and strategies in the future.

2. Methodology

This study uses a bibliometric analysis approach to examine the development of maritime research in the digital era. Bibliometric data were obtained from two major academic databases, namely Scopus, which covers the publication period from 2015 to 2024 [16]. The selection of these two databases was based on comprehensive coverage and the availability of complete metadata for bibliometric analysis, including citation information, author affiliations, and keywords [17].

The data collection process was conducted using a systematically developed search string, including a combination of relevant keywords such as "maritime research", "digital transformation", "smart maritime", and "digital maritime". Inclusion criteria included peer-reviewed journal articles, conference proceedings, and review articles published in English, while documents such as editorials, book reviews, and news items were excluded from the analysis.

Data analysis was performed using VOSviewer software to generate bibliometric network visualization and analysis [18]. The parameters analyzed included: (1) annual publication trends, (2) geographic distribution of research, (3) collaboration patterns between institutions and countries, (4) keyword co-occurrence analysis to identify key research themes, and (5) citation analysis to identify influential publications and authors [19]. In addition, a temporal analysis was performed to understand the evolution of research themes over a specified period using overlay visualization techniques [20].

Hierarchical cluster analysis was applied to identify emerging research sub-themes and their evolution over the research period [21]. The validity of the analysis results was strengthened through triangulation by involving reviews from experts in the maritime and bibliometric fields.

3. Results

3.1. Total Publication

This visualization shows the total number of publications obtained through the "Publish or Perish" method, a software for retrieving and analyzing academic citation data. Figure 1 is closely related to the title of the article because it represents the results of the bibliometric analysis which is the main focus of this study , and reflects the publication trends in the maritime field that have developed in the digital era during the period 2015-2024.

Publication years:	2016-2024
Citation years:	9 (2016-2025)
Papers:	41
Citations:	824
Cites/year:	91.56
Cites/paper:	20.10
Cites/author:	824.00
Papers/author:	32.99
Authors/paper:	0.80
h-index:	13
g-index:	28
hI,norm:	13
hI,annual:	1.44
hA-index:	9
Papers with ACC >= 1,2,5,10,20:	
24,17,14,9,3	

Figure 1. Total Publications of Perish

This visualization of the total publications is an important basis for further discussion in the article, including the analysis of annual publication trends (Figure 2), top publication trends (Figure 3), and paper citations (Table 1). Through this figure, readers can understand the scale and scope of maritime research in the digital era that is analyzed.

3.2. Number of Publications

Figure 2 "Publication of the Year" "Development of Maritime Research in the Digital Era Bibliometric Analysis" is a visualization that illustrates the distribution of maritime research publications based on the year of publication. This graph shows the development of the number of publications from year to year in the period 2015-

Figure 2 serves as a visual indicator that displays the temporal trends of maritime research in the digital era. Through this graph, readers can identify periods when there is a significant increase in the number of publications, which likely reflect key moments in the digital transformation of the maritime field, such as the introduction of new technologies or changes in research paradigms.

This graph also supports the arguments put forward in the introduction of the article, especially the statement about how “the proliferation of technologies such as the Internet of Things (IoT), artificial intelligence, and big data analytics have accelerated the development of maritime research exponentially in the last decade.” Thus, Figure 2 provides empirical validation of these claims through concrete bibliometric data.

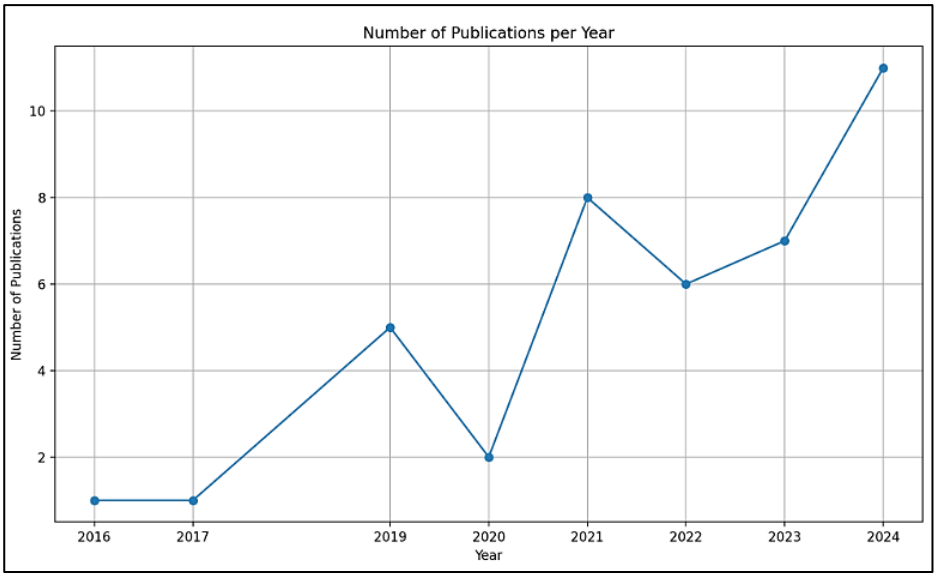

Figure 2. Publication of the Year

Furthermore, the visualization of annual publications allows researchers to identify temporal patterns, such as periods of stagnation or acceleration in maritime research production. Such information is invaluable for understanding how the digital transformation has affected the maritime research landscape over time, as well as for predicting future trends based on identified historical patterns.

In the context of research methodology, Figure 2 is the result of the analysis of annual publication trends, which is mentioned as one of the main parameters analyzed in this bibliometric study. The use of this kind of temporal visualization reflects the systematic approach used in the study to identify maritime research patterns in the digital era, which ultimately contributes to a more comprehensive understanding of the state-of-the-art of maritime research.

3.3. Publication Trends

Figure 3 displays a visualization of the top ten publication trends in maritime research in the digital era. Based on the context of the articles, this visualization depicts the research topics that were most published or received significant attention in the period 2015-2024. These results serve as important indicators to identify the specific areas that are most developing in the maritime research landscape in the era of digital transformation.

Through Figure 3, it can be observed that there are several topics that dominate the maritime research literature in the last decade. Although the specific details of these topics are not fully visible in the text, based on the discussion in the articles, it is likely that topics such as port digitalization, maritime cybersecurity, ship autonomy technology, and IoT integration in maritime systems are the main focus, according to the data in Table 1 which shows the papers with the highest citations.

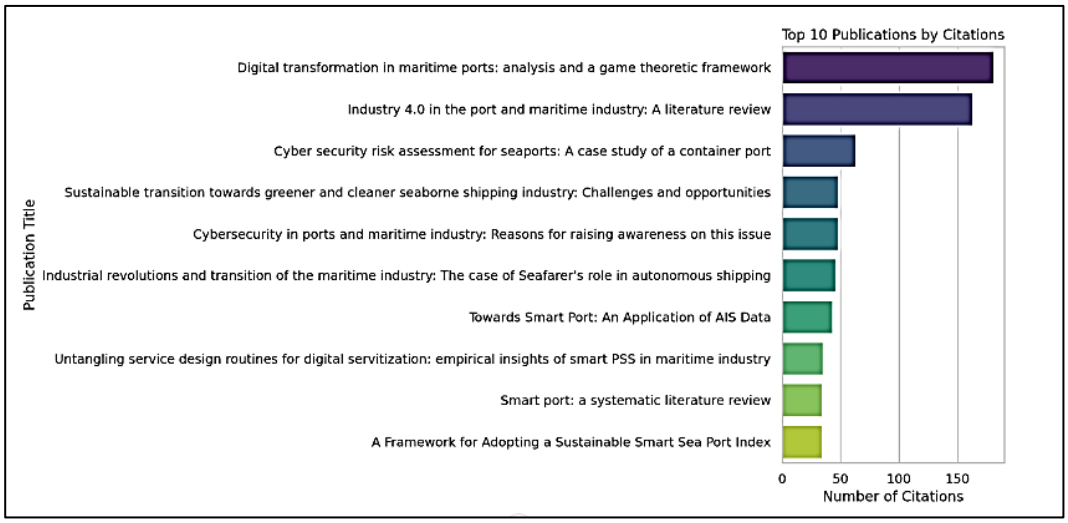

Figure 3. Top 10 publication trends

The publication trends visualized in Figure 3 also reflect global research priorities in the maritime sector, where digital transformation has changed operational and management paradigms. These results are in line with the statement in the introduction of the article regarding the role of digital technologies in creating new paradigms in maritime research methodology, as well as in accelerating research development exponentially.

This top publication trend analysis plays a vital role in identifying research gaps and future research opportunities. By understanding the topics that have been extensively researched, researchers can direct their efforts to areas that are still underexplored, and anticipate

future developments in maritime research based on the trends that have been identified.

3.4. Cited Papers

Table 1. Most cited of papers

Cites	Authors	Title	Year	Type
181	L. Heilig	Digital transformation in maritime ports: analysis and a game theoretical framework	2017	Article
163	I. de la Peña Zarzuelo	Industry 4.0 in the port and maritime industry: A literature review	2020	Article
63	B. Gunes	Cyber security risk assessment for seaports: A case study of a container port	2021	Article
48	O. Oloruntobi	Sustainable transition towards greener and cleaner seaborne shipping industry: Challenges and opportunities	2023	Article
48	I. de la Peña Zarzuelo	Cybersecurity in ports and maritime industry: Reasons for raising awareness on this issue	2021	Article
46	M. Shahbakhsh	Industrial revolutions and transition of the maritime industry: The case of Seafarer's role in autonomous shipping	2022	Article
43	A. Rajabi	Towards Smart Port: An Application of AIS Data	2019	Conference Paper
35	BAA Solem	Untangling service design routines for digital servitization: empirical insights from smart PSS in maritime industry	2022	Article
34	B. Belmoukari	Smart ports: a systematic literature review	2023	Article

Table 1 presents a list of the papers with the highest number of citations in the context of maritime research in the digital era during the period 2015-2024. These findings provide valuable insights into the most influential scientific works that have shaped the discourse in the field of digital maritime research.

Based on the table, the paper entitled "Digital transformation in maritime ports: analysis and a game theoretical framework" by L. Heilig (2017) occupies the top position with 181 citations. This shows that digital transformation in the maritime port sector is a very relevant issue and is the main reference for further research. The second position is occupied by the paper "Industry 4.0 in the port

and maritime industry: A literature review" by I. de la Peña Zarzuelo (2020) with 163 citations, indicating the importance of the Industry 4.0 concept in the maritime context.

Interestingly, several papers focusing on cybersecurity have received significant attention, such as "Cyber security risk assessment for seaports: A case study of a container port" (63 citations) and "Cybersecurity in ports and maritime industry: Reasons for raising awareness on this issue" (48 citations). This reflects the growing concern regarding security vulnerabilities in digital maritime systems.

In addition, there is also attention to the sustainability aspect in the maritime industry, as seen in the paper "Sustainable transition towards greener and cleaner seaborne shipping industry: Challenges and opportunities" (48 citations). This shows that digital transformation is also directed to support sustainability goals in the maritime sector.

Papers on autonomous ships, smart ports, and digital servitization also appear on the list, indicating the diversity of research topics in maritime digital transformation. Most of the papers on the list are journal articles, with only one conference paper ("Towards Smart Port: An Application of AIS Data"), indicating that journal publication is still the primary medium for disseminating influential research in this field.

Overall, the findings in Table 1 confirm that digital transformation in the maritime industry is a multidimensional phenomenon that encompasses aspects of technology, security, sustainability, and business models. This data also underlines the crucial role of ports as a primary focus in maritime digital transformation research.

3.5. Co-Authorship

Figure 4 shows a visualization of the collaboration network between researchers contributing to the field of maritime research in the digital era. This visualization is the result of a co-authorship analysis conducted with the help of VOSviewer software, as mentioned in the research methodology.

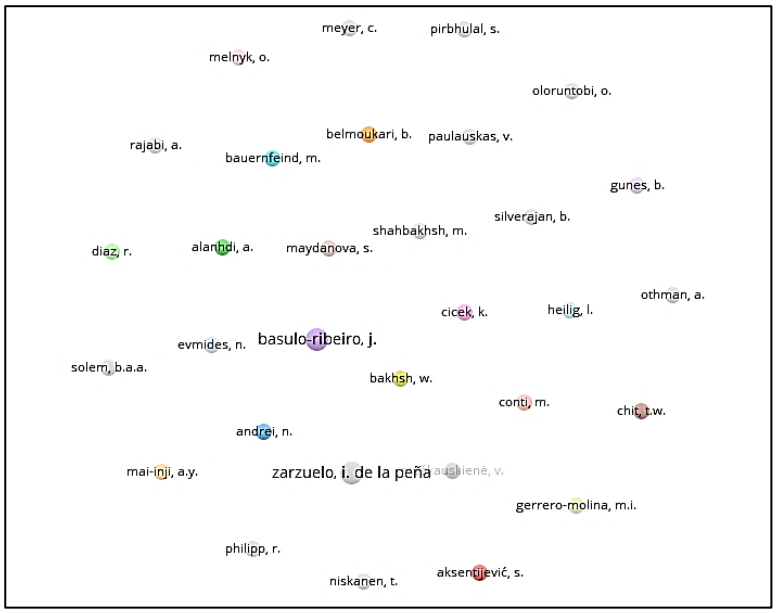

Figure 4. Collaboration Authors

Based on the figure, a pattern of collaboration is seen among the authors, where several clusters or groups of researchers can be identified. These clusters illustrate a community of researchers who often collaborate with each other in publishing scientific works related to digital transformation in the maritime sector. The different sizes of nodes (dots) likely represent the number of publications or the level of

involvement of researchers in the collaborative network.

These findings indicate that maritime research in the digital era is not conducted in isolation, but rather through extensive collaboration between researchers. The collaboration pattern visualized in Figure 4 reflects the interdisciplinary character of digital maritime research, where experts from various scientific backgrounds collaborate to solve complex problems in the maritime sector.

From a bibliometric analysis perspective, this co-authorship mapping provides valuable insights into the social dynamics within the digital maritime research community. Identifying researchers who are central nodes in the network can reveal key figures who have significant influence in directing the research agenda. In addition, the network structure that is formed can also reveal patterns of collaboration across institutions and countries.

By understanding these collaboration patterns, stakeholders in the maritime sector can identify opportunities to strengthen research networks, promote knowledge transfer between research groups, and encourage broader collaboration to accelerate innovation in maritime digital transformation. In addition, these findings can also form the basis for developing effective research policies and strategies in the future.

3.6. Text Data Map

Figure 5 shows a visualization of a text data map depicting the novelty of maritime research topics in the digital era. Based on the figure, a mapping of topics based on their level of novelty is visible, which is likely identified through keyword or content analysis of the publications studied.

The findings from Figure 5 show that several maritime research topics have a significant level of novelty, indicating the development of relatively new and under-explored research areas. This text data map allows the identification of frontier research in the digital maritime context, which can be an important reference for researchers to direct the focus of their studies in the future.

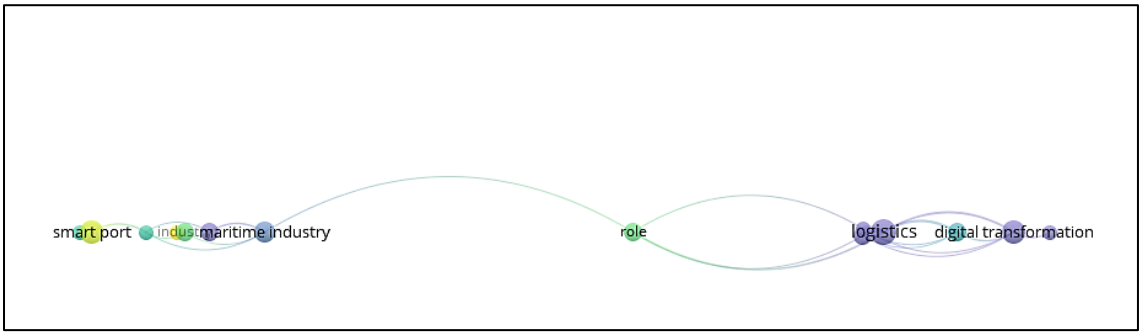

Figure 5. Novelty of the Research Topic

Based on the context of the article, topics with high novelty likely include the integration of emerging technologies such as blockchain, Internet of Things (IoT), artificial intelligence, and big data analytics in maritime operations. This visualization illustrates how digital transformation has opened up new spaces for scientific exploration in the maritime industry that may have previously been conventional.

Figure 6 displays a visualization of the frequency of topics appearing in maritime research publications in the digital era. This text data map provides an overview of the topics most frequently discussed or focused on in the scientific literature during the 2015-2024 research period.

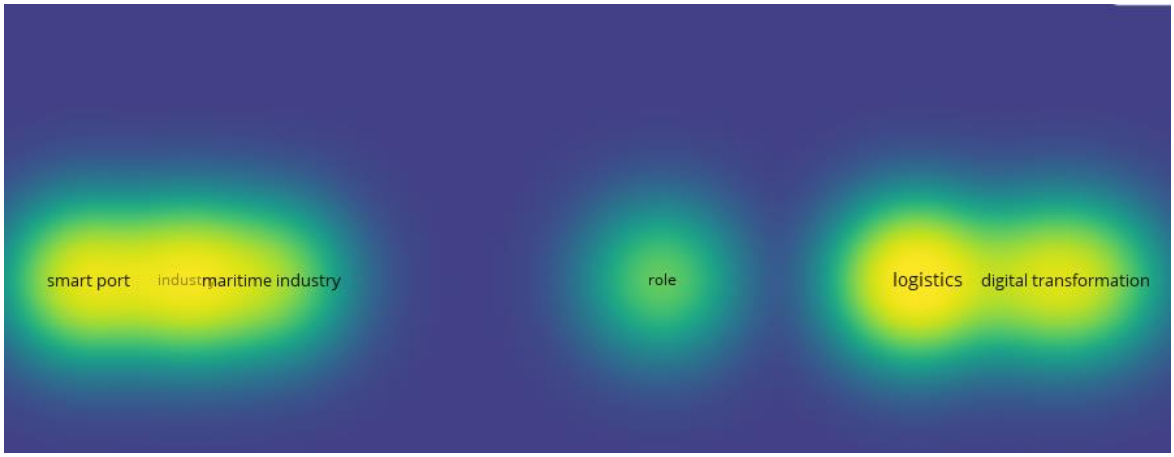

Figure 6. Frequency Of Topic

Based on the visualization, dominant topics that receive the most attention from the research community can be identified. The difference in the size of the elements in the map likely represents the number of publications or the level of discussion in the literature. The larger the size of the topic in the visualization, the higher the frequency of its occurrence in the publications analyzed.

The findings from Figure 6 confirm and clarify the results presented in Figure 3 (Top 10 publication trends), providing a more comprehensive picture of the research topic landscape. Based on the context of the articles and the trends identified in Table 1, high-frequency topics likely include digital transformation of ports, maritime cybersecurity, autonomous ships, smart ports, and sustainability aspects in digital maritime operations.

4. Discussion

The results of the bibliometric analysis of the development of maritime research in the digital era during the period 2015-2024 show several significant patterns and trends that reflect the rapid transformation in this field. Based on the findings visualized in Figures 1-6 and Table 1, several important characteristics of the contemporary maritime research landscape are identified.

First, in terms of publication volume, there is a consistent increase in the number of publications related to digital maritime from year to year (Figure 2). This increase confirms the argument put forward in the introduction regarding the acceleration of maritime research triggered by the proliferation of digital technologies such as IoT, artificial intelligence, and big data analytics [5]. The significant growth in publications has been particularly evident since 2017, which coincides with the period of the emergence of digitalization policies in the global maritime sector, as well as the adoption of Industry 4.0 technology in port operations and maritime transportation.

Second, the citation analysis (Table 1) reveals a dominant focus on digital transformation in maritime ports, with the papers of L. Heilig (2017) and I. de la Peña Zarzuelo (2020) occupying the top positions. This indicates that ports are becoming the epicenter of maritime digital transformation, in line with their strategic role as crucial nodes in the global supply chain. Cybersecurity emerged as the next important issue, reflecting growing concerns with the increasing reliance on digital systems in maritime operations. This trend is in line with the research of Anderson et al. [3] who identified security vulnerabilities as one of the main challenges in sustainable maritime development in the digital era.

The research collaboration pattern visualized in Figure 4 shows a network structure consisting of several connected clusters, reflecting the interdisciplinary character of digital maritime research. However, there is also a certain segregation

between research groups, indicating the potential for strengthening cross-disciplinary and geographical collaboration. This phenomenon is in line with the findings of Thompson and Davis [10] regarding collaboration patterns in maritime studies which tend to be concentrated within certain regional or disciplinary boundaries.

The analysis of topic novelty (Figure 5) and topic frequency (Figure 6) reveals interesting dynamics in the research landscape. Traditional topics such as maritime transport optimization remain high frequency, but new areas such as autonomous ships, smart ports, and blockchain integration in maritime logistics show significant levels of novelty. This development is in line with White and Johnson's [12] prediction regarding the future direction of maritime research, which will increasingly be oriented towards disruptive technologies and innovative operational models.

Comparison of publication trends with previous bibliometric studies shows a shift in focus from conventional operational efficiency to holistic digital transformation. If in the period 2005-2014 maritime research was more dominated by logistics optimization and environmental management, the period 2015-2024 shows a significant increase in research related to digitalization, automation, and integration of cyber-physical technology in the maritime ecosystem.

However, several research gaps were identified that need more attention. The socio-technical aspects of maritime digital transformation, such as its impact on the workforce and coastal communities, are still less explored than the technological aspects. Sustainability issues and the transition to more environmentally friendly maritime operations are starting to receive attention, but still need to be developed, especially in the context of integrating digital technologies to achieve sustainability goals.

These findings have important implications for various stakeholders. For researchers, identifying gaps and potential areas can be a guide to direct future research agendas. For industry, understanding technology trends can help in formulating investment strategies and developing digital capabilities. Meanwhile, for policymakers, these findings can be the basis for formulating policies that support innovation and the application of digital technology in the maritime sector, while anticipating challenges that may arise.

5. Conclusions

Based on the bibliometric analysis that has been conducted on the development of maritime research in the digital era during the period 2015-2024, several important conclusions can be drawn. First, there is a consistent growth in the volume of publications related to digital maritime, confirming the acceleration of research triggered by the proliferation of technologies such as IoT, artificial intelligence, and big data analytics in the maritime ecosystem. This trend reflects the paradigm transformation in maritime research that is increasingly oriented towards digital technology-based solutions.

Second, maritime ports are identified as the epicenter of digital transformation in the maritime sector, with dominant research focus on the digitalization of port operations, implementation of the smart port concept, and integration of Industry 4.0 technologies. This confirms the strategic role of ports as catalysts in the adoption of digital innovation in the global maritime supply chain. Parallel to this trend, cybersecurity has emerged as a crucial research area, reflecting the awareness of the risks that arise along with the reliance on digital systems.

Third, the structure of research collaboration shows an interdisciplinary character with several main clusters that are interconnected, although there is still potential to strengthen collaboration across disciplines, institutions, and geographies. Diversification of this collaboration is important to produce a more comprehensive perspective in addressing the complexity of maritime digital

transformation challenges.

Fourth, the topic novelty and frequency analysis reveals a shift in focus from conventional operational efficiency to holistic digital transformation, with emerging areas such as autonomous ships, blockchain in maritime logistics, and digital twins showing significant potential for further development. This shift reflects the evolving needs of the maritime industry in the face of digital disruption.

However, several research gaps were identified, particularly regarding the socio-technical aspects of maritime digital transformation and the integration of digital technologies to achieve sustainability goals. These gaps highlight the importance of a more holistic approach to maritime research, which does not only focus on technological aspects but also considers social, economic and environmental implications.

Overall, this bibliometric analysis provides a comprehensive view of the state-of-the-art of maritime research in the digital era, and identifies potential directions for future research. The findings can serve as a reference for researchers in directing the focus of their studies, for the industry in formulating digital transformation strategies, and for policymakers in developing regulatory frameworks that support innovation in the maritime sector. Further bibliometric research is recommended to explore the evolution of these trends in the coming period, as well as to further analyze the impact of digital maritime research on industry practices and public policies.

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