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Review

Smart Ports in Industry 4.0: A Systematic Literature Review

Antonios Paraskevas [1,*], Michael Madas [1], Vasileios Zeimpekis [2] and Konstantinos Fouskas [1]

[1] Information Systems and e-Business Laboratory (ISeB), Department of Applied Informatics, School of Information Sciences, University of Macedonia, 54636 Thessaloniki, Greece; mmadas@uom.gr (M.M.); kfouskas@uom.edu.gr (K.F.)
[2] Design, Operations and Production Systems Laboratory (DeOPSyS), Department of Financial and Management Engineering, School of Engineering, University of the Aegean, 82132 Chios, Greece; vzeimp@fme.aegean.gr
* Correspondence: aparaskevas@uom.edu.gr

Abstract: *Background*: Information and communication technologies (ICT) have introduced "smart" concepts across industries, including ports. Smart ports, leveraging IoT, cybersecurity, and cloud computing, are trending in maritime operations. They optimize data for informed decision-making, cutting costs, enhancing efficiency, mitigating risks, and fostering growth. *Methods*: To consolidate knowledge in this area, we are conducting a systematic literature review and meta-analysis using the PRISMA framework. Our goal is to synthesize existing insights, minimize biases, increase reliability, and effectively communicate our findings. To address the research needs mentioned, the current study focuses on implementing a systematic literature review (SLR). *Results*: The goals of this review are: (i) to present and describe the main categories and themes within the research topic, and (ii) to identify research gaps that will aid future research. Key findings include the identification and classification of current literature trends in the smart port performance evaluation framework and the examination of fundamental themes discussed within this area of research. *Conclusions*: In our review, we emphasize the smart port concept, clarifying its common interpretations amid the industry 4.0 revolution. We discuss recent advancements in emerging technologies and identify key challenges driving researchers' exploration of the evolving smart port landscape.

Keywords: smart ports; port performance; industry 4.0; information and communication technologies; PRISMA framework; systematic literature review

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Citation: Paraskevas, A.; Madas, M.; Zeimpekis, V.; Fouskas, K. Smart Ports in Industry 4.0: A Systematic Literature Review. *Logistics* **2024**, *8*, 28. https://doi.org/10.3390/logistics8010028

Academic Editor: Robert Handfield

Received: 19 November 2023
Revised: 31 January 2024
Accepted: 27 February 2024
Published: 11 March 2024

1. Introduction

With 80% of the world's commodities being transported by water, ports are rightfully considered as the pillars of the global economy. They are part of a large supply chain network that allows commerce and information to be transmitted across locations and geographical areas that are far apart. In the present day, a wave of technological innovations and integration is prompting industries and companies to adapt in order to develop their strategic plans. Port operations are being transformed by the introduction of new technologies in the maritime, land, and air transport sectors. These technologies have the ability to eliminate human error, accelerate processes, and reduce emissions, but they are also part of a broader digital shift in industry and port operations improvement. In this context, it is appropriate to consider that ports are in a unique position to take advantage of the new technological developments and capitalize on them.

The global economy necessitates effective and efficient maritime transport. As a result, ports have been placed under increasing pressure to enhance their performance in the face of economic, ecological, energy, and functional constraints that impede their long-term sustainability [1]. It is clear that port stations transform into complex environments that encompass multiple layers of organization, institution, and function, where different actors interact at various levels. To address these issues, ports have adopted technology-based solutions and new approaches to port operational planning and management.

A smart port is a concept, first coined in 2011, that proposes to leverage new technologies to enhance the interactive and dynamic capabilities of traditional port services, thereby improving their performance and transparency [2]. Future-oriented ports will, in addition to automation, participate in the transition to the next era of "port 4.0" in parallel with the ongoing evolution of "Industry 4.0". All terminal operators, trucking firms, railways, shippers, supply chain businesses, and freight transport companies will be linked to optimize not only the port, but the entire ecosystem. The cornerstone of "smart ports" will be automation, which will be able to transform ports into highly reliable and flexible logistics hubs, offering immediate and predictable physical flows and using elements of transport networks to mitigate the multiple variables that appear in transport networks.

A smart port comprises the entire required infrastructure, an IT info-structure (or the information-structure) for the collection and management of data, and the most current technologies in the fields of telecommunications, electronics, and engineering [3,4]. A smart port's purpose is to improve overall efficiency, lower costs, boost capacity, improve safety, and reduce the environmental effect of port operations. Smart ports aim to remain competitive and assist global trade growth by integrating advanced technology and data-driven techniques. Although the concept has been embraced by many researchers, the term smart port and the underlying technology remain, until today, in a "grey zone" due to a lack of concise and thorough academic research [5].

Industry 4.0 has led to a surge in the use of digital technologies in supply chains, such as IoT, big data, cloud computing, and artificial intelligence (AI). The four main characteristics of Industry 4.0 are hyper-connectivity, intelligence, autonomy, and predictability [6]. Research on port evolution has indicated that ports are transitioning from first- to fifth-generation systems with advanced technology and a broader range of services [7]. It is anticipated that port development will move towards smart ports with greater involvement of high technology [8].

Seaports face many challenges across many important dimensions, including crucial factors such as operations, environment, energy, safety, security, and human resources. As the maritime industry moves forward to a new era of interconnected and intelligent ports, gaining a deeper understanding of smart port development and its performance will be essential for unlocking the full potential of these transformational nodes.

Performance measurement is crucial in all aspects of business management because it explains how well companies and organizations have met their goals and objectives, and provides suggestions on how they might improve. The performance of smart ports is a very important factor that has been examined by many researchers [9–11] in an effort to properly define measurement frameworks or metrics. Port authorities and stakeholders frequently utilize a combination of quantitative measurements, such as turnaround time, cargo throughput, and cost savings, as well as qualitative indicators, such as customer satisfaction and sustainability objectives, to evaluate the effectiveness of smart ports. Smart port performance is also an evolving concept, as technological advances continue to provide new methods to enhance and optimize port operations. However, determining the performance of a smart port is a topic of complicated agreement. Furthermore, it has recently been stated that the majority of research on port performance evaluation is biased and out of date [12,13]. Thus, harnessing smart ports' potential in the port and maritime industry (PMI) is becoming more relevant in addressing the continually expanding complexity in the port organization ecosystem offering ideal territory for the research and conceptualization of these advanced technologies within the framework of the long-term development of smart ports considering their performance.

This systematic literature study attempts to fill the knowledge gap by thoroughly reviewing the available research on smart ports in the context of Industry 4.0 due to the lack of comprehensive scholarly work. Our goals include identifying major technical developments, evaluating the influence of smart ports on their ecosystem, and understanding the problems and possibilities related to their implementation. By doing so, we aim to provide a more nuanced view of the existing state of knowledge and contribute to the ongoing discussion about the future of maritime operations.

Furthermore, despite the growing interest of business and academia in the terminology of the smart port and the increasing number of experimental use-cases, few researchers have attempted to construct the conceptual framework of the smart port and the parameters that influence its performance to improve the economic, social, and environmental aspects of such ports.

As a prelude to our detailed analysis, it is imperative to briefly highlight key findings that underscore the relevance of our study. Our systematic literature review has shown that there are four key research themes, including analysis of port performance assessment, digitization, and its implementation in smart ports. As a result, this study gives insights into the major trends and future research directions in smart port.

The current study attempts to shed light on the subject by conducting a systematic literature review (SLR) with the purpose of identifying and classifying the prominent categories in the context of smart ports and their performance. Section 2 discusses the SLR approach used to guarantee the legitimacy and validity of the literature review's conclusions. Section 3 offers a descriptive analysis of the SLR findings as well as a qualitative theme analysis based on current research trend classification. Finally, Section 4 formulates a research agenda for the future, while Section 5 discusses the concluding remarks of our research.

2. Materials and Methods

2.1. Methodological Approach

According to Molavi [14], the topic of smart ports in the PMI sector is highly fragmented and to some extent "primitive" due to a lack of literary evidence on current research trends and viewpoints on the continuing smart port digital transformation via the employment of such sophisticated technologies. To the best of our knowledge, three review studies have been conducted, each focusing on a distinct topic, such as the state of the art in emerging technologies [15], the issue of energy efficiency in terms of identifying difficulties, strategies, infrastructure, and technology for smarter ports [16], and the most recent successes of 5G network slicing in a smart port based on a machine learning program [17]. In parallel, scholars have made significant contributions to port optimization studies in order to establish an operational framework for smart ports. This framework aims to enhance logistics supply efficiency, expand port service tasks, reduce environmental pollution at ports, and decrease equipment energy consumption e.g., [18–26].

However, the existing evaluation of smart port performance has limitations, as it lacks an objective and scientific evaluation approach making it difficult to identify problems in ports.

In an effort to address the aforementioned research needs, the current study focuses on the implementation of a systematic literature review (SLR) with the goals of: (i) presenting and describing the principal categories and themes within the research topic, and (ii) identifying research gaps in order to facilitate future research.

In order to identify and analyze related literature on the topic of evaluating smart port performance, an SLR process is used. The study was built on a compilation of diverse scientific publications available on various databases. In terms of methodology, this study follows the review technique established by [27]. This strategy enables researchers to get the necessary knowledge by comparing and evaluating many sources in an unbiased manner. The procedure includes five major steps: (1) forming research questions, (2) identifying studies, (3) choosing and assessing studies, (4) analysis and synthesis, and (5) reporting (Figure 1). Each stage helps to reduce errors and prejudice in assessing the review.

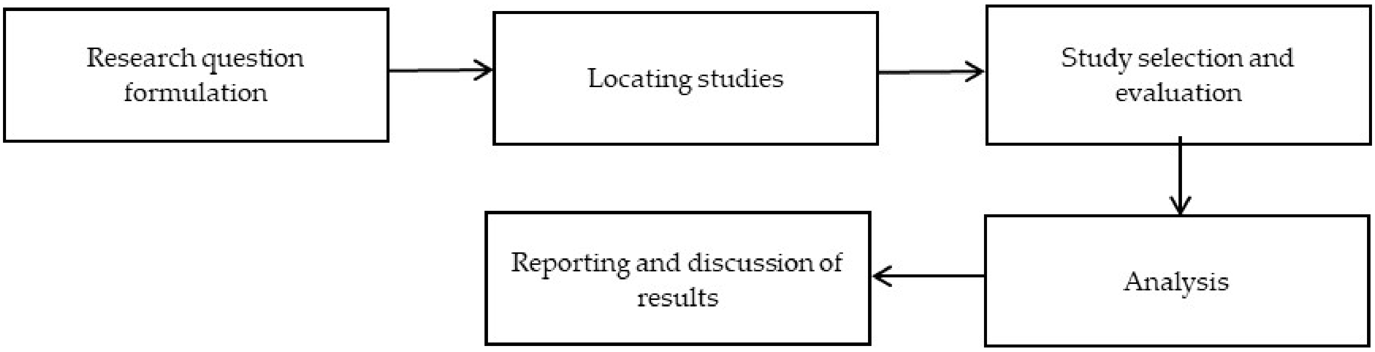

Figure 1. Research steps.

In this respect, the following research questions are to be addressed throughout our review article:

RQ1: How is the trend in smart port framework from 2015 and onwards?

RQ2: What are the current researched fundamental themes in this field?

RQ3: What are the current literature trends in the smart port evaluation framework and what is the manner in which can they be classified?

RQ4: What research implications could be proposed in order to further develop the smart port field?

Table 1 summarizes the total number of results obtained from literature search engine results using PRISMA, which will be discussed at a later stage of this study.

Table 1. Research of literature review.

Stage	Sub-Stage	Description	Number of Records
Step 1	Question formulation	RQ1: How is the trend in smart port framework from 2015 and onwards? RQ2: What are the current researched fundamental themes in this field? RQ3: What are the current literature trends in the smart port performance evaluation framework and what is the mode in which can they be classified? RQ4: What research implications could be proposed in order to further develop the smart port field?	362
Step 2	Locating studies	The following inclusion/exclusion criteria will be used to filter the database in the next phase of this research: Libraries: Scopus/Elsevier, Web of science, IEEExplore, Science Direct, Google scholar. Chronologically: Articles published after 2015 were excluded to guarantee the inclusion of current research and to limit the findings. Language barrier: all articles sought must be written only in the English language. Access: articles accessible from the electronic services of the Library of University of Macedonia, Greece. Subject area: Some subject areas have to be eliminated from some libraries owing to a lack of relevance to the issue. Some libraries allow you to search exclusively in the topic area(s) of interest to narrow down the results to more relevant sources. Removal of duplicates.	305
Step 3	Study selection and evaluation	A comprehensive screening of the abstracts of the citations chosen in the second phase, followed by selection of the ones most relevant to the current study subject (snowball technique incorporated).	82
Steps 4 and 5	Analysis and Discussion	A descriptive and thematic overview of the information obtained from articles on research questions that are identified in the evaluation process.	39

In the following sections, each source/library will be examined in terms of the search technique and keywords used:

1. Scopus/Elsevier.

Scopus is one of the most important research databases. To guarantee that the subject is covered completely, Boolean operators were applied. The following search strings were used to begin the retrieval (Table 2):

Table 2. Search strings and keywords.

Title	smart port OR smart ports OR smart terminal OR smart terminals
Title-Abstract-Keywords	effectiveness OR efficiency OR operations OR performance
Title-Abstract-Keywords	assessment OR evaluation OR measurement OR kpi OR "key performance indicator*" OR "kpi*"

It should be noted that the wildcard character "*" serves as a placeholder which can be interpreted as a number of literal characters or an empty string. In our case, kpi* matches kpi, kpis, kpi's, kpindicators etc. in the search string used to produce results in the research database. Each row is linked to an AND operator, implying that all requirements must be met. Articles are picked at this stage after the publishing year of 2015. Articles irrelevant to the topic areas have been prudently removed. The articles that were found were written in English language. The above-mentioned search yielded 57 documents in total.

2. Web of Science: Advanced search for journals and other academic records with a wider scope than Scopus. The following sophisticated search and Boolean operators were leveraged by the authors:

- First set: ti = (smart terminal* OR smart port*)
- Second set: ts = (effectiveness OR efficiency OR performance OR assessment OR evaluation OR measurement OR "kpi*" OR "key performance indicator*")
- Combine sets 1 and 2 with an and operator→#2AND#1

"Ts" denotes the topic database while "ti" denotes the titles. The year of publication is also included in this engine as the years 2015–2023 (until 31st of July), while there was a proper refinement in the subject area excluding irrelevant research areas, e.g., chemistry, telecommunications, instruments, etc. The numbers of results end up being **27**. The total database query is as follows: *((TI = "smart port*" OR "smart terminal*")) AND TS = (assessment OR evaluation OR measurement OR "kpi*" OR "keyperformanceindicator*")*.

3. IEEE explore: Advanced search for journals and various academic records with an emphasis on research articles in engineering. The database query used is as follows:

("All Metadata": "smart port") OR ("Full Text & Metadata": "smart port performance").

Also, certain filters were applied, e.g., publication date range from 2015–2024 and selected publication types such as "sea ports", "ships", "logistics", "transportation", "optimization", "decision making", "sustainable development", "analytic hierarchy process", "data analysis", "environmental management", "freight handling", "innovation management", and "marine power systems", included in conferences and journals.

The previously described search yielded 33 documents.

4. Science Direct: Used in the same logic as in previous academic database searches for gaining access to journals and sources that were not otherwise accessible. The results of the specific search were **52** documents.

5. Google Scholar: A secondary search engine for the research process, where findings are validated and duplicates are deleted. Used mainly for manual searching. Advanced search was used with the keywords used in the title of the article in the engine containing the following keywords: "smart port" OR "intelligent port" OR "automated port", giving us a result of n = (193). The results were filtered with publications in the range of 2015–2023 while the search excluded languages other than English.

The total query used for the aforesaid search is given below:

("intelligent port" OR "automated port* OR "smart port*" OR "smart port" literature review OR performance OR assessment OR evaluation OR KPIs OR key performance indicators OR SLR OR systematic literature review).*

We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework as a tool of our methodology in order to capture the search results in the aforementioned databases as described above, already within the framework of "smart port performance evaluation" and filtered by English language (see Figure 2). PRISMA focuses on how authors may ensure transparent and comprehensive reporting while conducting a systematic literature review. Researchers must develop research objectives that address the research issue, identify keywords, and establish a set of exclusion and inclusion criteria. During the review step, relevant articles are found and irrelevant ones are eliminated. In the last stage of screening, we determined how many of these studies can be included in a quantitative synthesis, also called a meta-analysis. Meta-analyses may not include all studies that qualify for a systematic review. Meta-analyses are statistical analyses that aggregate data from several studies to investigate a hypothesis. Not all studies will include the data required for a quantitative synthesis.

2.2. Reporting

2.2.1. Search Strategy

We implemented a comprehensive search strategy for this systematic review in order to determine relevant literature studies on smart ports. This search method was designed and implemented utilizing the four major databases (i.e., Scopus, Web of Science, IEEE explore, and Science Direct) and one search engine (Google Scholar). We note that the basic search terms used were the following: "smart port*" OR "smart terminal*".

All searches ranged from years 2015 to 2023 and covered journal articles, review papers, and research reports, all written in English.

2.2.2. Selection Criteria

The selection criteria were based on the PRISMA Statement [28]. The search was principally focused on mapping existing literature on smart ports, with an emphasis on computer science, decision sciences, environmental science, engineering, and social sciences. The search span was from year 2015 to 2023 so as to include state-of-the-art research work. A total of 362 research studies were extracted at this stage of the methodology.

2.2.3. Quality Assessment

This research is only based on original research publications, review papers, and reports, as well as a few conference papers. All duplicates were extensively examined to ensure the quality of the systematic review. Abstracts of articles were verified for analysis and purification to ensure the quality and relevance of the academic material included in the review process. At a subsequent point, each research article was carefully evaluated. Finally, we chose 305 articles after evaluating them against the aforementioned inclusion and exclusion criteria.

2.2.4. Data Extraction

In the data extraction phase, 163 articles were selected after the following general characteristics:

1. Articles should be original papers, review papers and conference papers. Literature reviews, case studies, conference proceedings, newspaper articles, software articles, technical reports, dissertations, brochures, and PowerPoint presentations were excluded from our methodology.
2. The paper must be written in the English language and categorized under the following subject areas: computer science, decision sciences, environmental science, engineering, and social sciences.
3. Extracted articles were published between the years 2015 and 2023.

4. The extracted articles were from a wide range of countries worldwide not focusing on particular country or countries.
5. In the last phase, only 39 articles were finally chosen for meta-analysis review.

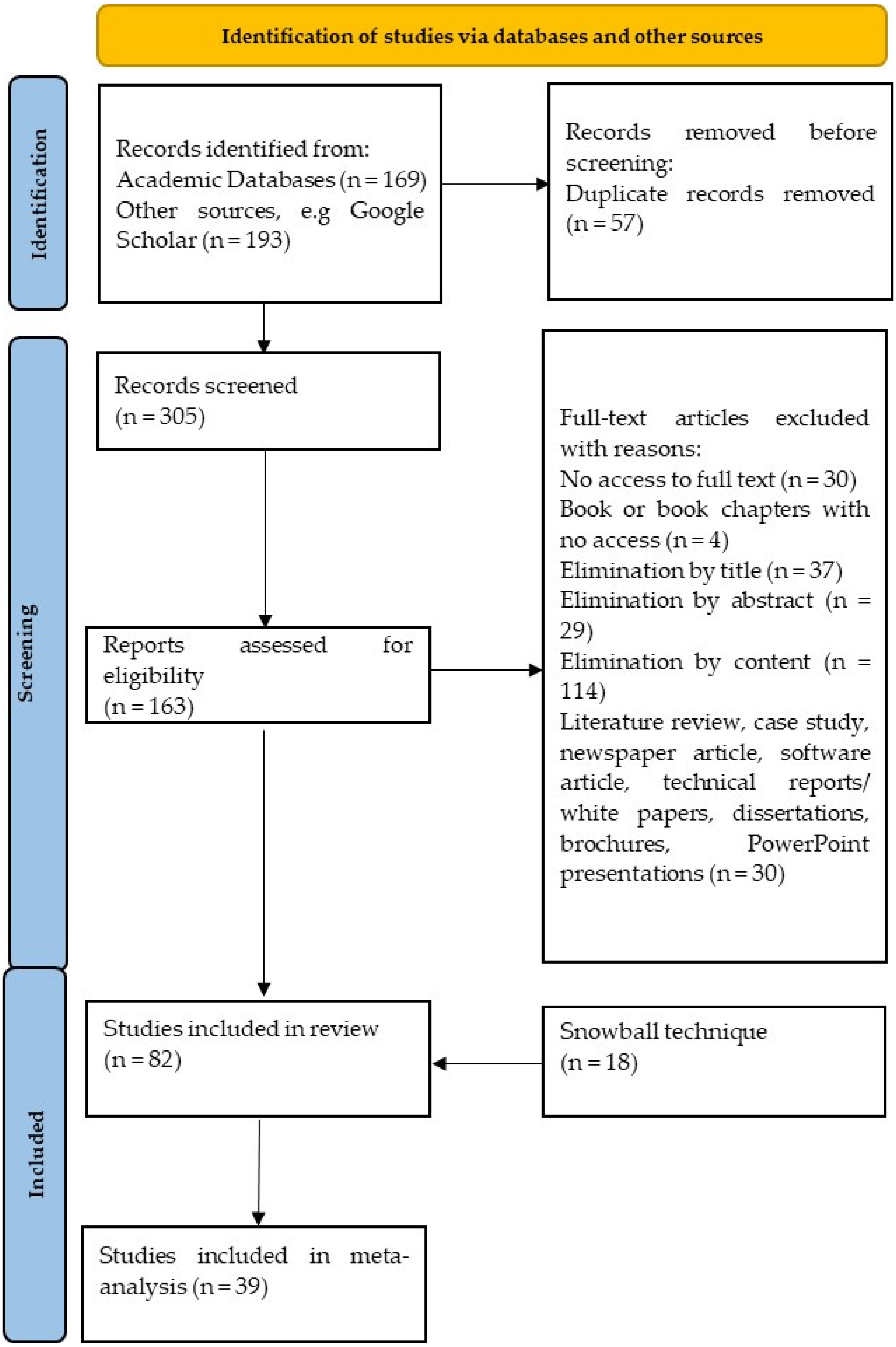

Figure 2. PRISMA framework.

3. Findings of Systematic Literature Review

As already mentioned, 39 articles were chosen as the core of the research topic linked to the smart port idea and its aspects (operation, environment, energy, safety and security, and human resources) in order to accomplish and improve port performance.

The comparison and summarization of all data generated by the retained articles for the purpose of compiling and mapping the current relevant literature is one of the most significant, if not the most important, actions of the SLR approach [29]. We used text analytics techniques, specifically Microsoft Research application programming interfaces (APIs), to generate a heat map of keywords and assess their frequency in the 39 articles selected for this study. VOS viewer software was employed to capture and analyze the appearance of these keywords. By utilizing the text data (RIS file) exported from Mendeley Preference Manager, which served as a reference utility tool in our systematic literature review (SLR), the authors created a map. The binary counting approach resulted in the red regions depicted in Figure 3, which represent the most frequently occurring keywords (we selected those with 5 or more occurrences during our analysis). Each point in the item density visualization is assigned a color that represents the density of items at that specific point. By default, colors range from blue to red. The color of a point is determined by the number of items in its vicinity and the weights of those neighboring items. A point will appear closer to red if it has a higher number of items and heavier weights in its neighborhood. Conversely, a point will appear closer to blue if it has a lower number of items and lighter weights in its vicinity.

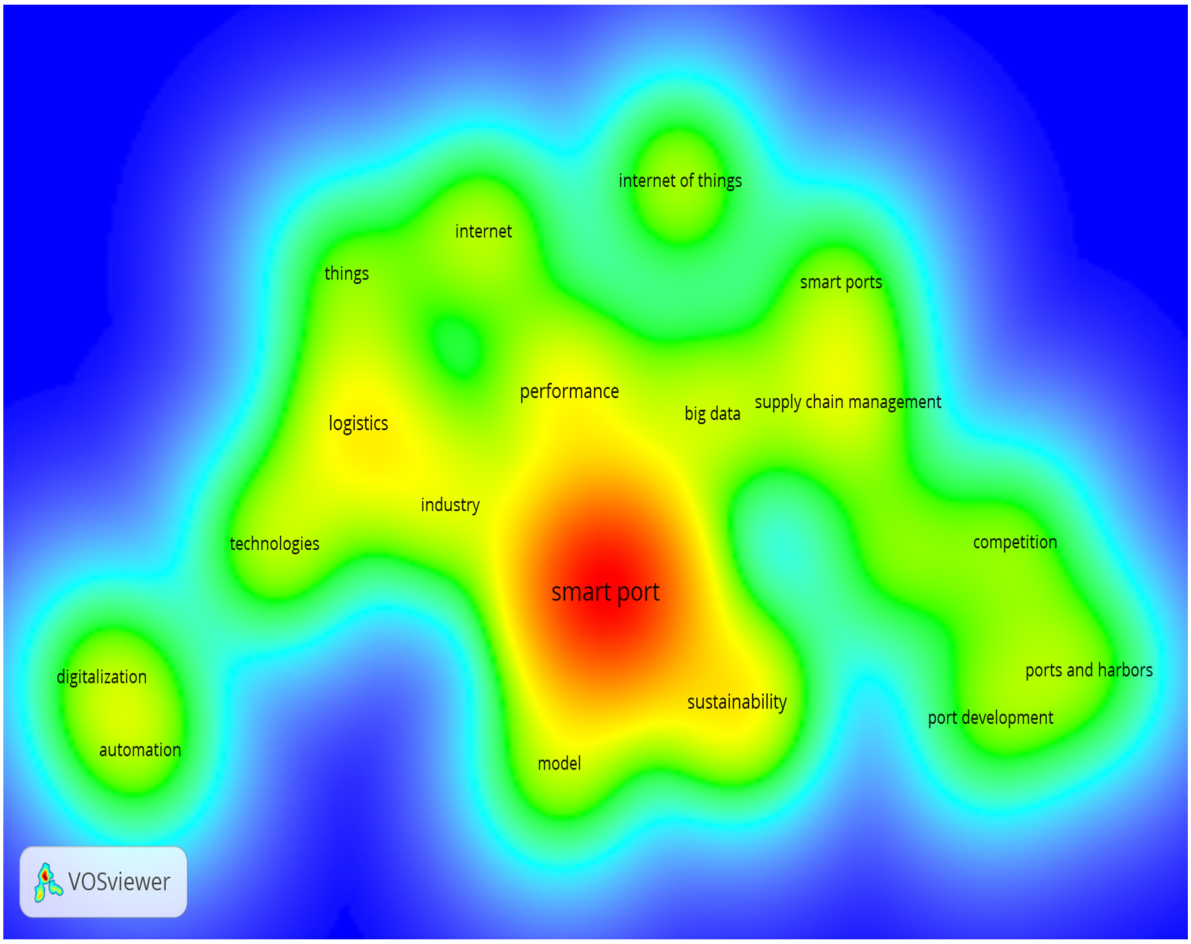

Figure 3. Heat map of keyword frequency.

These high-frequency keywords, indicated by larger circles in the network, shape the main research focus of our current study.

Based on the previously explained text analytics approach's findings, the identified keywords' numerical occurrences are shown in Table 3 below (for brevity reasons, only keywords with 5 occurrences or above are only shown).

Table 3. Keyword occurrence.

No	Keywords	Occurrences
1	smart port	24
2	sustainability	7
3	performance	6
4	logistics	6
5	internet	5
6	technologies	5
7	industry	5
8	internet of things	5
9	big data	5
10	supply chain management	5

As already stated, 39 publications were chosen as the core of the study field dealing with smart port performance. The generic descriptive and content analysis findings are provided and discussed in detail throughout this section. Each of the following subsections covers a distinct research subject by displaying various charts and tables.

3.1. RQ1: How Is the Trend in Smart Port Framework from 2015 and Onwards?

From 2015 to 2023, all the selected papers were published based on the criteria for inclusion in the Materials and Methods section, ensuring the best way to highlight research gaps in this specific scientific field and capture the growing popularity of the port digitalization phenomenon while highlighting the growing popularity of the digitalization phenomenon.

This review seeks to validate the primary sources by analyzing the core studies that were reviewed after applying the PRISMA framework. Figure 4 depicts the distribution of papers based on their publication year. The great majority of selected publications (about 75, 7%) were published between 2021 and 2023, demonstrating a dramatic rise in this specific study topic in recent years. Observing the broad interest in literature on smart port applications in the port and maritime industry, one can predict that the number of articles will continue to grow in the future.

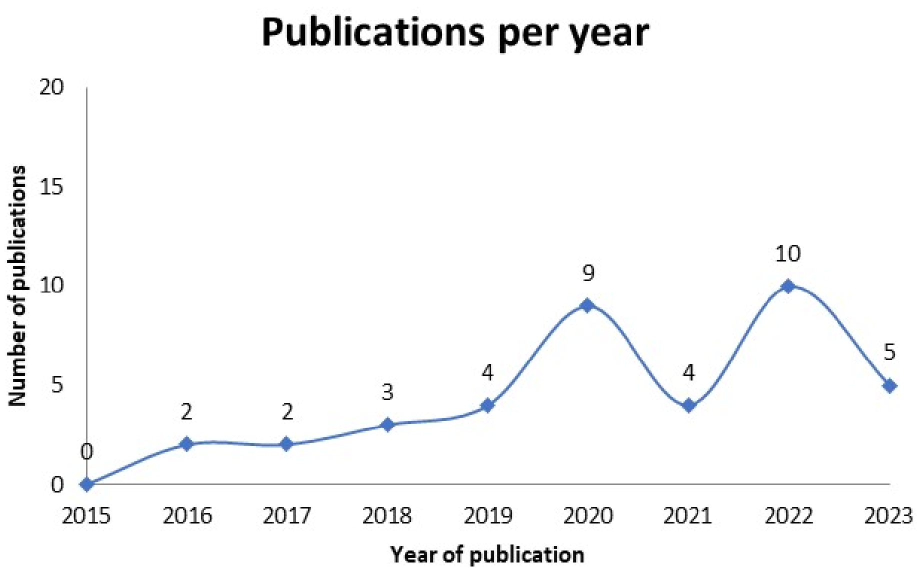

Figure 4. Distribution of the selected articles by year of publication.

3.2. RQ2: What Are the Current Researched Fundamental Themes in this Field?

A network citation analysis was created to show the connections between the nodes on smart port studies that are related with the smart port performance framework. This procedure finally resulted in the depiction of the major research themes in the existing literature aiming at the identification of relations among the authors of the selected articles (i.e., the number of times that an author appears as a co-author).

The depicted network (Figure 5) consists of six nodes that represent the total number of the authors and their possible interrelationship regarding their co-authorship amongst the selected references in our SLR. The minimum threshold value was set to three documents, meaning that in the following network, only those authors that are found as co-authors in at least four academic papers appear. In this perspective, it is shown that author "Yang, y" is amongst the most prolific co-authors in our analysis.

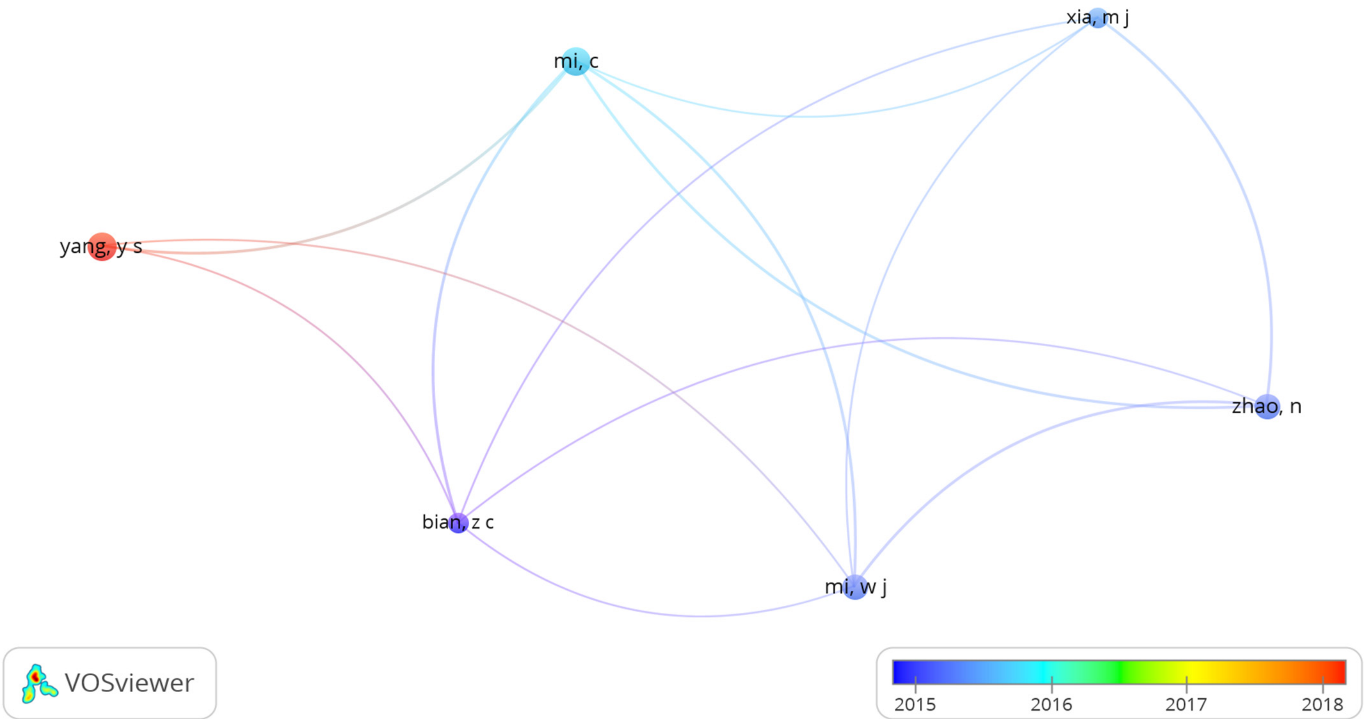

Figure 5. Citation network analysis.

The citation network analysis revealed thirteen linkages between the selected papers that supported the authors' claim regarding the extremely fragmented character of the study topic, characterizing this area as "primitive".

3.3. RQ3: What Are the Current Literature Trends in Smart Port Performance Evaluation Framework and What Is the Manner in Which Can They Be Classified?

One of the main goals of our review was to categorize existing study themes in order to represent the current status of research in the subject. The authors developed the classification by a full-text screening approach that includes processing information from each selected article regarding the frequency of keywords and their associated study targets. The ideas, implications, and outcomes provided by each paper identified four (4) study themes. The data were quantified, organized, and classified according to the study subjects. These themes included the smart port concept and conceptual framework, analysis of key performance indicators, the utilization of digital technologies to enhance port efficiency, and correlating factors that influence smart port performance.

An Important remark should be referenced in this part of our review article. Despite our best efforts to classify the research articles in the literature into the most appropriate categories, it is noteworthy that this was not always a straightforward issue due to the interdisciplinary nature of the field of smart ports. It is common to study the smart port concept from different perspectives, internal and external, such as economic, operational, environmental, technological, societal, political, etc. For example, there is a thin line that separates thematic categories 1 (smart port's KPIs) and 2 (smart port determinants) shown in Table 4, because both categories are valuable for managing and improving the operations of a smart port, and they are often considered together to form a comprehensive picture of a port's performance. But we consider that KPIs are the specific measurable metrics used to assess the performance of a smart port, while determinants are the broader, often qualitative factors that influence the performance of those KPIs. KPIs give actionable data for instant decision-making, whilst determinants aid in strategic planning and knowledge of the port's operating environment. Consequently, a research article could be classified into more than one field of study. Still, for reasons of research scope, we included each article in a distinct thematic category based on its main research objective.

The context of each category is described below:

Table 4. Thematic categories of studies.

Thematic Category	Context
Analysis/selection of key performance indicators (KPIs) for port performance assessment	The researchers recommend or create appropriate KPIs for current port demands. The framework for KPIs is being developed. The importance of KPIs varies depending on the stakeholders.
Identifying and measuring the effect of port performance determinants	The researchers identify or develop suitable key performance indicators (KPIs) for contemporary port demands. The KPI framework is being created. The significance of KPIs changes according to the stakeholders. Examining cause and effect factors and determining the most important factors. Environmental and energy efficiency studies affecting smart ports' performance are included in this category
Definition of the term of "smart port" and theoretical implications	The authors try to examine the theoretical concepts of smart port development, synthesizing core smart port concepts in order to motivate new research interest in this new academic area.
Suggestion of digital technologies included in "smart ports" to improve their services	The authors try to determine which technologies to choose and how to implement them to establishing effective systems and technical means for port development in the port industry.

The distribution of selected articles according to the above thematic categories is depicted in the chart below (Figure 6):

The distribution of articles across the various topics is almost very balanced, further reinforcing the notion of the fragmentation of this field. Nevertheless, the findings enabled the current study to conduct a thorough analysis of the emerging themes, which in turn enabled the categorization of current literature trends.

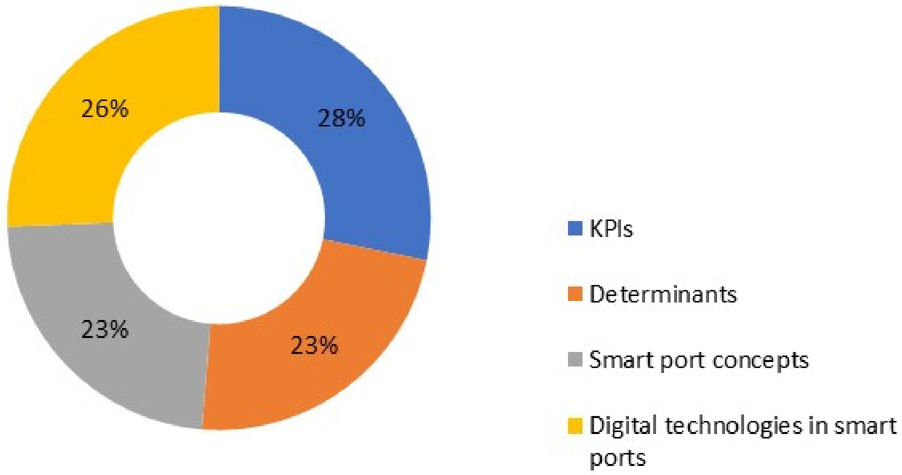

Figure 6. Sources by thematic category.

Classification of Current Literature Trends

Table 5 displays the distribution of each article throughout the specified categories, offering the created insights and the connected outcomes in brief, depicting the core studies that characterize each thematic category. Section 3.4 contains a more extensive explanation of the scope and content of the identified thematic/research areas.

Table 5. Categorization of current literature trends.

Category	Reference	Research Type	Research Objectives
KPI's	Hsu et al. (2023) [30]	Conceptual	This study uses the service quality scale (SERVQUAL) to examine the major indicators and service quality of smart ports in the post-pandemic period using MCDM methods (AHP and DEMATEL).
	Makkawan and Muangpan (2023) [31]	Empirical	Confirmation of the efficacy of smart port indicators and definition of the primary strategies for optimizing the performance of smart ports in Thailand, in order to reduce pollution and ensure port safety and promote innovation.
	Makkawan and Muangpan (2023) [32]	Conceptual	The goal of this study is to define the smart port indexes and develop a theoretical framework for smart port performance in the context of a case study on Thailand's Eastern Economic Corridor (EEC).
	Liu et al. (2022) [33]	Empirical	This paper defines an index system for evaluating smart port development level based on six indicators, utilizing the TOPSIS entropy weight method as a comprehensive assessment.
	Zhou et al. (2022) [34]	Conceptual	This paper categorizes container ports' business sectors as indicators, identifies the indicators that define a port's operational condition, identifies the primary operational risks of a port, and analyzes the predictive indicators for a port's operational advantages.

Table 5. *Cont.*

Category	Reference	Research Type	Research Objectives
Determinants	Molavi et al. (2020) [35]	Conceptual	This article's purpose is to provide a framework for the smart port concept as well as a quantitative indicator, the smart port index (SPI), that ports may use to improve their resilience and sustainability. The proposed SPI is based on an evaluation of key performance indicators from the literature.
	Zhao et al. (2020) [36]	Empirical	This study examines the effectiveness of the measures taken by the coalport in terms of its sustainability by analyzing modifications to key performance indicators and exploring the role of smart technologies in the integration and optimization process.
	González et al. (2020) [37]	Empirical	The purpose of this article is to present the indicator developed for the purpose of ranking and prioritizing the ports in the smart port category and its implementation in the Spanish port scheme, enabling the ranking of Spanish smart ports.
	Lakhmas and Sedqui (2020) [38]	Empirical	Developing a simulator model that includes all aspects of operations and the operational process by selecting relevant key performance indicators (KPIs) that are completely proportional with the quantity of traffic sent by port boats.
	González et al. (2019) [39]	Empirical	This paper provides an analysis of the Spanish port system to assess its ports, taking into account the new concept of "SmartPort". It defines certain indicators and measures variables to facilitate the quantification of technical items.
	Chen, J. et al. (2017) [40]	Empirical	This work presents an introduction of the "smart port" idea, proposes a set of smart port evaluation indicators, and incorporates a single-valued, neutrosophic, exponential similarity measure into port evaluation to simplify quantitative evaluations of port integrity.
	Yen et al. (2020) [41]	Empirical	Using a three-stage DEA-TOBIT modelling technique, this study investigates the influence of smart port design on the operational efficiency of marine transit. The model findings show that not all design elements have a beneficial effect.
	Azisah et al. (2023) [42]	Empirical	This study was conducted to evaluate the capability of the current port to meet the requirements of a smart port. This analysis was conducted through direct observation of the port's location, as well as interviews with port stakeholders in accordance with their respective fields and authorities.
	Othman et al. (2022) [43]	Conceptual	This study aims to investigate the potential of Egyptian ports to use smart practices and harness technology to improve port performance. It highlights the enormous potential of utilizing technology to achieve sustainable performance in Egyptian ports by highlighting the key hurdles and problems that may obstruct the adaption process.

Table 5. *Cont.*

Category	Reference	Research Type	Research Objectives
	Molavi et al. (2020) [44]	Empirical	This paper examines the utilization of microgrids in ports and provides a comprehensive framework for assessing the advantages of integrating microgrids into the system in order to generate sustainable value through strategic planning.
	Jun et al. (2018) [45]	Conceptual	This study analyzes the various concepts and regulations associated with the smart port sector and utilizes a modified hybrid approach that combines Delphi surveys with input-output analyses to construct an accurate estimation of the economic impact that the smart port sector has on the Korean national economy.
	Buiza-Camacho-Camacho et al. (2016) [46]	Empirical	This paper focuses on identifying the most significant elements that would necessitate a container port to align itself with the SP concept. To this end, it takes into account factors related to operations, energy, and the environment, and is based on the opinion of a sector expert. The technological level is the primary factor that influences the SP configuration, with the automation level following.
	El Imrani (2021) [47]	Empirical	One of the primary objectives of any port authority is to optimize logistics costs in order to render port operations more efficient. This research contributes to this objective by examining the situation of carriers in Tangier Med, a port in Morocco, and identifying the key challenges they face.
	Othman et al. (2022) [48]	Conceptual	The goal of this research is to develop an integrated SPI that captures multiple smart port components and links them with port sustainability results. The study's findings show that various smart port efforts throughout the world have differing degrees of integration.
	Karli et al. (2021) [49]	Empirical	The purpose of this study was to determine the significance of Filyos Port's smart port dimensions. Fuzzy AHP is used to rank each dimension and its sub-dimensions based on their relative relevance. According to the study's findings, the most essential aspect is operation, followed by environmental, energy, finance, and safety and security.
	Paulauskas et al. [50]	Empirical	The objective of this article is to create a methodology to assess the level of port digitization. Data was collected through the use of a marketing research tool. Additionally, a mathematical model to facilitate simulations has been proposed, as well as a case study covering 30 ports in the Baltic Sea, North Sea, and Mediterranean Sea.
Concepts	Nquyen et al. (2022) [51]	Conceptual	The aim of the review is to analyze and discuss the various approaches and applications that have been identified in the field of smart port energy systems, as well as to demonstrate that the various perspectives of smart port founding have a major influence on the development of a port energy system.

Table 5. *Cont.*

Category	Reference	Research Type	Research Objectives
	Jahn and Nellen (2022) [52]	Conceptual	It presents scientific and practical approaches on how ports are attempting to incorporate the trend of digitization into their daily operations. The goal of the study is to suggest how to make constitute processes more accessible, reliable, and ethically sound. This allows for better management of complexity in terms of structural, data, product, and network and e-commerce complexity.
	Mi and Liu (2022) [53]	Conceptual	This study explores the main categories that affect the ecology of smart ports and suggests how these factors could contribute to the process of port logistics operations as drivers of innovation and development.
	Alamoush et al. (2020) [54]	Conceptual	This research investigates and categorizes the technological and operational initiatives implemented by ports to minimize greenhouse gas emissions and improve energy efficiency. The data show that there is a scarcity of study on ports in poor countries, while the majority of research focuses on ports in developed countries.
	Frazzon et al. (2019) [55]	Conceptual	The objective of this paper is to suggest a concept of Smart Port–Hinterland Integration, which would enable visibility of vehicle flow and synchronization. The concept was evaluated in the light of real-time data collected from five major Brazilian ports, which was intended to alleviate infrastructure issues.
	Sari and Pamadi (2019) [56]	Conceptual	This study employs a descriptive technique to assess the existing status of the Batu Ampar port and the feasibility of implementing the smart port concept. The study's findings show that the smart port idea is suitable in the current circumstances.
	Shuo et al. (2016) [57]	Conceptual	This article explores the necessity of constructing a "smart port" in Huizhou Port and provides an overview of the overall framework design. Constructing the "smart port" is claimed to be essential in order to progress with the current times and implement the strategy of developing "new-type" ports.
	Tan et al. (2018) [58]	Conceptual	The suggested framework provides a process-oriented approach to energy management across a variety of company functions. It considers four key assessment criteria: transparency, technology, best practices, and policies. The framework's goal is to offer sustainability and policy decision-makers a framework to guide the development of energy-efficient smart ports.

Table 5. *Cont.*

Category	Reference	Research Type	Research Objectives
ICT	Durán et al. (2019) [59]	Conceptual	In order to identify the essential elements that demonstrate the current shortcomings of those working within Industry 4.0, a systemic conceptual model for a smart medium-size port is proposed, containing cyber-social-technological cognitions (CSTCs), where there are associated concepts, perceptions, data, and knowledge that would benefit from a highly automated port for the efficient management and optimization of logistics processes.
	Al-Fatlawi and Motlak (2023) [60]	Empirical	This research aims to identify the most important tasks performed by smart ports, such as the smart ship industry, smart cranes and container cranes, transportation automation, smart containers, and energy efficiency. It presents the idea of smart ports and discusses key current technologies that support ports.
	de Moura (2022) [61]	Empirical	This study examines the implementation of technologies from the Industry 4.0 platform in container-handling operations of five ports in order to evaluate their environmental management impact. The purpose of the study is to conduct an analysis of certain container terminal operations in order to evaluate the applicability and potential impact of the technologies on sustainable environmental management.
	Zhuang et al. (2022) [62]	Empirical	This study focuses on the integrated scheduling of intelligent handling equipment at automated container terminals in the context of resource allocation and scheduling at container terminals.
	Hirata eta al. (2022) [63]	Empirical	This study proposes a description of the concept of shipping digitization and port automation, as well as a review of the associated technologies and business strategies, including international initiatives, for the automation of global ports.
	Yao et al. (2021) [64]	Conceptual	The contents of this paper provide an overview of research currently underway on the design and construction of automated terminals and the planning of intelligent port systems, as well as the future course of construction of automated terminals, including equipment upgrades, the standardization of technical processes, and improvements in system integration.
	Shah (2021) [65]	Conceptual	The contents of this paper provide an overview of current research on the design and construction of automated terminals, the planning of intelligent port systems, and the future course of automated terminal construction, including equipment upgrades, standardization of technical processes, and improvements in system integration.

Table 5. *Cont.*

Category	Reference	Research Type	Research Objectives
	Karas (2020) [66]	Conceptual	This article seeks to demonstrate that intelligent ports are a necessary next step in the evolution of port operations, and that the concept of intelligent ports is a binding trend that will shape the future of modern maritime ports. It covers the most up-to-date digital technologies being implemented in ports such as Hamburg and Rotterdam, and analyzes decision-making strategies to drive digital transformation in maritime ports.
	Inkinen et al. (2020) [67]	Empirical	This paper examines the potential of digitalization for the future of international trade and transport operations in Finnish ports. It identifies the primary drivers and technologies relevant to port digitalization. Additionally, three alternative scenarios are discussed, including digital supremacy, business as usual, and digital failure, which are categorized according to SWOT and PESTEL frameworks.
	Acciaro et al. (2018) [68]	Empirical	The objective of this paper is to bridge this gap by conducting a field analysis that aggregates case studies from various world regions and evaluates the adoption pathway of innovation using a combination of three different methods (H- and I- indexes; system innovation analysis, and qualitative comparison analysis). The research results demonstrate that success of an innovation can be affected by a variety of factors, including the ranking of objectives, coordination between actors and institutions, and the level of innovation adoption.
	Belfkih et al. (2017) [69]	Empirical	This paper provides an overview of the concept of smart ports and proposes some Internet of Things (IoT)-based solutions that can be implemented in Le Havre port to enhance logistics and transportation services.

3.4. RQ4: What Research Implications Could Be Proposed in Order to Further Develop the Smart Port Field?

The authors refer the reader to Section 4 where detailed analysis and further implications concerning the future research agenda about the concept of smart ports is given.

3.5. Thematic Analysis

In this section, the author discusses the content of the selected articles within the respective conceptual framework as indicated in Table 4. The process of categorization was consequently followed by the gathering of homogenous information in order to develop the subclasses within every category.

3.5.1. Definition of Term "Smart Port" and Suggestion of Proper Framework of an Intelligent Port

The first subcategory that was observed and thus included in the systematic literature review (SLR) analysis is that of "smart ports". This subcategory provides a theoretical framework for the development of smart ports, consolidates the fundamental concepts of smart ports, and proposes a suitable framework to address the key issues associated with smart ports. The concept of a smart port is developed within the context of modernizing and optimizing port operations, primarily to address the increasing demands and challenges of global trade and logistics. The primary objective of the researchers in this classification of studies concerning automated ports is to identify and implement strategies to move away from conventional port supply chains and towards smart ports, thus enabling informed decisions and the optimization of logistics and transportation operations [55,57].

Smart ports are a prime example of a highly complex system. The term "smart" is used to refer to a port platform that is optimized for user behavior and action. Complexity of a port system is still a concept that is thought to be vague and subjective, and due to the size and number of technologies employed, it is considered a system that presents considerable difficulties in its design, maintenance, and development.

This framework consolidates the fundamental principles of smart ports by evaluating their advantages and disadvantages, outlining fundamental architecture, and proposing concrete milestones for the implementation of a smart port as part of a global supply chain approach.

According to the literature review, smart port definitions emphasized its goals and strengths. Productivity, sustainability, reliability [33], operations, environment, energy, safety, security [43], and so on are all components of the smart port idea. A smart port, according to scholars in [53], is one that optimizes commodity and information flow, resulting in sustainable growth, safety, and security based on port community skills and technology.

The main functions of intelligent ports are the integration of the entire port supply chain and the automation of port operations and equipment. Thus, the interrelationship of the whole logistics chain and the automation of port operations and equipment prove the overall competitiveness of the port [70] while simultaneously increasing the integration of the port chain, thereby saving time and money in document and human resource management. Some authors argue that efficient, safe, and sustainable ports provide value [2,37] and give priority to customer satisfaction [2,59]. Using modern communications and information technologies (ICTs), intelligent ports are a practical solution for efficient decision-making support [33].

These articles create a new body of knowledge by establishing basic conceptual frameworks and protocols that enable modern ports to advance their smart port transition incrementally. The findings of these articles indicate that smart ports can significantly reduce port-user waiting times, enhance port asset utilization, and improve maritime logistics visibility by automating and digitalizing port operations.

In conclusion, it is applicable to highlight the work of authors, such as in [58,59], who advocate for the construction of smart ports in the regions studied by emphasizing the importance and influence of each port on the regional economy. This fact is based on core themes such as intelligent control or digital supply chain and the use of "Internet + Port" information services that leverage advanced technologies.

3.5.2. Analysis/Selection of Key Performance Indicators (KPIs) for Port Performance Measurement

KPIs (Key Performance Indicators) fall into the category of partial productivity measures, which are a subgroup of variables that influence port performance. Selecting and analyzing KPIs for measuring port performance is a crucial task, as KPIs provide valuable insights into the efficiency and effectiveness of port operations. The choice of KPIs should align with the port's strategic goals and operational priorities. This is considered rather important, as the proper application of KPIs in port operations can offer a lot of benefits such as improved productivity, increased profitability, and customer satisfaction amongst others. By measuring and monitoring KPIs, the port operators can identify areas for improvement and to take corrective action to ensure performance targets are met.

Within this context, as a preliminary step, the authors attempt to find a complete set of KPIs for assessing port performance in each smart port activity category from the literature (see Table 5 for pertinent references).

In this manner, researchers in [35] used 68 KPIs from various sources to develop their smart port index (SPI), a quantitative metric that is a convex combination of four indices, namely the smart operations index (SOI), smart energy index (SEgI), smart environment index (SEnI), and smart safety and security index (SSSI). Each of the four indices (SOI, SEgI, SEnI, and SSSI) is computed as a function of the relevant KPI, and the SPI value is computed by solving the applicable linear programming equations using data from the port authorities' websites. We draw attention to the research conducted by scholars in [31,32,37], in which a variety of indicators are employed as inputs into various methods, such as Delphi, SWOT, and content analysis (a quantitative research tool primarily used in systematic literature review), to evaluate the performance of smart ports. These indicators are classified into three distinct groups: smart port operation, smart port energy/environment, and smart port safety. In this line of work, researchers in [39,40], study the literature concerning port indicators and classify them into clusters according to the smart port concept. The fundamental categories that are observed, and that are considered the most influential as far as smart performance is concerned, are economic, operational, social, and environmental key performance indicators. According to the authors, this provides a secure, efficient, convenient, environmentally friendly, and sustainable form of port development to enhance the overall effectiveness of ports. After identifying the main pillars, MCDM methods are utilized in port evaluation to enable quantitative assessment of port integrity.

3.5.3. Identifying and Quantifying the Impact of Determinants That Affect Port Performance

In the third category, the primary determinants/dimensions are those that influence port performance, such as the size, operations, infrastructure, security, digitization, and energy/environment of the port. The determinants that affect port performance have a significant impact on the efficiency, competitiveness, and overall effectiveness of a port. These drivers are often external factors that define the operating environment of a port. These are identified as major variables in the literature review (LR) and are used to identify the relationship between these primary determinants and the efficiency of the port. This field of study is characterized by the use of multi-criteria decision analysis methods, or MCDMs, as well as linear programming tools.

Within this scope, reference is cited to the articles [34,41,46,49,58], in which the authors employ a single MCDM method or a combination of methods, such as fuzzy MCDM methods, to assess the opinions of a stakeholder group on the relative significance of the key criteria that affects smart port performance, as well as to suggest policy implications for prioritizing the smart aspects that contribute to the creation of smart ports.

These approaches have been used to develop decision-making processes that can be used to improve ports in real-world applications. The results of these studies are highly relevant to ports that wish to achieve smart port status, as they provide essential information to create the strategic plan that will enable them to achieve this goal.

The authors in [43] aim to examine the extent to which Egyptian ports can utilize innovative practices and technologies to achieve and enhance sustainable port performance. In a similar vein, researchers in [47] have established a smart port maturity model that encompassed five areas: port operations, synchro-modality, safety and security, energy and environment, and capabilities.

It is common for ports to face decision-making difficulties when assessing their digitalization level and selecting policies for advancement. To address this issue, Paulauskas et al. [50] suggest developing a method to assess port digitalization levels using a marketing research tool to collect the data required for the analysis, which is applied to a sample of 30 ports in the Baltic, North, and Mediterranean Sea. The ports were divided into three categories: small, medium, and big. As a result, the degree of digitalization in small and medium-sized ports is projected to be roughly 30% lower than in big seaports.

Acknowledging the fact that smart port industry plays a particularly significant role in terms of productivity, added value, and employment compared to the port industry, scholars in [45] assess the economic effects of the intelligent port sector on the Korean national economy through the utilization of a hybrid approach that combines the results of a Delphi survey with input–output analysis.

3.5.4. Suggestion of Digital Technologies Included in "Smart Ports" to Improve Their Services

In this last category, technological progress is examined, wherein the authors attempt to determine which technologies to choose and how to implement them to develop efficient systems and technical assets for port development, as outlined in Table 5. Traditional ports are being transformed into smart, data-driven centers that are more efficient, ecologically friendly, and capable of meeting the expanding needs of global commerce. Port operators and authorities are always looking for new ways to increase their competitiveness and sustainability in the ever-changing maritime and logistics market. Technological progress offers the potential to achieve a level which will enable us to constitute contemporary ports as smart ports. Without such tools, the digital status of ports and the development of a specific strategic approach to port digital transformation cannot be achieved.

Technologies are present at both the instrumentation level and the information system level, where instrumentation is becoming more communicative (for example, sensors and RFID, Internet of Things, etc.), and information systems are becoming more complex (for example, big data, semantic processing for detection, machine learning, etc.). Innovations are progressing at a remarkable rate, particularly with the introduction of new technologies of digitalization and transformation of cyber physical systems. Nevertheless, any prediction of how these new technologies will revolutionize shipping, supply chains, and shipbuilding, on the other hand, remains an open problem to be answered.

In the past, port operations were largely based on the port's size (e.g., length of quay, number and efficiency of cranes). However, port and maritime sectors have been found to be lagging behind in terms of digitization, as demonstrated in [60,61,68]. In recent years, however, the ports sector has seen a surge in the adoption of Industry 4.0 technology. As Industry 4.0 has had similar effects on other industries, it is anticipated that ports will follow suit in the coming years.

For example, Ref. [69] proposes a range of Internet of Things (IoT) solutions that can be applied to improve logistics and transport services in Le Havre port. A significant investment in efficient technological solutions, such as sensors, smart devices, and cloud computing, is required to properly shift the port supply chain from a traditional port to a smart port. This presents a range of challenges, such as the heterogeneous nature of technologies, the wide variety of data types, and the need for greater transparency and security. Some examples of smart port solutions include intelligent ship management, intelligent traffic flows and intelligent port transportation. In a smart port logistics context, intelligent logistic solutions can be employed to improve container management and traffic flows, as well as the capacity of terminals and parking slots [65].

The researcher in [66] presents a selection of ports in the North and Baltic Sea that have implemented the concept of a smart port. These ports are equipped with the most advanced equipment, and the technology used is tailored to the business profile and type of goods handled. This allows for the management, analysis, and use of large amounts of data to ensure that efficient and high-quality services are provided. Other studies, such [63,67], have also explored the potential for the development of a physical internet in ports, as well as collaboration and environmental aspects.

In line with previous studies, a number of authors [71,72] have proposed the concept of a "fifth generation port", which is centered on the customer and community, and is expected to offer services at a higher level through the use of market forces, incentives, and government regulations. Key elements of a fifth generation port include customer satisfaction, service, and technology orientation. When considering the technological aspects of ports, the ports that have been in operation since the 2010s are referred to as "fifth generation ports".

It is worth noting, however, that academics have just lately begun to discuss sixth generation ports. For example, a scholar in [73] recommends identifying sixth generation ports capable of accommodating ships more than double the size of those already in use.

4. Future Research Agenda

The smart port model is heavily reliant on the utilization of intelligent and environmentally friendly technologies to enhance port efficiency, enhance performance, promote innovation, increase flexibility, protect the environment, and contribute to economic growth. The development of such a port constitutes a significant step forward in the implementation of energy efficiency and greenhouse gas reduction in the application of cutting-edge technologies in port and maritime shipping industries.

In this research, we collected and evaluated articles in the area of smart ports. The results of these studies demonstrate that a substantial amount of research has been conducted on this subject, and the volume of publications is on the rise. As discussed in Section 3, the growth of smart port studies is still in its infancy, with a rapid increase in publications. This suggests that the field of smart port research is gaining more attention and is a potential area of research that should be further explored in the future.

The research agenda of RQ4 (What research implications could be proposed in order to further develop the smart port field?) drew upon existing literature and identified promising areas of research that have not yet been extensively discussed. The findings of this study are essential for reinforcing the systematic nature of smart-port-related studies, as they classify various perspectives on important issues and provide guidance for future research directions and domains of interest.

Governance and financial models: This aspect is one of the main difficulties in implementing smart port technologies. In many situations, implementing these technologies necessitates substantial financial investment in infrastructure, equipment, software, staff, training, and so on. Port authorities nowadays are hybrid organizations that operate and evolve beyond the control of operations under their authority. Port management companies are increasingly working as community and port cluster managers, interacting with stakeholders, and engaging in activities such as information technology, port promotion and marketing, and training and education. Port governance (PG) models change in response to the socioeconomic framework and port performance [74]. That is, each country's PG evolution is distinct, resulting in distinct port development methods. This is due to the fact that in many cases, these technologies necessitate substantial financial investments in terms of infrastructure, machinery, software, staff, training, and so on [75]. Creating open and inclusive governance systems is critical to the success of smart ports. These institutions promote accountability and informed decision-making by bringing together key stakeholders, such as port authorities, shipping corporations, and regulatory organizations. By integrating financial specialists into the decision-making processes, governance can be aligned with long-term financial sustainability objectives.

Therefore, it is essential for decision-makers to thoroughly assess the feasibility of the measures and the potential for public and private sector involvement in order to ensure successful deployment. Overall, the current issue could be addressed by prioritizing efforts; leveraging and giving incentives, financing, or support for innovation; developing open innovation channels; or employing creative public procurement procedures.

Change management and innovation: The shift to smart ports necessitates a range of changes, including technological advancements, increased productivity and collaboration between businesses, as well as alterations to processes, financial strategies, and corporate culture [76,77]. In order to successfully implement these alterations, organizations must have the capacity to anticipate and manage personnel changes. The implementation of new technologies necessitates a shift in the strategy and approach of the ports in question. In this context, digital twins, which are virtual replicas of physical assets or systems, offer the potential to revolutionize decision-making processes, enhance efficiency, and optimize resource utilization within smart ports. To create a holistic and integrated system, researchers should investigate the integration of digital twins across diverse aspects of ports, ranging from infrastructure to logistics.

Incorporating change management strategies specifically tailored to the adoption of new technologies and processes facilitates a smoother transition. Establishing innovation labs or centers encourages collaboration, experimentation, and the development of cutting-edge solutions that contribute to the ongoing evolution of smart port operations. In a nutshell, port ecosystems that support innovation are being called upon to help organizations and workers improve their culture by bringing new principles and perspectives towards the port's digital transformation [78].

Social criticism: This is due to the fact that new technologies are often used to replace humans, and there is a perception that automation and robotization of operations will lead to job loss. Industry digitalization introduces significant psychological, social, organizational, and ergonomic risks, as well as security issues [79]. Organizations must encourage risk-aversion strategies and practices. Coaching methods, training, rules of behavior supporting remote working and the right to disconnect, psychological risk assessments, and smart safety systems are among them [80]. Addressing social criticism necessitates a proactive strategy focused on increased stakeholder participation and communication. Smart ports must develop communication strategies that guarantee stakeholders receive timely and accurate information about port operations, developments, and community benefits. By establishing constant channels of communication with local communities, problems can be heard and resolved swiftly.

Cyber-security issues: Concerns about possible vulnerabilities that might damage digital assets and data can arise as a result of the introduction of new technologies or a lack of knowledge of them. Threats appear either from malicious actions (hacking, malware infection) or as a consequence of omissions in system maintenance and the application of security rules. Furthermore, ports are prone to a variety of security challenges, which can result in losses in terms of income, the port's reputation, and the efficiency of its operations [80]. The key challenges in this sector include direct terrorist attacks, the exploitation of ports as a conduit for weapons commerce [81], natural dangers, and inherent risks in port activities that are security related. This situation can make individuals and organizations hesitant to adopt these new technologies due to the insecurity they create [82,83]. Because malicious actions will not stop and the means used will evolve in parallel with the evolution of technology, the correct preparation to prevent the occurrence of the risk as well as the gradation of access to the systems to limit the damage should be at the heart of the design of info structure. Regular cybersecurity audits and risk assessments can help uncover vulnerabilities and enable proactive remediation. Creating and executing cybersecurity policies and procedures that are tailored to the unique demands of smart port operations is essential for ensuring a safe digital environment. Additionally, providing employee cybersecurity training raises awareness, reduces the risk of cyber-attacks, and safeguards the integrity of vital port operations.

The lack of skilled workforce: Knowledge and innovation are not limited by technological developments, but they help to develop hard and soft skills. They can also be characterized as human skills; they are subjective abilities and can have an impact on the work environment. Industry 4.0 and the Internet of Things (IoT) have created a need for highly skilled personnel with novel professional profiles and abilities in fields such as data analytics, predictive maintenance, cyber-security, or blockchain applications [84,85]. For the shipping of the digital age, they will be needed workers specialized in new technologies, but also familiar with these even if their tasks are not directly related to the application of new technologies; this should be taken into account in the context of educational programs in the relevant schools and universities. Unfortunately, there are not enough training options to fulfil this demand, so professionals are forced to study on their own.

Environmental challenges: The use of smart ports often necessitates the use of cutting-edge technologies, including automated cranes and electric vehicles, as well as data centers that can have significant energy requirements. This can lead to an increase in greenhouse gas emissions when energy sources are not renewable or sustainable [78]. In addition, port activities can result in water pollution through a variety of sources, such as the discharge of oil, dangerous substances, and the discharge of ballast water from ships [86]. Sustainability considers social, economic, and environmental problems in order to achieve better economic and social outcomes while minimizing environmental repercussions [76]. Therefore, intelligent ports must implement effective pollution prevention strategies and comply with environmental regulations. To overcome these environmental concerns, smart ports should implement ecologically friendly and sustainable practices. This involves switching to greener energy sources, adopting pollution control systems, monitoring and regulating noise and light pollution, and ensuring environmental standards are followed [36]. In this manner, investing in eco-friendly technology, such as electric equipment and renewable energy sources helps to reduce the environmental impact. Furthermore, developing and implementing environmental management systems that align with international standards ensures regulatory compliance and promotes responsible operating practices. Lastly, collaborating with environmental organizations fosters ongoing support for sustainability projects, enabling smart ports to make a positive contribution to environmental conservation while maintaining efficient operations.

The effective deployment of smart ports in the maritime industry depends on several critical factors, including effective governance, innovation, cybersecurity, and sustainable strategies. Governance plays a crucial role in driving innovation and managing change by fostering adaptability and promoting the adoption of transformative technologies. To address social criticism surrounding the integration of advanced technologies, it is important to have an open government that engages in transparent decision-making and incorporates community-based approaches.

In the digital landscape of smart ports, cybersecurity becomes a vital aspect of governance. Robust measures are necessary to protect against evolving digital threats and ensure the integrity and security of sensitive data and critical infrastructure. Additionally, sustainable strategies are essential for mitigating the environmental impact of smart ports. This requires coordinated efforts across governance, innovation, and regulatory frameworks.

Developing smart ports that embrace technological advancements while also navigating social dynamics, cybersecurity challenges, and environmental considerations is a complex task. It highlights the need for comprehensive, multidisciplinary research and collaborative endeavors to create a holistic and resilient blueprint for the future of smart ports.

5. Conclusions

In the last few years, there has been substantial and dynamic growth in the number of research articles published in the field of smart port applications within the framework of evaluating their performance. Yet, the topic remains "primitive" and dispersed with inadequate research to connect theory with practice. As a consequence, our current review article attempts to suggest new perspectives in an in-depth overview of the current state of smart port performance. This is achieved by presenting and addressing the main categories of existing literature trends, which ultimately leads to the delineation of research gaps that are further elaborated upon.

The findings of this review contribute significantly to both academic scholarship and practical industry applications. Academically, our study brings together and synthesizes disparate information, providing a comprehensive framework for comprehending the various elements of smart ports. In practical terms, our findings can assist port authorities in implementing technologies that enhance operational efficiency, reduce environmental impact, and ensure the resilience of marine supply networks in an era of rapid technological innovation.

5.1. The Future of Smart Ports in the Port and Maritime Industry

The modern world is characterized by globalization and the rapid advancement of technology, which has had a significant impact on human life. Technology has enabled the development of a wide range of innovative applications, ranging from those available in the most prominent companies in the world, to those that support operations and decisions of all kinds. The major trend in company development today, along with all other areas of digital transformation, is the digitization of the corporate environment. The digital ecosystem (DE) paradigm is gaining popularity and is currently at the heart of the most successful modern organizations. The notion of DE is developing as a new way to see today's increasingly complex and linked systems [87].

Although ports have been slower to implement automation than other industries, the pace is now accelerating. The port industry is a key component of the international economy, and its functioning is dependent not only on the maintenance of essential daily operations, but also on its own survival, as it serves the majority of international trade.

It is interesting to mention the survey conducted by McKinsey and company in 2017, which received replies from more than 40 participants from important ports in China, Europe, the Middle East, Singapore, and the United States, regarding the future of automated ports. The survey reached the following key conclusions: The operating costs of a green automated terminal would need to be 25% lower than a conventional one, or productivity would need to increase by 30% while operating expenses would decrease by 10% [88].

Smart ports will offer seamless integration into complete supply chain solutions, improving transparency and cooperation between stakeholders. The future of smart ports promises to revolutionize global logistics and make the maritime industry more connected, resilient, and eco-conscious. Globalization, greater competitiveness, efficient use of energy sources, and reduction of environmental effect, notably in terms of pollutants and greenhouse gas emissions, are all difficulties for modern marine transport. In this context, ports are being urged to adapt by implementing the smart port model, the primary features of which are automation of operations and supply chain integration.

It is evident that there is a greater need for the development of ICTs to enhance the competitive advantage of all stakeholders using the port. It is difficult to understand supply chain strategy without recognizing port-based ICTs. Nowadays, the role of ports is very different from what it was a few decades ago. More emphasis is placed on the competitive advantage of e-logistics and digital supply chain that ports provide to their customers. The investment of ICTs in ports is an extremely necessary ensuring an important part and needs many difficult decisions. Value-added activities will allow the port to analyze its market, define logistics objectives and build a dynamic and highly competitive strategy.

5.2. Challenges to the Transition to the Smart Port Model

The future anticipates numerous obstacles, but it will also present many new opportunities for the maritime sector. The smart port paradigm necessitates a fundamental change in the way ports operate and manage their resources. Maintaining competitiveness in a globalized environment, ensuring the greatest use of energy sources, and minimizing environmental effect, particularly in terms of pollutants and greenhouse gas emissions, are current issues for the sustainable growth of marine transport. Technology may help alleviate environmental issues associated with shipping and enhance operational efficiency, while sustainable technology can help utilize the ocean while protecting the environment.

In this perspective, the American Association of Port Authorities (AAPA) has identified three significant challenges confronting contemporary ports [89]:

- Economic Impact—In order for modern ports to compete in today's global trade and economy, investment in modern, accessible ports with non-congested intermodal cargo accessibility is essential.
- Security—safe and trustworthy port services are critical for both border protection and global trade.

- Environment—seaports are attempting to find solutions to improve our coastal assets while reducing environmental effects.

Some of the key reasons of the fourth industrial revolution, which occurred in 2011, were the magnitude of global competition, frequent market instability, the need for personalized products, and the shortening of product life cycles [76]. This recent revolution is facilitated by the emergence of new technological solutions such as the Internet of Things (IoT) and big data, which not only create new possibilities for the port industry but also notably contribute to port industry development, supply chain management, and logistics [90].

5.3. Final Remarks

In an effort to summarize, we claim that the need to modernize ports to smart ports due to the increasing demands and pressures on shipping industry becomes obvious. The industry faces challenges such as the continuous growth of world trade, the increasing volume of cargo, and the need for more efficient and sustainable operations. In this regard, ports are being urged to adapt through the implementation of the smart port model, the primary components of which are automation of operations and supply chain integration.

Bearing in mind the above, we should acknowledge the fact that it is fundamental to understand that the success of the transition to the smart port concept will necessitate interdisciplinary collaboration between researchers, policy makers, industry professionals, and port entities for promoting sustainable and responsible port operations. Successful transitions to smart ports involve addressing these topics in a comprehensive and adaptable manner to ensure the benefits of increased efficiency and competitiveness. The resolution of the aforementioned research issues and challenges, hopefully, will facilitate the further development and optimization of smart ports as essential elements of international trade and logistics networks.

Limitations of our study could include the fact that relying solely on peer-reviewed literature might exclude valuable insights from grey literature, such as reports, theses, or conference papers. Grey literature can provide practical perspectives and real-world applications. In addition, technology in the smart ports domain is evolving rapidly. The SLR may capture a snapshot of the existing literature, but it might not fully reflect the latest technological advancements or implementations in the field.

Author Contributions: Conceptualization, A.P., M.M., V.Z. and K.F.; Methodology, A.P. and M.M.; Validation, A.P., M.M., V.Z. and K.F.; Formal Analysis, A.P.; Investigation, A.P.; Data Curation, A.P.; Writing—Original Draft Preparation, A.P.; Writing—Review & Editing, A.P., M.M., V.Z. and K.F.; Visualization, A.P.; Supervision, M.M.; Project Administration, M.M., V.Z. and K.F.; Funding Acquisition, M.M. All authors have read and agreed to the published version of the manuscript.

Funding: This work is part of a project that has received funding from University of Macedonia Research Fund under the Basic Research 2023 funding programme.

Data Availability Statement: Data is contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Puig, M.; Wooldridge, C.; Darbra, R.M. Identification and selection of Environmental Performance Indicators for sustainable port development. *Mar. Pollut. Bull.* **2014**, *81*, 124–130. [CrossRef]
2. Heilig, L.; Lalla-Ruiz, E.; Voß, S. Digital transformation in maritime ports: Analysis and a game theoretic framework. *NETNOMICS Econ. Res. Electron. Netw.* **2017**, *18*, 227–254. [CrossRef]
3. Ding, Y.; Jin, M.; Li, S.; Feng, D. Smart logistics based on the internet of things technology: An overview. *Int. J. Logist. Res. Appl.* **2021**, *24*, 323–345. [CrossRef]
4. Philipp, R.; Prause, G.; Olaniyi, E.O.; Lemke, F. Towards green and smart seaports: Renewable energy and automation technologies for bulk cargo loading operations. *Environ. Clim. Technol.* **2021**, *25*, 650–665. [CrossRef]
5. Triska, Y.; Frazzon, E.M.; Silva, V.M.D.; Heilig, L. Smart port terminals: Conceptual framework, maturity modeling and research agenda. *Marit. Policy Manag.* **2022**, *51*, 1–24. [CrossRef]

6. Aoun, A.; Ilinca, A.; Ghandour, M.; Ibrahim, H. A review of Industry 4.0 characteristics and challenges, with potential improvements using blockchain technology. *Comput. Ind. Eng.* **2021**, *162*, 107746. [CrossRef]
7. Dalaklis, D.; Christodoulou, A.; Ölcer, A.I.; Ballini, F.; Dalaklis, A.; Lagdami, K. The port of gothenburg under the influence of the fourth stage of the industrial revolution: Implementing a wide portfolio of digital tools to optimize the conduct of operations. *Marit. Technol. Res.* **2022**, *4*, 253844. [CrossRef]
8. Cammin, P.; Yu, J.; Heilig, L.; Voß, S. Monitoring of air emissions in maritime ports. *Transp. Res. Part D Transp. Environ.* **2020**, *87*, 102479. [CrossRef]
9. Rodič, B. Industry 4.0 and the New Simulation Modelling Paradigm. *Organizacija* **2017**, *50*, 193–207. [CrossRef]
10. Zarzuelo, I.d.l.P.; Soeane, M.J.F.; Bermúdez, B.L. Industry 4.0 in the port and maritime industry: A literature review. *J. Ind. Inf. Integr.* **2020**, *20*, 100173. [CrossRef]
11. Gunes, B.; Kayisoglu, G.; Bolat, P. Cyber security risk assessment for seaports: A case study of a container port. *Comput. Secur.* **2021**, *103*, 102196. [CrossRef]
12. Marlow, P.B.; Paixao-Casaca, A.C. Measuring lean ports performance. *Int. J. Transp. Manag.* **2003**, *1*, 189–202. [CrossRef]
13. Bichou, K. The ISPS Code and The Cost of Port Compliance: An Initial Logistics and Supply Chain Framework for Port Security Assessment and Management. *Marit. Econ. Logist.* **2004**, *6*, 322–348. [CrossRef]
14. Molavi, A. Designing Smart Ports by Integrating Sustainable Infrastructure and Economic Incentives. Ph.D. Thesis, University of Houston, Houston, TX, USA, 2020.
15. Zarzuelo, I.d.l.P. Cybersecurity in ports and maritime industry: Reasons for raising awareness on this issue. *Transp. Policy* **2021**, *100*, 1–4. [CrossRef]
16. Sadiq, M.; Ali, S.W.; Terriche, Y.; Mutarraf, M.U.; Hassan, M.A.; Hamid, K.; Ali, Z.; Sze, J.Y.; Su, C.-L.; Guerrero, J.M. Future Greener Seaports: A Review of New Infrastructure, Challenges, and Energy Efficiency Measures. *IEEE Access* **2021**, *9*, 75568–75587. [CrossRef]
17. Sohaib, R.M.; Onireti, O.; Sambo, Y.; Imran, M.A. Network Slicing for Beyond 5G Systems: An Overview of the Smart Port Use Case. *Electronics* **2021**, *10*, 1090. [CrossRef]
18. Wu, J.; Yan, H.; Liu, J. DEA models for identifying sensitive performance measures in container port evaluation. *Marit. Econ. Logist.* **2010**, *12*, 215–236. [CrossRef]
19. Tongzon, J. Efficiency measurement of selected Australian and other international ports using data envelopment analysis. *Transp. Res. Part A Policy Pract.* **2001**, *35*, 107–122. [CrossRef]
20. Cullinane, K.; Song, D.-W.; Ji, P.; Wang, T.-F. An Application of DEA Windows Analysis to Container Port Production Efficiency. *Rev. Netw. Econ.* **2004**, *3*, 184–206. [CrossRef]
21. Cullinane, K.; Wang, T.-F. Data Envelopment Analysis (DEA) and Improving Container Port Efficiency. *Res. Transp. Econ.* **2006**, *17*, 517–566. [CrossRef]
22. Barros, C.P.; Athanassiou, M. Efficiency in European Seaports with DEA: Evidence from Greece and Portugal. *Marit. Econ. Logist.* **2004**, *6*, 122–140. [CrossRef]
23. Coto-Millan, P.; Banos-Pino, J.; Rodriguez-Alvarez, A. Economic efficiency in Spanish ports: Some empirical evidence. *Marit. Policy Manag.* **2000**, *27*, 169–174. [CrossRef]
24. Cullinane, K.; Song, D.-W.; Gray, R. A stochastic frontier model of the efficiency of major container terminals in Asia: Assessing the influence of administrative and ownership structures. *Transp. Res. Part A Policy Pract.* **2002**, *36*, 743–762. [CrossRef]
25. Lirn, T.C.; Thanopoulou, H.A.; Beresford, A.K. Transhipment port selection and decision-making behavior: Analyzing the Taiwanese case. *Int. J. Logist. Res. Appl.* **2003**, *6*, 229–244. [CrossRef]
26. Chiu, R.-H.; Lin, L.-H.; Ting, S.-C. Evaluation of Green Port Factors and Performance: A Fuzzy AHP Analysis. *Math. Probl. Eng.* **2014**, *2014*, 802976. [CrossRef]
27. Denyer, D.; Tranfield, D. *The Sage Handbook of Organizational Research Methods*; Sage Publications Ltd.: Thousand Oaks, CA, USA, 2009.
28. Page, M.J.; Moher, D.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; McKenzie, J.E. PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews. *BMJ* **2021**, *372*, n160. [CrossRef]
29. Lacey, F.M.; Matheson, L.; Jesson, J. Doing your literature review: Traditional and systematic techniques. In *Doing Your Literature Review*; SAGE Publications Ltd.: Thousand Oaks, CA, USA, 2011; pp. 1–192.
30. Hsu, C.-T.; Chou, M.-T.; Ding, J.-F. Key factors for the success of smart ports during the post-pandemic era. *Ocean Coast. Manag.* **2023**, *233*, 106455. [CrossRef]
31. Makkawan, K.; Muangpan, T. Developing Smart Port with Crucial Domains and Indicators in the Thai Port Case: A Con-firmatory Factor Analysis. *Trans. Marit. Sci.* **2023**, *12*, 7. [CrossRef]
32. Makkawan, K.; Muangpan, T. A Conceptual Model of Smart Port Performance and Smart Port Indicators in Thailand. *J. Int. Logist. Trade* **2021**, *19*, 133–146. [CrossRef]
33. Liu, C.; Zhan, S.; Heng, L. Evaluation of smart port development level based on entropy weight TOPSIS method. In Proceedings of the International Conference on Frontiers of Traffic and Transportation Engineering, Lanzhou, China, 17–19 June 2022; Volume 12340, pp. 368–375.
34. Zhou, D.; Zhang, L.; Zhou, Y.; Lia, C.; Liub, C. Operational Indicators of Smart Container Ports. In *Hydraulic and Civil Engineering Technology VII*; IOS Press: Amsterdam, The Netherlands, 2022.

35. Molavi, A.; Lim, G.J.; Race, B. A framework for building a smart port and smart port index. *Int. J. Sustain. Transp.* **2019**, *14*, 686–700. [CrossRef]
36. Zhao, D.; Wang, T.; Han, H. Approach towards Sustainable and Smart Coal Port Development: The Case of Huanghua Port in China. *Sustainability* **2020**, *12*, 3924. [CrossRef]
37. González, A.R.; González-Cancelas, N.; Serrano, B.M.; Orive, A.C. Smart ports: Ranking of Spanish port system. *World Sci. News* **2020**, *144*, 1–12.
38. Lakhmas, K.; Sedqui, P.A. Toward a smart port congestion optimizing model. In Proceedings of the 2020 IEEE 13th International Colloquium of Logistics and Supply Chain Management (LOGISTIQUA), Fez, Morocco, 2–4 December 2020; pp. 1–5.
39. González, A.R.; González-Cancelas, N.; Serrano, B.M.; Orive, A.C. Preparation of a Smart Port Indicator and Calculation of a Ranking for the Spanish Port System. *Logistics* **2020**, *4*, 9. [CrossRef]
40. Chen, J.; Xue, K.; Ye, J.; Huang, T.; Tian, Y.; Hua, C.; Zhu, Y. Simplified Neutrosophic Exponential Similarity Measures for Evaluation of Smart Port Development. *Symmetry* **2019**, *11*, 485. [CrossRef]
41. Yen, B.T.; Huang, M.-J.; Lai, H.-J.; Cho, H.-H.; Huang, Y.-L. How smart port design influences port efficiency—A DEA-Tobit approach. *Res. Transp. Bus. Manag.* **2023**, *46*, 100862. [CrossRef]
42. Azisah, N.; Asdar, M.; Paotonan, C. Fulfillment of Smart Port Criteria for the Existing Terminal 2 of the New Makassar Container Port. *Zona Laut J. Inov. Sains Dan Teknol. Kelaut.* **2023**, *4*, 67–76. [CrossRef]
43. Othman, A.; El Gazzar, S.; Knez, M. Investigating the Influences of Smart Port Practices and Technology Employment on Port Sustainable Performance: The Egypt Case. *Sustainability* **2022**, *14*, 14014. [CrossRef]
44. Molavi, A.; Shi, J.; Wu, Y.; Lim, G.J. Enabling smart ports through the integration of microgrids: A two-stage stochastic programming approach. *Appl. Energy* **2019**, *258*, 114022. [CrossRef]
45. Jun, W.K.; Lee, M.-K.; Choi, J.Y. Impact of the smart port industry on the Korean national economy using input-output analysis. *Transp. Res. Part A Policy Pract.* **2018**, *118*, 480–493. [CrossRef]
46. Buiza-Camacho-Camacho, G.; del Mar Cerbán-Jiménez, M.; González-Gaya, C. Assessment of the factors influencing on a smart port with an analytic hierarchy process. *Rev. DYNA* **2016**, *91*, 498–501.
47. El Imrani, O. Study to reduce the costs of international trade operations through container traffic in a smart port. In *Innovations in Smart Cities Applications Volume 4: The Proceedings of the 5th International Conference on Smart City Applications*; Springer International Publishing: Cham, Switzerland, 2021; pp. 477–488.
48. Othman, A.; El-Gazzar, S.; Knez, M. A Framework for Adopting a Sustainable Smart Sea Port Index. *Sustainability* **2022**, *14*, 4551. [CrossRef]
49. Karli, H.; Karli, R.G.Ö.; Çelikyay, S. Fuzzy AHP Approach to the Determinatıon of Smart Port Dimensions: A Case Study on Filyos Port. *Düzce Üniversitesi Bilim Ve Teknol. Derg.* **2021**, *9*, 322–336. [CrossRef]
50. Paulauskas, V.; Filina-Dawidowicz, L.; Paulauskas, D. Ports Digitalization Level Evaluation. *Sensors* **2021**, *21*, 6134. [CrossRef] [PubMed]
51. Nguyen, H.P.; Pham, N.D.K.; Bui, V.D. Technical-Environmental Assessment of Energy Management Systems in Smart Ports. *Int. J. Renew. Energy Dev.* **2022**, *11*, 889–901. [CrossRef]
52. Jahn, C.; Nellen, N. Smart Port Concept: Strategic Development, Best Practices, Perspectives of Development. In *Arctic Maritime Logistics: The Potentials and Challenges of the Northern Sea Route*; Springer International Publishing: Cham, Switzerland, 2022; pp. 81–93.
53. Mi, W.; Liu, Y. Ecology of Smart Port. In *Smart Ports*; Springer: Singapore, 2022; pp. 13–25.
54. Alamoush, A.S.; Ballini, F.; Ölçer, A.I. Ports' technical and operational measures to reduce greenhouse gas emission and improve energy efficiency: A review. *Mar. Pollut. Bull.* **2020**, *160*, 111508. [CrossRef] [PubMed]
55. Frazzon, E.M.; Constante, J.M.; Triska, Y.; Albuquerque, J.V.D.S.; Martinez-Moya, J.; Silva, L.D.S.; Valente, A.M. Smart port-hinterland integration: Conceptual proposal and simulation-based analysis in Brazilian ports. *Int. J. Inte-Grated Supply Manag.* **2019**, *12*, 334–352. [CrossRef]
56. Sari, Y.A.; Pamadi, M. The Smart Port Concept of Batu Ampar Port in Batam. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *343*, 012095. [CrossRef]
57. Shuo, C.; Jian, W.; Ruoxi, Z. The Analysis of the Necessity of Constructing the Huizhou "Smart Port" and Overall Framework. In Proceedings of the 2016 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS), Changsha, China, 17–18 December 2016; pp. 159–162.
58. Tan, K.W.; Kan, M.; Tan, P.J.; Schablinski, S. A Framework for Evaluating Energy Sustainability Efforts for Maritime Smart Port Operations. In Proceedings of the 2018 International Conference on ICT for Smart Society (ICISS), Semarang, Indonesia, 10–11 October 2018; pp. 1–5.
59. Durán, C.A.; Córdova, F.M.; Palominos, F. A conceptual model for a cyber-social-technological-cognitive smart medium-size port. *Procedia Comput. Sci.* **2019**, *162*, 94–101. [CrossRef]
60. Al-Fatlawi, H.A.; Motlak, H.J. Smart ports: Towards a high performance, increased productivity, and a better environment. *Int. J. Electr. Comput. Eng.* **2023**, *13*, 1472–1482. [CrossRef]
61. de Moura, D.A. Analysis of industry 4.0 and their impact on port environmental management. *Indep. J. Man-Agement Prod.* **2022**, *13*, 1168–1190. [CrossRef]

62. Zhuang, Z.; Zhang, Z.; Teng, H.; Qin, W.; Fang, H. Optimization for integrated scheduling of intelligent handling equipment with bidirectional flows and limited buffers at automated container terminals. *Comput. Oper. Res.* **2022**, *145*, 105863. [CrossRef]
63. Belfkih, A.; Duvallet, C.; Sadeg, B. The Internet of Things for smart ports: Application to the port of Le Havre. In Proceedings of the IPaSPort, Le Havre, France, 3–4 May 2017.
64. Karas, A. The role of digitalization for smart port concept. In *Economic and Social Development: Book of Proceedings 2020*; Varazdin Development and Entrepreneurship Agency: Varazdin, Croatia, 2020; pp. 406–412.
65. Hirata, E.; Watanabe, D.; Lambrou, M. Shipping Digitalization and Automation for the Smart Port. In *Supply Chain-Recent Advances and New Perspectives in the Industry 4.0 Era*; IntechOpen: London, UK, 2022.
66. Yao, H.; Xue, T.; Wang, D.; Qi, Y.; Su, M. Development Direction of Automated Terminal and Systematic Planning of Smart Port. In Proceedings of the 2021 IEEE 2nd International Conference on Big Data, Artificial Intelligence and Internet of Things Engineering (ICBAIE), Nanchang, China, 26–28 March 2021; pp. 708–712.
67. Shah, V. Internet of Things for Smart Ports: Technologies and Challenges. *IEEE Instrum. Meas. Mag.* **2018**, *21*, 34–43.
68. Inkinen, T.; Helminen, R.; Saarikoski, J. Technological trajectories and scenarios in seaport digitalization. *Res. Transp. Bus. Manag.* **2021**, *41*, 100633. [CrossRef]
69. Acciaro, M.; Ferrari, C.; Lam, J.S.; Macario, R.; Roumboutsos, A.; Sys, C.; Vanelslander, T. Are the innovation processes in seaport terminal operations successful? *Marit. Policy Manag.* **2018**, *45*, 787–802. [CrossRef]
70. Chiang, C.H.; Hwang, C.C. Competitiveness of container ports in a region with cooperation and integration. *J. Soc. Transp. Traffic Stud.* **2009**, *1*, 77–91.
71. Flynn, M.; Lee, T.; Notteboom, T. The next step on the port generations ladder: Customer-centric and community ports. In *Current Issues in Shipping, Ports and Logistics*; Academic and Scientific Publishers: Brussels, Belgium, 2011; Volume 27, pp. 497–510.
72. Lee PT, W.; Lam, J.S. *Developing the fifth generation ports model. Dynamic Shipping and Port Development in the Globalized Economy: Volume 2: Emerging Trends in Ports*; Palgrave Macmillan: London, UK, 2016; pp. 186–210.
73. Kaliszewski, A. Fifth and sixth generation ports (5GP, 6GP)–evolution of economic and social roles of ports. *Retrieved* **2018**, *5*, 31.
74. Lin, S.-C.; Chang, H.-K.; Chung, Y.-F. Exploring the Impact of Different Port Governances on Smart Port Development Strategy in Taiwan and Spain. *Sustainability* **2022**, *14*, 9158. [CrossRef]
75. Chen, J.; Huang, T.; Xie, X.; Lee, P.T.-W.; Hua, C. Constructing Governance Framework of a Green and Smart Port. *J. Mar. Sci. Eng.* **2019**, *7*, 83. [CrossRef]
76. Boullauazan, Y.; Sys, C.; Vanelslander, T. Developing and demonstrating a maturity model for smart ports. *Marit. Policy Manag.* **2022**, *50*, 447–465. [CrossRef]
77. Heikkilä, M.; Saarni, J.; Saurama, A. Innovation in Smart Ports: Future Directions of Digitalization in Container Ports. *J. Mar. Sci. Eng.* **2022**, *10*, 1925. [CrossRef]
78. Verhoeven, P. A review of port authority functions: Towards a renaissance? *Marit. Policy Manag.* **2010**, *37*, 247–270. [CrossRef]
79. Conti, M.; Zilvetti, M.; Kotter, R. Challenges and Opportunities for UK Seaports Toward Future Sustainability: The UK's North East Smart Ports Testbed Case Study. In *Handbook of Sustainability Science in the Future: Policies, Technologies and Education by 2050*; Springer: Cham, Switzerland, 2022; pp. 805–844.
80. Fabiano, B.; Currò, F.; Reverberi, A.P.; Pastorino, R. Port safety and the container revolution: A statistical study on human factor and occupational accidents over the long period. *Saf. Sci.* **2010**, *48*, 980–990. [CrossRef]
81. Altiok, T. Port security/safety, risk analysis, and modeling. *Ann. Oper. Res.* **2011**, *187*, 1–3. [CrossRef]
82. Ben Farah, M.A.; Ukwandu, E.; Hindy, H.; Brosset, D.; Bures, M.; Andonovic, I.; Bellekens, X. Cyber security in the maritime industry: A systematic survey of recent advances and future trends. *Information* **2022**, *13*, 22. [CrossRef]
83. Yau KL, A.; Peng, S.; Qadir, J.; Low, Y.C.; Ling, M.H. Towards smart port infrastructures: Enhancing port activities using information and communications technology. *IEEE Access* **2020**, *8*, 83387–83404.
84. Li, K.X.; Li, M.; Zhu, Y.; Yuen, K.F.; Tong, H.; Zhou, H. Smart port: A bibliometric review and future research directions. *Transp. Res. Part E Logist. Transp. Rev.* **2023**, *174*, 103098. [CrossRef]
85. Duin, H.; Gorldt, C.; Thoben, K.D.; Pawar, K. Challenges for the port of the future: Findings from a scenario analysis. In Proceedings of the 2015 IEEE International Conference on Engineering, Technology and Innovation/International Technology Management Conference (ICE/ITMC), Belfast, UK, 22–24 June 2015; pp. 1–9.
86. Lalla-Ruiz, E.; Heilig, L.; Voß, S. Environmental sustainability in ports. In *Sustainable Transportation and Smart Logistics*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 65–89.
87. Petrova, M.; Popova, P.; Popov, V.; Shishmanov, K.; Marinova, K. Digital Ecosystem: Nature, Types and Opportunities for Value Creation. In *International Scientific Conference on Innovations in Digital Economy*; Springer International Publishing: Cham, Switzerland, 2021; pp. 71–85.
88. McKinsey Global Institute. A Future That Works: Automation, Employment και Productivity. Available online: https://www.mckinsey.com/~/media/mckinsey/featured%20insights/Digital%20Disruption/Harnessing%20automation%20for%20a%20future%20that%20works/MGI-A-future-that-works-Executive-summary.ashx (accessed on 25 October 2023).

89. Burns, M.G. *Port Management and Operations*; CRC Press: Boca Raton, FL, USA, 2015; ISBN 9781315275215.
90. Douaioui, K.; Fri, M.; Mabrouki, C. Smart port: Design and perspectives. In Proceedings of the 2018 4th International Conference on Logistics Operations Management (GOL), Le Havre, France, 10–12 April 2018; pp. 1–6.