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Article

A smart port development: Systematic literature and bibliometric analysis

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Original article

A smart port development: Systematic literature and bibliometric analysis

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ABSTRACT

Improving the efficiency of operating activities while minimizing the impact on the environment are increasingly prioritized of seaports over stiff competition in global supply chains. Incorporating advanced technologies connected with the fourth industrial revolution, smart port has become a strategic direction towards sustainable development of modern seaports. Consequence, there have been a growing concern over smart port in both academic and practical. Therefore, this study conducts a systematic literature review and a bibliometric analysis evaluating the current research of smart port derived from Web of Science. This study's findings illustrate that there are three main research themes in the smart port literature in which digitalization and its application in smart port has been a major topic in the smart port literature. Accordingly, this study provides insights into the main trends and future research directions on smart port.

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1. Introduction

The fourth industrial revolution is characterised by a wide range of advanced technologies including internet of things (IoT), autonomous, artificial intelligence and 3D printing (Koh et al., 2019) which affect every aspect of life and reshape the economy (David et al., 2022). The fourth industrial revolution becomes an inevitable revolution for efficiency, effectiveness and competitive edge in many industries (David et al., 2022). In line with this trend, this evolution is particularly striking in the maritime sector, which take responsibility for the carriage of over 80 % of the volume of international trade (UNTACD, 2021). Ports are being challenging to enhance efficiency and productivity in an increasingly competitive environment (Parola et al., 2017). On the contrary, the port operations and development are facing higher pressure from the public to comply with social responsibility and environmental performance in associate with climate change and global warming issues (Lam & Theo Notteboom, 2014; Monios et al., 2020). It is evident that the environmental impacts deriving from port activities are paramount, namely air pollution, water pollution, and waste disposal. Creating a safety working environment and minimizing environmental impacts, hereby, has become a key focus of modern seaports. Ironically, an adaption by ports mitigating port disruptions is being

emphasized for tackling climate change with the impacts of natural disasters (Verschuur et al., 2020).

In this scenario, smart port development taking advantages of new technologies to improve competitiveness and resilience has become a strategic direction towards sustainable development (Othman et al. 2022). There have been huge efforts to adapt smart technology in the port industry. The Korean government is formulated a roadmap for smart port development which would contribute a vital role in Korean economy (Jun et al., 2018). Similarity, China have been promoting the construction of smart ports by encouraging technology development to increase safety, efficiency and environmental friendliness. The port of Hamburg introduced the SmartPort project implementing an IoT-based cloud communication platform focusing on renewable energy, energy efficiency, mobility and economic efficiency, resulting in reducing the operational cost by 75 % and port congestion by 15 % (Heilig et al., 2017). Meanwhile, the Maritime and Port authority of Singapore developed the “sense-making analytics for maritime event recognition” system in 2017 which is an AI-based system for the port of Singapore to provide new capabilities to reduce navigation accidents. The port of Rotterdam established as a smart port enables shipping companies to reduce ship waiting time and estimate the optimal time of arrival.

Simultaneously, in recent years, the research field of smart port has been raised concerns to possess a thorough understanding of the evolution in port development. However, studies on the synthesis of smart port in maritime transport industry are rare, which has

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created a gap in the academic literature. To the best knowledge of author, there have been three review studies focused on specific discipline such as the state of the art on the new technologies such as internet of things, sensing solutions, cloud computing, 3D printing and additive manufacturing, big data which are pillars of industry 4.0 impacting the port and maritime industry (Zarzuolo, 2021), energy efficiency aspect in terms of identifying challenges, measures, infrastructure, and technologies towards smarter ports (Sadiq et al., 2021). the latest achievements of 5 G network slicing based on machine learning program in a smart port (Sohaib et al., 2021). Therefore, it is worthwhile to understand the dimensions of smart port due to the importance of seaport in global supply chain.

Hence, this study attempts to critically review of a thorough search on the new era of smart ports. By adopting bibliometric approach and content analysis, the study identifies the key journals, articles, institutions and authors within this research domain. Research review published studies that deal with smart port in maritime transport industry to map the conceptual structure of the field and identify future research avenues. Accordingly, the study contributes several academic and industry implications. The remaining of the paper is constructed as follows: Section 2 introduces applied methodology, Section 3 present bibliometric analysis and findings, followed by Section 4 provides an analysis of literature review. Finally, a conclusion with some implications and recommendation on the future research is mentioned in Section 5.

2. Methodology

In order to achieve the objective, the study applied bibliometric analysis to provide an overview in smart port studies. Bibliometric analysis is a literature review method which is widely applied in business fields to reveal the evolution of the research domain (Adepoju et al., 2022; Khan et al., 2021). Bibliometric analysis is “systematic, transparent, and reproducible” by providing and mapping objectively and reliably quantitative data in associate with VoSviewer (Aria & Cuccurullo, 2017). In addition, in order to provide a profound insights into current research interests, the study applied exploratory research through a systematic review following three steps namely defining selection criteria, grouping studies, and discussing and synthesizing (Crossan & Apaydin, 2010). It is appropriate to apply a systematic literature review to investigate a research field being at a relatively early stage in its evolution (Petticrew and Roberts, 2008).

In this study, bibliography data was collected from the leading academic database which is the Web of Science (Henriquez et al., 2022). The data was extracted by a keyword search in November, 2022. All articles about smart port topic were selected by the Boolean expression. The first part (“smart port” OR “smart ports”) cover articles including these keywords, while the second part (“maritime” OR “shipping” or “port”) to extract articles in maritime industry. Fig. 1.

After refining the search including English articles in peer-reviewed international journals (Colicchia & Strozzi, 2012), 69 were left for consideration. Meeting abstract, proceeding paper and editorial material are excluded due to limited impact on academic literature (Parola et al., 2017). Finally, all articles were manually screened by relevance to the smart port in the maritime industry focusing on port area included in this study and excluded irrelevance articles because of (1) the problem with homonymy of keywords in which “smart port” or “port” is a part of a new route architecture in a communication network; (2) focusing on autonomous vessels, smart shipping and smart port - city. A final sample of 53 works were selected for bibliometric analysis and systematic literature review including 46 articles, 3 review papers, and 4 early access articles published since the year 2016. In order to extract and present results

for the analysis, this study used the software tools VOSviewer version 1.6.18 developed by Van Eck and Waltman (2022).

3. Bibliometric analysis and findings

This study reviews a sample of 53 studies relating to smart port research in the shipping industry published in 40 publication outlets over 7 years from 2016 to 2022, written by a total of 197 authors. Multi-authored studies are the majority (96,2%), while only 3,8% are single-authored studies (2 authors).

The evolution of published studies in the domain of smart port is indicated in Fig. 2. The first study was conducted since 2016. Albeit the outputs were quite low in the first few years, the number of published articles has been increased significantly from 2019.

3.1. Author keyword co-occurrence

The mapping of author keyword co-occurrence illustrates the frequency of occurrence of keywords in the same article and the interrelation between topics. It is visualized by Vos Viewer to represent several clusters of keywords which is regarded as the main research topic in the research field. A total of 17 selected keywords were extracted and illustrated in Fig. 3. These words co-occurred at least two times and excluded general keyword such as “maritime transport”, “maritime transportation”, “industries”, “maritime industry”, “survey”, “seaport” specific name of port such as “Spanish port system”; combined keywords with the same meaning, for example, digitalization, digitalization, internet of things (IoT), internet of things, IoT, IoT-based monitoring, smart ports, smart port. The network illustrated that the most predominant are “internet of things”, “digitalization”, and “sustainability”.

3.2. Top journals

The sample of 53 studies reviewed were published in 40 scientific journals. Most of the journals (45) published only one paper on smart port. The remaining that published more than one papers are Maritime Policy & Management (4), Sustainability (3) IEEE Access (3), Sensor (3), Logistics Basel (2), Transport policy (2), Journal of marine science and engineering (2), Electronics (2) and Journal of coastal research (2). In general, these journals focus on computer science, engineer, and transportation area.

3.3. Most relevant institutions and countries

Out of the 93 institutions publishing research on smart port in maritime industry, 10 organizations that were contributed more than one paper published 25 papers of the 53 papers reviewed, the remaining published only one paper. Notably, only one representative which Shanghai Maritime University is specialized maritime university in Asia published 5 articles (9,3%). The other top relevant institutions comprise University Polytechnic of Madrid in Spain (3 articles), University Hamburg in Germany (3 articles).

Table 1 illustrates the contribution of the six countries which research has been concentrated with a minimum of four relevant publications. Among countries, China is the most a productive country in studying on smart port in shipping industry, and China is also actively cooperating with other nations with the highest link strength. Spain ranked 2nd in the number of published articles, the average citation and the link strength. Italy has 6 documents ranking 3rd in the total number of papers over time, while the average citation is 8,3, which is the lowest average citation among the countries, presenting its limited impact in the smart port studies. USA has an equal number of articles to South Korea, but the average citation and link strength are considerably higher than South Korea. Notably, Germany has only 4 documents, but Germany's research has the

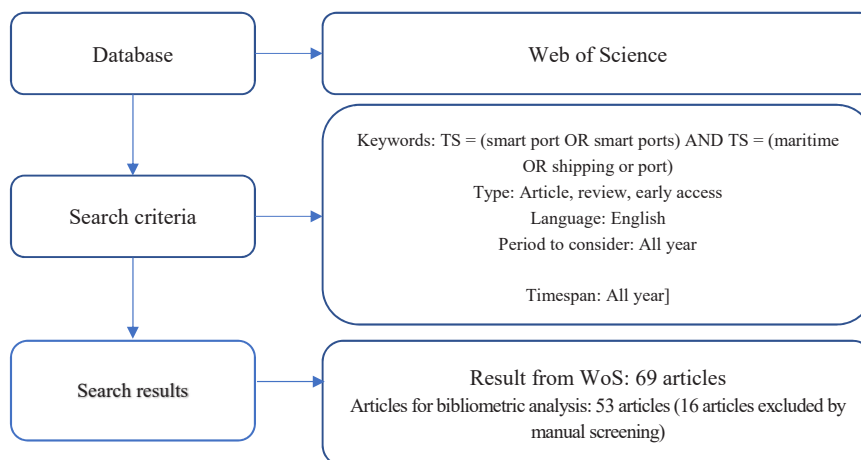


Fig. 1. Bibliography data extraction.

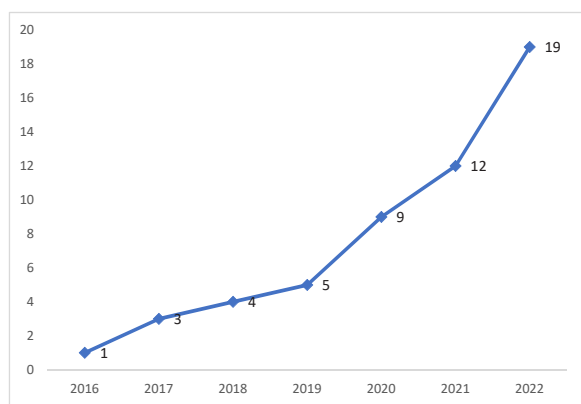


Fig. 2. Number of articles per year (Source: WoS).

highest score of the frequency of citation, which illustrates a significant contribution of research in smart port studies.

3.4. Most impactful authors

Of the 201 authors, 17 meet the thresholds of more than one of documents of an author. Accordingly, the most impactful authors in

Table 1

Most relevance countries.

Rank	Country	Articles	Citations	Average Citation	Total link strength
1	China	14	231	16,5	66
2	Spain	8	97	12,13	52
3	Italy	6	50	8,3	31
4	Germany	4	125	31,25	38
5	USA	4	82	20,5	38
6	South Korea	4	40	10	23

the smart port in maritime industry are Fu, Xiuwen; Yang, Yongsheng; Yao, Haiqing Heilig, Leonard. Among that, Fu, Xiuwen; Yang, Yongsheng; Yao, Haiqing have the highest citation scores, but Heilig, L Leonard is the most cited scholar of all time with the highest average citation number and the interrelationship between authors.

4. The concept of smart port and research clusters

4.1. The concept of smart port

There is no agreement on a precise definition of smart port has been built and the relevant literature indicates that significant

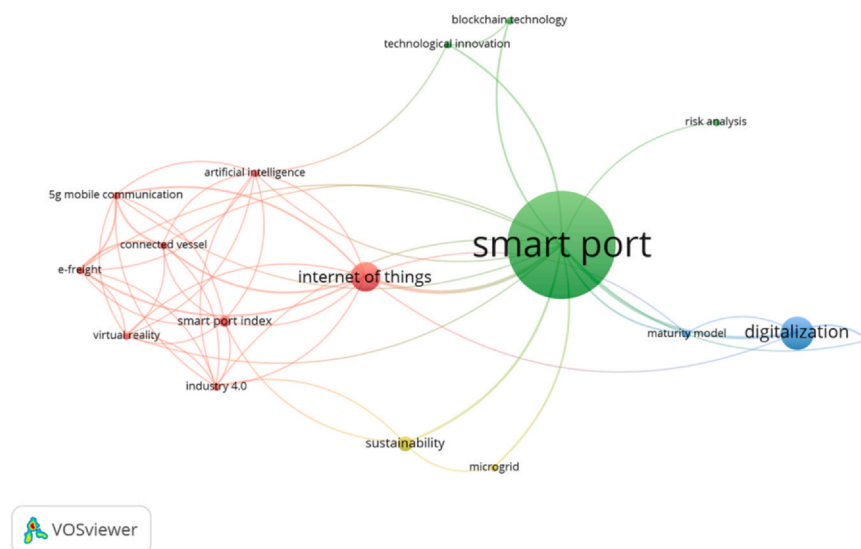


Fig. 3. Keyword matching (elaborated with VOSviewer).

discrepancies regarding the explanation of the concept. Some definitions were solely technology oriented to improve port operations. Some researchers defined a smart port as an automated port using smart technologies such as IoT technology (Zhong et al., 2019; Bracke et al., 2021), big data, automation, and eco-friendly technology (Zhao et al., 2020). Lin et al. (2022) introduced a concept of a smart port that is built on three components namely computation, communication, and control technologies. According to Jiang et al. (2022) and Gonzalez et al. (2020), digitalization with information and communication technology and automation is a fundamental factor to promote a port towards smart port to become more intelligent, competitive and productivity. Meanwhile, Botti et al. (2017) and Yau et al. (2020) asserted that information and communication technology play crucial role in smart port industry by improving vessels and container management contributing into the supply chain management.

The literature review also revealed that the smart port definitions emphasized its objectives and strengths. The concept of smart port could be viewed as productivity, sustainability, reliability (Molavi et al., 2020a), operations, environment, energy, safety, and security (Othman et al. (2022)). Meanwhile, Boullauazan et al., (2022) defined a smart port which optimize the flows of commodity and information resulting in sustainable development, safety, and security based on the capabilities of port community and technologies. In general, smart port is an evolution of seaport development incorporating advanced technology to foster the sustainable growth.

4.2. Research clusters

In smart port in maritime research, the literature is divided into three underlying clusters which are the applications and implications of digital transformation technologies, smart port performance evaluation, and challenges and barriers of smart port development.

4.2.1. The applications and implications of digital transformation technologies

From reviewing the previous studies, major attention of the existing research has analyzed the adoption of advent digital technologies related with the industry 4.0 paradigm which is a vital motivating element for the development of smart port (Henriquez et al., 2022; Philipp et al., 2021; Zarzuelo, 2021). Most used studies employed content analysis with illustrated cases to demonstrate advantages in which technologies involved are varied.

Among new technologies, specifically, IoT technology which connect wired and wireless networks to surrounding objects (Ferretti & Schiavone, 2016) has introduced in numerous studies. Yang et al. (2018) proposed sensing systems, communication standards, and computer vision application for smart ports with smart sensing and IoT technologies. Bracke et al. (2021) proposed an IoT integration platform focusing on three capabilities which are interoperability, multi-tenancy, and scalability illustrated by the use case of air quality monitoring. Meanwhile, Kamolov and Park (2019) presented an IoT-based system with sensors to support ship berthing at the port. Yau et al. (2020) discussed the benefits of information and communications technology in reducing energy consumption, emissions, delay, cost and increasing the accuracy in prediction. Botti et al. (2017) highlighted the crucial role of cloud computing in connecting all the involved stakeholders to improve efficiency of resources resulting in reducing the costs. Nguyen et al. (2022) affirmed AI and IoT technology having a decisive contribution on optimizing port energy management. Sifakis et al. (2021) introduced a smart system to control the outdoor lighting which decrease annual energy consumption and environmental footprint. Ozturk et al. (2018) introduced an ap of IoT technology to enable a better energy consumption. Yao et al. (2018) introduced a wireless sensor network in smart ports as a solution for network security, fault diagnosis, and

intrusion detection. Li et al. (2022) introduced a framework using big data technology overcome the increase of data in ports. Ortiz et al. (2022) indicated the feasibility of the Web of things in controlling and alerting air quality controlling and in smart ports.

Besides, some studies focus on virtual reality technologies to improve port efficiency. Han et al. (2022) demonstrates the feasibility and reality of 5 G and virtual reality technologies in improving port operation safety and efficiency. Another study conducted by Wang et al. (2021), digital twin is proposed to visualize and enable better management of port operations. Barasti et al. (2022) developed an information and communications technology framework to provide an interconnected information network for the port communities.

Some studies promoted blockchain technology and machine learning to enhance smart ports performance. Duran et al. (2021) presented blockchain and crowdsourcing systems for transforming data and information to support decision making process. Serra et al. (2022) introduced block chain application for building an interport community in where all related stakeholders can benefit in a secure and effective way. Heilig and Voss (2017) explained how information systems contributing into the competitiveness of ports and the smart port development. Rolan et al. (2019) suggested the use of cold ironing to minimize emissions from ships. Chang et al. (2022) exploited deep-learning for recognition ability to enable higher accuracy with lower costs for ship detection.

It is notable that some studies attempt to render a clearly quantitative evaluation of smart port performance using mathematical models. Jun et al. (2018) employed Delphi and input-output methodology to clarify the positive impact of smart port on the Korean economy. An and Park (2021) used the case Busan port in Korea to analyze the economic feasibility of automated container terminal investment. Molavi et al. (2020b) applied using Lexicographic Goal Programming to examine the advantages of microgrid integration enabling operations, environment, energy, safety and security. Meanwhile, Heilig et al., (2017) introduced a framework using game theory to examine the impact of digital transformation in seaport with new opportunities and issues. Jiang et al. (2022) used the partial least squares structural equation modelling to explore how digitization improving information integration among port communities. Sadri et al. (2022) applied a data envelopment analysis for measuring benefits from green and intelligence components in using smart technologies. Similarly, Castellano et al. (2019) employed a fuzzy DEA approach to examine the influence of some digital technologies for communication in ports. Yang and Yang (2021) demonstrates effectiveness and superiority of the combination of artificial intelligence and big data to port supply chain. de Moura (2022) verified the impact of the use industry 4.0 technologies in Los Angeles, Hamburg, Rotterdam, Singapore on environmental management.

4.2.2. Smart port performance evaluation

Another stream is to underline framework for the sustainable growth of the smart port based on performance milestone. Accordingly, Othman et al. (2022) introduced a framework of five smart port index including operation, environment, energy, safety and security, and human factor linking with sustainable performance by a systematic literature review methodology. Xiao et al. (2022) introduced a framework of smart ports including production operation, production management, intelligent services, risk management and control, and intelligent scheduling. Meanwhile Molina et al. (2021) proposed the Blue Ocean Strategy to achieve the three aspects: economic, social, and environmental using the case study of the Spanish ports. Gonzalez et al. (2020) applied Delphi method to introduce criteria to evaluate and rank the Spanish Port System adapting to the smart port concept in the four facets which are operational economics, social, political and institutional, and

environmental. Molavi et al. (2020a) provided an empirical assessment of 14 ports basing on four main activities domains of a smart port, namely, operations, environment, energy, and safety and security. In the line, Zhao et al. (2020) investigated the case of Huanghua Port, China to measure sustainable practices by smart technologies based on triple bottom line. In the line, Lin et al. (2022) applied fuzzy analytic hierarchy process to compare the performance of smart ports in Taiwan and Spain regarding to operational economics, environmental protection, energy sustainability, maritime safety, community service aspects using fuzzy analytic hierarchy process. Notably, Lin et al. (2022) conducted a content analysis to develop an architecture of a smart port and propose key performance indicators of the progress of smart port transformation. Triska et al., (2022) proposed maturity indexes including infrastructure and superstructure, cargo handling, intermodal traffic, customs and collections, safety and security, and energy and the environment for general assessment of smart port terminal maturity. Similarity, Boullauazan et al. (2022) developed a smart port maturity model covering five domains namely port operations, synchro-modality, safety and security, energy and environment and capability.

4.2.3. Challenges and barriers studies of smart port development

Another research topic has been discussed within the smart port studies which are the challenges and barriers in the evolution of smart ports. Jia and Cui (2021) examined interrelationships of barriers in the development to smart port using the case of China, thereby fifteen barriers are identified by applying a hybrid of grey theory and the decision-making trial and evaluation laboratory and the support from the government in R&D are the significant challenge. Along this line, Yang et al. (2020) used the combination of fuzzy set theory, DEMATEL, and ISM to examine factors effecting the development of sustainable smart ports. The study indicated that policy support, integration, knowledge and skills are the most crucial elements to contribute into the sustainable smart ports. Meanwhile, Chen et al. (2019a) used interpretive structural modeling analysis to analyze the inherent relationships of factors impacting on the evolution to green and smart ports. Accordingly, the study suggested that building green and smart ports should accelerate the cooperation between stakeholders in ports and the application of advanced technology. Gonzalez-Cancelas et al. (2020) proposed SWOT analysis to measure the level of digitalization of Spanish ports. The study affirmed that technologies alone is not enough to reach smart port, which need to be integrated by all members in the port community. Specially, Zarzuelo (2021) concluded that the cybersecurity issue in the port industry as a result of the digital transformation. Similarity, Ben Farah et al. (2022) affirmed the role of IoT and big data in decreasing in the number of cybercrimes.

5. Conclusion

Incorporating with the advent of new technologies of Industry 4.0, smart port development is recognized as a strategic direction of a number of ports towards sustainable growth resulting in a growing concern over smart in both academic and practical. Thus, the need for a holistic approach to have insights into the smart port is crucial. Accordingly, the study conducted a comprehensive review of smart port studies using bibliometric analysis and systematic literature review. A bibliography data of 53 studies from Web of Science, written by 197 authors introduced in 40 academic outlets. The findings indicate that there is growing interest in recent years from 2016 to present, although. It was observed from the bibliometric analysis that authors such as Heilig, Leonard. Yao, Haiqing; Yang, Yongsheng; Fu, Xiuwen; and Voss, Stefan has impactful articles in smart port studies. The most central scientific journals are Maritime Policy & Management, Sustainability, IEEE Access and Sensors. China

is the most active country with the highest number of publications in which Shanghai Maritime University is the distinct university. Moreover, there are three underlying research themes in smart port studies. The themes are (1) the applications and implications of digital transformation technologies in various aspects such as operations, environment, energy, safety and security with both qualitative and quantitative assessments (2) smart port performance evaluation using different indexes, and (3) addressing challenges and barriers of smart port development. The study provides a stepping stone from which to explore thematic areas and avenues for future research. Overall, the main theme of current studies focuses on analyzing the feasibility of new digital technologies in port operations as. However, in order to these technologies are more widely adopted, identifying challenges and barriers incorporating empirical cases on increasing transparency, collaboration, and trust deserves more attention due to the requirement for a dramatic transformation of smart port operations. In addition, though a smart port would gain a wide range of benefits and opportunities from new technologies, comprehensive evaluations of the overall performance would be emphasized to examine how the transformation would contribute and enhancing the smart port development.

The study outlines both academic and industrial implications. Regarding academic contributions, the study contributes to the better understanding of the concept of smart port which no agreement on a precise definition. Additionally, it provides an overview of the publication trend and distribution, impactful authors, and the most institutions and countries in studying smart port by using bibliometric analysis. It also figures out the high concerned topics and research themes in this domain which results in future research directions are uncovered. Regarding industrial contribution, the findings of this study would support seaport stakeholders in better understanding issues regarding the development of smart port to make critical decision about applying advanced technologies to improve port performance.

The research has several limitations. First, albeit studies extracted from the most prestigious database of Web of Science, other databases such as Scopus, Google scholar would be included to provide an adequate consideration for smart port studies. Second, the study has investigated articles in indexed journals, thus, grey literature, proceeding papers, and non-English publications would be underestimated. Third, the evaluation of this study is based on only 53 publications caused by scarcity of the literature covering smart port in maritime industry. Theses might limit the assessment for the bibliometric analysis due to the development of smart port remaining in the nascent stage. Indeed, it is recommended that the future research should be replicated this study to shed light on the evolution of research with the growing interest in smart port with multiple databases and publications.

Declaration of Competing Interest

The author whose name is listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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