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Article of investigation

Usefulness of industry 4.0 technologies in smart ports

Utilidad de las tecnologías de las industria 4.0 en los smart ports

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Abstract

Smart Ports focus on developing more competitive processes based on criteria such as costs, time, and information across the entire supply chain with the assistance of Industry 4.0 technologies. This research aims to analyze the use of emerging technologies in Smart Ports through a literature review from the Scopus database until 2022. Bibliometrix and Vosviewer are employed for quantitative analysis, followed by a qualitative approach in an exploratory study to categorize common themes in the addressed publications. The study concludes the rise and development of emerging technology adoption in ports, primarily IoT, Big Data, Blockchain, and Artificial Intelligence. These technologies have contributed to securing and streamlining port logistics processes. There is also a notable emphasis on contributing to environmental sustainability processes through technologies ensuring improvements in port terminals. Key examples of ports incorporating Industry 4.0 technologies include Shanghai, Huanghua, Rotterdam, Hamburg, Barcelona, Salerno, Ravenna, Vancouver, and Los Angeles.

Resumen

Los Smart Ports (Puertos Inteligentes) se enfocan en desarrollar procesos más competitivos bajo criterios de costos, tiempos e información alrededor de toda la cadena de suministro con ayuda de las tecnologías pertenecientes a la industria 4.0. La presente investigación, tiene como objetivo analizar el uso de tecnologías emergentes empleadas en Smart Ports mediante consultas de análisis bibliométrico y revisión de literatura de la base de datos Scopus, donde se categorizaron por temáticas comunes. Se concluye el auge y desarrollo de la adopción de tecnologías emergentes en los puertos, principalmente el Internet de las Cosas (IoT), Big Data, Blockchain e Inteligencia Artificial; estas tecnologías han ayudado a que los procesos logísticos portuarios sean seguros y eficientes. También se identifica un énfasis por aportar a procesos de sostenibilidad ambiental, garantizando mediante tecnologías acciones de mejora en las terminales portuarias. Los principales ejemplos que están utilizando tecnologías de industria 4.0 en puertos se ubican en Shanghai, Huanghua, Rotterdam, Hamburgo, Barcelona, Salerno, Rávena, Vancouver y los Ángeles.

Keywords: Smart ports, Internet of things, Industry 4.0, Supply chain.

Palabras clave: Puertos inteligentes, Internet de las cosas, industria 4.0, Cadena de suministro.

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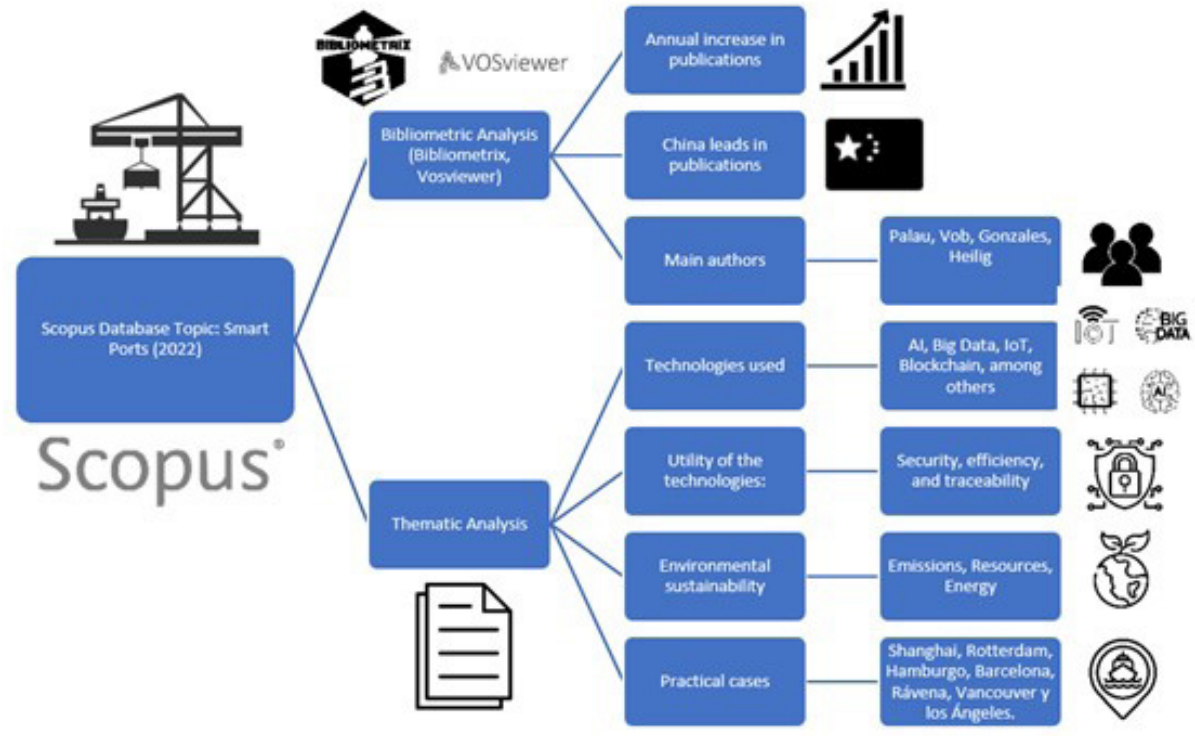
Why was it carried out?
The main focus of the research lies in the rise and development of the adoption of emerging technologies in ports, with a particular emphasis on technologies such as Internet of Things, Big Data, Blockchain, and Artificial Intelligence. These technologies have proven to be instrumental in enhancing the security and efficiency of port logistics processes, as well as contributing to environmental sustainability at port terminals. The article was conducted to explore how Industry 4.0 technologies are transforming Smart Ports, providing benefits in terms of competitiveness, efficiency, sustainability, and security in the maritime supply chain.

What were the most relevant results?
The main findings obtained in the research article on Smart Ports and Industry 4.0 technologies include key trends such as port sustainability, supply chain management, and the adoption of emerging technologies, highlighting the dynamic, global relevance, and interdisciplinary nature of Smart Ports research. Additionally, the crucial role of technology in enhancing the efficiency and sustainability of port operations is underscored, especially through the implementation of logistics 4.0 principles and emerging technologies such as the Internet of Things (IoT). Despite promising prospects, challenges like cybersecurity vulnerabilities require comprehensive risk management strategies. The integration of sustainable practices and technologies emerges as a critical imperative, not only optimizing port operations but also mitigating environmental impacts and benefiting surrounding communities. Leading port terminals worldwide in this field include Shanghai, Rotterdam, and Hamburg, which have embraced smart technologies to enhance automation, sustainability, and operational efficiency.

What do these results provide?
The results of the article on Smart Ports and Industry 4.0 technologies provide a comprehensive view of current research in the field, identifying trends, key areas, and technologies used in the maritime industry, contributing to the advancement of knowledge in port logistics and emerging technologies. Additionally, they serve as a guide for strategic decision-making for both companies and governmental entities seeking to implement these technologies, highlighting their potential to drive technological innovation and promote more sustainable practices in the maritime industry, which could improve the efficiency and sustainability of port operations.

Graphical Abstract



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Introduction

Maritime transport accounts for more than 80% of the world's freight mobility, generating collaterally an increase in traffic in port operations with the respective emission of greenhouse gases, pollution and increased risks in the logistics chain (1,2). The growth of countries is driven by port strengthening, where infrastructure, space and trade are articulated within the dynamics of supply chains. The fourth industrial revolution presents the application and adoption of emerging technologies in various fields in order to optimize processes involving physical and digital spaces to achieve optimal advantages and operations for the end consumers, with ports being the main focus of innovation in value-added services (3,4).

The advance of the digitalization of logistics information has become the guarantee to promote the quality of port services, competitiveness and process optimization solutions; hence the expression "smart port" thatemerged in the 80's with the development of a Chinese port where advances in information systems, electronic data interchange and rapid evolution of the economy oriented to promote the efficiency and quality of port services are presented (5). The new digital era is leading countries to become leaders in growth and innovation with port/city interconnections that generate competitive environments (6,7). In thisregard, ports have become real design systems that help to identify and evaluate resources that provide quality operational services capable of preventing delays, congestion, and lead to cost and time reductions in supply chains (8,9). The importance of port areas is to generate optimization alternatives and face the pressure of climate change (2). Sustainability is therefore indispensable to the extent that operations are eco-friendly and energy- efficient (10,11). Simultaneously, it has allowed the promotion of distribution and safer data flow, shorter times and real-time monitoring (12), without disregarding the fact that the use of technologies contributes to the protection of the environment and the reduction of negative impacts on the ecosystem (13,14).

The process of employing emerging technologies responds to challenges and influencing factors such as governance, people, information and supply chain nodes; all of which are immersed in the evolution of portterminals that catalyze global trade (13,15). Within the application of these technologies in smart ports, theInternet of Things (IoT) is highlighted, which detects, communicates and influences cyber-security. Now, the IoT through Big Data generates a flow of information that support and monitor port systems that supportcompetitiveness and are the basis for the application of other technologies such as sensors, cloud computing,RFID, artificial intelligence, digital twins, blockchain, among others (1,16). Ports are compelled to adapt to the new needs of the population, integrate technologies and make processesautomated and dynamic in the links of the supply chain (17).

However, the acceptance of new trends requires investment and adaptation spaces for the maritime industry, which are the main development and economic integration and growth of a country (16).

In this research as case studies, through the literature review process, studies were found in the ports of Shanghai (China), Hamburg (Germany), Barcelona (Spain), Rotterdam (Netherlands), Salerno (Italy), Los Angeles (United States), among others, which have demonstrated the improvement of their processes within the terminals by applying 5G technology and sensors to visualize information in real time, identify

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possiblebottlenecks and location of machinery and equipment used for maneuvering in ports (18). Therefore, the objective was to analyze the use of technologies employed in smart ports through a review of literature thataddresses this field and that have been published in the Scopus database, using a qualitative and exploratoryapproach to identify common themes that are addressed in the publications. The study is structured as follows: introduction, methodology, bibliometric analysis, results and discussion, conclusion and references.

Methodology

The methodology used is based on the approach proposed by (19) to develop a literature review, in an exploratory study on a growing topic and under a qualitative approach. The phases developed are describedbelow:

Determination of the objective: it arises from the researchers' interest in developing a booming topic of greatprofessional attention, within the framework of industry 4.0 or fourth industrial revolution; with a special motivation for logistics and supply chain processes, determining that addressing Logistics 4.0, and especially its development in smart ports is an objective of contribution to the research and professional field. Emphasizing the importance of identifying the predominant technologies and their usefulness in the processes of port terminals and the maritime operation of goods.

Bibliographic consultation: includes consultation of the database, which in this case was Scopus, (table 1) to then define the search strategy, according to specific criteria of the subject matter on smart ports, and then inclusion and exclusion criteria were defined for the articles to be addressed on smart ports. It should be noted that the search was in English, since this is the dominant language in this database and therefore allows a greater number of publications to be consulted.

Table 1. Criteria for consultation in Scopus

Period of time	Every year until 2022 (August)
Type of documents	Articles, conference papers, books and book chapters
Type of magazine	Open Access, Gold Open, Hybrid Gold, Bronze y Green
Search equation	TITLE-ABS-KEY ("smart ports")
Results	172

Source: Own elaboration (2022)

Organization of the information: Initially, the search criteria focused mainly on publications that directly addressed the topic of Intelligent Ports. Therefore, in the inclusion criteria, publications related to businessprocesses, logistics, management, strategy, engineering, optimization, information systems, resource management, applied technology and decision making were selected. On the other hand,

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publications on health, chemistry, physics, astronomy, arts, philosophy and other distant areas, which are not relevant to this research, were excluded. The literature review for qualitative analysis and discussion ended up addressing 103 publications, which were categorized after detailed reading of title, abstract and conclusions,into common research approaches, regarding the usefulness of Industry 4.0 technologies in Smart Ports.

Article drafting: Complete reading of the selected articles to analyze the usefulness of technologies in smartports in the identified common categories, followed by discussion and conclusions.

Bibliometric analysis

With the consultation of publications carried out in Scopus until 2022, a bibliometric analysis was carried out using the Bibliometrix and Vosviewer tools, to identify the behavior of publications on Smart Ports in this database. This quantitative analysis covered aspects such as the volume of publications, types of documents and main countries, authors, areas, journals and research trends.

Regarding the volume of publications from the first study in Scopus in 2012 to the cut-off year of 2022, theconcentration of activity in the last year stands out significantly, representing 28.71% of the total. This is followed by the year 2021 with a contribution of 24.88%, while the year 2020 presents 14.83%. Likewise, a contribution of 11.48% is observed in 2019. These percentages reflect the accumulated publications on smart ports over the last four years, totaling 79.9%. This data highlights the contemporaneity of the topic inthe research community and its growing interest year after year, evidencing the dynamism and sustained relevance of this field of study. In a bibliometric analysis by areas, the following is identified; Engineering (21.3%), Computer Science (20.2%), Social Sciences (11.3%), Decision Sciences (8.1%) and Mathematics (7.7%). This is evidence that it is a multidisciplinary field and the importance of integrated approaches in the understanding and development of smart ports.

The analysis of the distribution of types of publications on smart ports reveals that Conference Papers and Articles are the two most predominant categories, representing a remarkable 47.37% and 42.11% respectively of the total number of publications. These results indicate a focus on the presentation of researchand findings through conferences, as well as a marked presence of scientific articles in the academic literature on this topic. In terms of the origin of the publications, the contribution from China stands out, leading with 23.44% of the total number of documents. Spain and Italy also followed with 12.92% and 11.96%, respectively. It is followed in order by Germany, the United States, Greece and the United Kingdom, which share a similar contribution, each contributing around 6.70% to 5.74%. This panorama reflects the global relevance of the subject and the identification of the countries where the ports contemplating the new emerging technologies are located.

In terms of author contribution, the bibliometric analysis on smart ports highlights the top five contributorswho lead in terms of percentage of publications. In first place, C.E. Palau (h-index 19) stands out with 7.61%, followed by S. Voß (h-index 46) with

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6.52%, N. González-Cancelas (h-index 10) with 5.43%, L. Heilig(h-index 15) with 5.43%, and I. Lacalle (h-index 5) with 5.43%. Therefore, the percentage sum of the firstfive authors is approximately 30.42%. Their prominent presence suggests a significant impact on current research and points to potential opinion leaders in the scientific community who contribute substantially tothe advancement of this emerging topic.

The publications presented as conference papers on intelligent ports offer an overview of recent advances, where the series “Lecture Notes in Computer Science” with 11 results stands out, evidencing the importanceof conferences in computer science and artificial intelligence. The “ICTIS 2021” conference contributes with 5 results on transportation information and safety. “Proceedings of SPIE” and “IFIP Advances” share third place with 4 results each, highlighting conferences in optical engineering and information technologies. “IEEE Access” stands out with 3 results, highlighting its relevance in electrical and electronicengineering applied to smart ports. As for the publications of articles in indexed journals, a thematic and disciplinary diversity is revealed. The Journal of Physics Conference Series (h-index 91) tops the list with7 results, highlighting its focus on physics applied to ports. Sustainability Switzerland (h-index 136, SJR Q1) follows closely with 6 results, underlining the importance of sustainability in the port context. The Journal of Marine Science and Engineering (h-index 39, SJR Q2) contributes 4 results, focusing on scientific and engineering aspects related to ports. Transport Policy (h-index 113, SJR Q1) and Maritime Policy and Management (h-index 67, SJR Q1) share third place with 3 results each, indicating the relevanceof these journals in the discussion of policies and management in the field of maritime transport and ports.

Regarding the most prominent research trends in the field of smart ports according to the bibliometric analysis (keyword co-occurrence analysis), three main approaches stand out, reflecting the emphasis of thepublications. First, port sustainability emerges as a crucial issue, addressing not only environmental considerations, but also energy efficiency and strategies for effective decision making in port resource management.

This approach not only responds to the demands of growing environmental awareness, but also recognizes the importance of optimizing resources and minimizing negative impacts. Secondly, there is a trend towards the articulation of ports in supply chain management. This approach involves the strategicintegration of information management, risk assessment and management, as well as the optimization of container operations. This approach reflects the increasing interconnectedness of the different stages of thesupply chain and the need for efficient and coordinated management to improve the agility and responsiveness of the entire system. Finally, the third key trend roots in the adoption of emerging technologies, such as the Internet of Things, big data, artificial intelligence and port digitalization processes. This approach is the central emphasis of this article, as the usefulness and impact of these Industry 4.0 technologies in the transformation and optimization of smart ports will be explored in depth.

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Results and discussion

In the present research, after reading the selected articles, the main focus was identified as the application of technologies in smart ports, emphasizing its usefulness and benefits; to then delve into particular categories or approaches where this usefulness is represented within the framework of the fourth industrial revolution used in logistics 4.0. Therefore, the following is a discussion of the four common thematic approaches identified from the Smart Ports literature: technologies employed, the usefulness of these technologies, the importance of sustainability and the case studies developed.

Technologies used in smart ports

The maritime industry is a major driver of economic growth and development, being the most widely usedmeans of moving goods worldwide (1). It plays a decisive role in aspects of cost, delivery times, reliabilityand environmental impact in operations (20). Currently the internet of things revolutionizes and provides a solution to the challenges of operability in ports, which includes sensors and systems integrated to the internet, forming a structure and basis of a smart port (21). According to Kamolov and Park (22) the new merit of smart ships is focused on controlling data and having communication with port areas, this transition is made through the application of sensors and networks that together with big data, artificial intelligence, among others, represent the adoption of industry 4.0.

Furthermore, international trade is the central driver of all economic globalization (23). Linked to this, theconstruction and/or retrofitting of automated port terminals is on the rise and the proposal for smart ports poses requirements for operations planning and improved systems integration capabilities (24). It is highlighted that, the structures and scope of application of digital platforms support and help promote the sector of commercial operability and autonomous technology on ships (25). Therefore, the exchange of information in real time is important to efficiently coordinate actors and container movements at terminals.(26). However, ports must be understood and visualized as a wide network of actors (27). In particular, theport industry has an impact on productivity, adding value to logistics activities (28). These areas are in search of a fifth generation where studies to smart ports are thanks to this relationship of emerging technologies (29).

On the other hand, Industry 4.0 in the current context generates development and innovation between portsand cities, transforming processes and making them more efficient, safe and sustainable (30). Smart ports are capable of responding to current and future logistics challenges (31). It is highlighted that the strategicchallenge in the ports of Hamburg and Rotterdam allows the articulation of technologies such as Big Data,Artificial Intelligence, among others, to obtain information flow and thus achieve that the processes improvetheir competitiveness and investment (16). However, when replacing traditional ports towards intelligent ones, it is considered that the application of these technologies in this field is not easy (32). The standardization of ICT services in future ports will be associated with shipping and maritime navigation,intermodal logistics, passenger transport and environmental sustainability (4). Efficiency is the key word in logistics, in turn, construction, infrastructure and integration allow for the smooth operation of port areas (6). Artificial intelligence drives the landscape of

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traditional port services in use today (33). Likewise, ports are complex, dynamic and daily work environments, which is why through processes and computational models artificial intelligence leads to a reinforcement and highlights the importance of a large volume of data to determine and optimize processes that lead to the productivity of the sector (34).

IoT enables monitoring and management of transportation equipment for cargo and warehousing, leading to the ports of the future involving sensors and data communication scenarios where interoperability occursand suppliers interfere and prioritize timely deliveries (35). According to (36) there is a need to design a location-based smart port, especially because it optimizes time by recognizing precisely where container and mobile equipment can be found through real-time location systems. Similarly, it is recognized that IoTis gaining speed and maturity in achieving optimization and connectivity towards fluidity in port processes (37). It is proposed that neither technology works in isolation, in the case of Blockchain with the increase in cargovolumes and the demand in the optimization of logistics processes ports must be more competitive; the relationship between the two technologies automates loading processes, data collection, time reduction, where the installation of sensors transmit everything to a system in real time (38). These, when properly integrated, allow control and generate a positive impact on logistics operations and port management today (39). Seaports are the nodes in the logistics sequence, where they are related to the integration, consolidationand digitization of logistics (40); This is why Blockchain technology solves problems such as cargo issues,poor data management, however, implementing this technology requires financial demand for maintenanceacquisition, so the combination of IoT and blockchain is viable for small ports that are in the process of achieving technological potential in their processes (41).

On the other hand, the collection of diverse information such as Big Data and geographic information systems enables real-time localization of goods (42) and the articulation of software that is of interest in theport-city relationship as a reliable scenario for carrying out foreign trade operations (7); highlighting breakthroughs in telecommunications resulting in smart services being provided throughout the supply chain (43) as global shipping demand enables algorithm-based technologies to effectively manage the mobility ofmotor vessels (44).

Similarly, Big Data allows the implementation of sensor networks that, together with the Internet of Things,form the data processing and storage infrastructure (45). These data allow better decisions to be made in port planning operations (46). In this way, this technology is applied to the construction of service modelsin the supply chain, establishing a mutual benefit through the coordination and flow of information (47). Italso highlights the Digital Twins technology where it allows to represent things in a real world, capable of predicting risks and integrating transportation and operation in supply chains related to smart ports (18). This diversifies the solution of different systems and operations in an integrated and intelligent network of the logistics chain (48). Through 5G wireless networks, measurements are taken to optimize processes, in the case of sensor networks and intelligent controllers are very useful in ports, as they monitor the location and removal of containers from loading and unloading processes, such as the automation of machines such as cranes (49). This technology is a multi-system support network that provides benefits to industries through its wide rangeof support for massively interconnected devices (50).

doi: 10.25100/iyc.v26i1.12814

Port issues face not only opportunities, but also problems and obstacles due to cyber-attacks that limit the growth of these important areas (51). Ports are key supports within the logistics value chain, which is whyit is essential to assess and avoid IT disruptions in operations involving risks (52). Cyber-security is one ofthe biggest challenges in this industry, where container management and system hacking lead to hiding processes as fundamental as inspections (53). Nowadays, different information technologies are involved that allow connectivity towards the new era of automation (54), where the establishment of new digital security practices is required towards the continuous improvement of the ports of the future (55).

Usefulness of emerging technologies in smart ports

Currently, the world's largest port terminals are generating strategies in line with the needs that arise daily in the logistics processes in order to perform adequate analysis in the supply chain and generate constant improvements and innovation in the development of port activities (6). It is important to note that the mainuse of emerging technologies is to ensure that information is distributed efficiently, as well as to manage existing cyber risks, reduce costs in the supply chain, minimize process times, reduce environmental effectsand, above all, generate reliable tools that allow port work to be carried out quickly and efficiently (52).

It should be noted that the use of various emerging technologies has evolved in recent years, therefore theproportion of a high optimization of shipping processes, updating and control of navigation times, transportefficiency and lower costs of storage of goods makes the connection and communication between port areasmore fluid and reliable (52,56). Therefore, their immersion guarantees port progress based on quality services and maritime support that generates tactics to prevent delays, port congestion and reduction of waiting times for ship arrivals (14,52,56).

Being more specific, ports are a fundamental base in the economy of the countries, therefore port terminalsmust maintain a high level of competitiveness (57), in order to provide confidence and continuous evolutionin the export and import processes, improve access channels and infrastructure through the introduction of technologies (6). Therefore, the connection between companies, cities and ports has ensured a wider and more flexible contact by virtue of the adaptation of technological pathways between them (58). Consequently, the transformation of paper and digitized ports has acquired added value in terms of the advancement of technologies, which allows them to emerge in the global context, since it is no longer only a communication within the port but a constant link between ports, cities and terminals integrated in the supply chain in general (59).

The appropriate use of technologies will allow for greater security in the supply chain processes, since the implementation of these technologies will prevent cyber-attacks that can spread and generate greater risks,so that they can be eradicated with the proper management of technological systems that have advanced over time (52). This has made it possible to eliminate manual errors in logistical processes, increase efficiency in data collection and ensure stability and faster transmission of information (59). Another important feature in the implementation of technologies in smart ports is automation, this is an area of constant change, as it has been a process of

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innovation in technology, which makes logistics operators andports to promote their competitiveness, evaluate the possibilities and advances that bring the incorporation of technological systems (60). In addition, automation streamlines the management of activities by simplifying the processes of loading and unloading goods, reducing time, resources and the efficient development of tasks (60,61).

Enabling the integration of connectivity systems with each other allows the distribution of data without interruptions and faster, driving processes of collection, processing, issuance, exchange and optimization ofinformation traffic with more secure, transparent and reliable features (62); Moreover, the transformation of data in real time requires digital platforms based on efficient technologies that enable the planning, delivery and execution of information movement solutions (63). In particular, the development of data technologies has led to an ideal improvement in the capacity and performance of port terminals, in order tostreamline processes and increase their competitiveness (64).

On the other hand, it is important to know the variables that are part of the port procedures in order to be clear about what type of technological implementation should be used to solve uncertainties that arise withthe development of logistics activities (65). At the same time, to ensure that networks are formed that interact with each other and are not isolated, thus achieving an effective integration that can generate betterresults. (66). At the same time, when developing any technology, risk management must be analyzed, sincein these cases it is necessary to be very careful not to generate systems susceptible to attacks or hackers (67); coordination of this is evidence of a reduction of dangers, adequate control and, above all, avoids consequences on the information platforms (68). In addition, the integration of technologies allows increasing the security of goods movement and container storage by expanding the functionality, management and monitoring of containers (69). Likewise, we seek to optimize the distribution of all typesof cargo, whether general or bulk, by means of control systems (70), without forgetting that these systems reduce costs and promote commercial opportunities (71); as well as to aim to use these benefits to close theexisting gaps in the logistics processes (72).

Finally, it should be understood that as time goes by, aspects such as sustainability are emerging and with the integration of technologies and their proper use, the emission of environmentally aggressive componentscan be reduced (73), In this case it applies not only to waste but also to noise pollution, since this is an important factor when working, as the reduction or eradication of loud sounds can generate a more pleasant and effective environment for the performance of port work, for example, the application of maturity modelscan promote sustainable development, optimization of information and ensure safer activities (13).

Importance of sustainability in smart ports

Technological advances in ports have been on the rise in recent years, as has the increasing search for sustainability and environmental care, therefore, talking about management models aimed at smart and sustainable ports is essential nowadays, where it is necessary an articulation between local actors, which have functions oriented to improvement processes in port activities with common objectives (74).

With the above and with the implementation of technologies, not only will a greater optimization of port operations be achieved, but also a decrease in the emissions

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produced by these places will be generated (75). Therefore, to speak of smart ports is to speak of sustainable ports, which will allow to increase the speed of goods transfer, access to ship tracking, increase the transparency of statistics, increase the quality and capacity of ports and reduce costs, all of this being possible from an ecological context (76), Althoughfew studies have analyzed port terminals from a sustainable perspective, it can be assured that theimplementation of both axes will make maritime operations more fluid (77). For this reason, smart or high-performance ports are implementing these technologies to achieve a more optimal and efficient managementof their activities, adding that they will have safer facilities and, of course, mitigate environmental impacts (11). By inserting these technologies in ports, safety, ecology and a higher quality of service will be promoted, all of this in order to improve the use of energy and logistics operations (78).

However, it is not only about the benefits that ports will have, but also for the regions and countries that host port ecosystems as these communities are the ones that are directly affected by pollution. As mentionedabove, an option for this situation could be the use of micronetworks in ports, which bring with them a substantial improvement in three areas: operations, environment and energy, which have become essential axes in port processes (79). For this reason, proposing a framework for analyzing and evaluating sustainability initiatives for terminal operations in the maritime sector is something that ports need to develop today (80).

Now, a very important axis that smart and green ports must take into account is energy emissions, since lighting exceeds 70% of the energy demand of a port in most cases (81), as an option to this problem, renewable energy generators and energy storage devices installed on board ships will achieve a transformation in the port context, since, by acquiring a greater implementation of renewable energies, the storage network will be expanded, and not only this, one could even speak of a reduction in monetary costs for boat owners and port administrators (82). Likewise, generating a database with port variables, classifiedinto economic, social, environmental and institutional variables, would achieve not only greater fluidity in the port but also a better evaluation of the progress made in terms of both automation and sustainability (83). Continuing with the line of renewable energy and micronetworks, it is known that the application of renewable energy sources for power distribution systems is growing, this advance brings several advantagessuch as sustainability, energy reliability, cost-effective and environmentally friendly energy sources.

Such application in maritime systems such as port micronetworks significantly improves energy efficiencyand reduces the use of fossil fuels, which is a serious threat to the environment (2), as another option is theuse of energy optimization algorithms based on dynamic programming, which can not only realize the control of the temperature of containers within the appropriate range, reduce the contact between workers and frozen products in the process of cold chain operation, ensure the reduction of energy demand during the period of high system load and solve the problem of optimizing the operation with the energy uncertaintyof the port to minimize costs (84).

Another point to consider is motorboats, when talking about vessels in the context of sustainability, it is worth mentioning cold ironing, which is the procedure for supplying electric power ashore to a vessel docked with its engines off, this emerges as an environmentally friendly option, with the objective of providing energy in an ecological way to the vessels while they are docked at the port, in order to avoid or

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mitigate the high emissions of greenhouse gases (85), it is important to keep this in mind as it is estimated that the international shipping industry is responsible for up to 5% of global carbon emissions, that share could be 25% by 2050. In fact, some studies indicate that as of 2020, the main source of atmospheric emissions of certain pollutants will be attributed to the shipping sector, thus surpassing land-based sources (86). Ports are among the main actors polluting the atmosphere, therefore, in order to talk about a smart and sustainable port, it is essential to talk about the treatment of dust pollution, air pollution and wastewater, byimplementing an intelligent ecological control system that integrates environmental protection functions could achieve a continuous improvement of decisions towards the sustainability of the port (87). In addition,the contribution of smart ports to the reduction of atmospheric emissions allows for greater operational efficiency and a vast contribution to environmental care (88). Addressing sustainability involves analyzingthe strategic advantages it brings, For this reason, we recommend the design of a conceptual model of an information system based on indicators to determine the status or degree of sustainability in the critical operational activities of port terminals, and thus indicate how far they have progressed towards becoming an ecological or green port (89), such advances can enable smart ports to generate local, national and globalbenefits by reducing greenhouse gas emissions, improving air quality, creating efficient supply chains and safer working environments (90).

As a result, the transport of goods is increasing all the time. In fact, maritime logistics plays a fundamentalrole in the world economy, since more than 80% of freight traffic is transported by sea (91). For this reason,it is necessary to talk about concepts such as the globalization of containers, since they lead to a high demandfor electricity in the terminals, which is very dynamic and depends on the different operating processes (92); This is subject to high energy requirements and a considerable proportion of emissions, while also driving awareness of a cleaner environment, for this reason, it is essential that ports adopt regulations and responsibilities aimed at the implementation of green ports (93), in order to improve not only their port activities, but also to exploit the usefulness of technologies both in their operations and in the care of the environment.

Studies and empirical cases in smart ports

Based on the above, technology use is essential for smart ports to optimize their supply chain processes andinformation management, so that they can achieve an effective interconnection of data and technologies. Therefore, aspects of the usefulness of smart port technologies around the world are mentioned below. Technologies in the contemporary context are constantly changing the maritime industry in significant ways,transforming the way ports operate in the international transportation system. Subsequently, to designate aport as “smart” it is necessary to be very competitive in the market and with the help of globalization to improve its productivity (94). Initially, it is emphasized that the ports of Shanghai, Rotterdam and Hamburghighlight transportation planning and this allows to achieve a coordinated development of all types of cargo movements in conjunction with urban planning activities, as well as a reasonable choice of the most effectivemeasures for the development of the haulage system; the above, in order to improve automation through theuse of Artificial Intelligence in processes involving logistics operations and cargo loading (6). In fact, in the port of Chile, a data warehouse system is proposed, with an information gathering center and a multidimensional database, which can be

doi: 10.25100/iyc.v26i1.12814

implemented in the analytical processing mode taking advantageof the good features that allow determining the status or degree of sustainability in critical operational activities in the port; this is based on the ports of Vancouver and Los Angeles, which have launched the sustainable activity (95).

To talk about Europe, there is the port of Salerno in Italy, where the dynamics of seaports and the creation of competitive port supply chains are understood, through the concept of intelligent service system, highlighting technology in its activities, which will make the relationship between the actors inside and outside the port more closely and efficiently connected (27), where ports are recommended to address the obstacles to promote innovation of port services, overcome the adverse effects of internal and external components, and achieve computerization, automation and intelligent development, in order to obtain addedvalue in the international port chain (96).

Likewise, in the port of Huanghua, China, is one of the largest coal transportation ports in the country, wheregood management of sustainable practices driven by smart technologies is identified and in essence, the useof the Internet of Things improves competitiveness at operational, energy and environmental levels (97). Likewise, the port of Ravenna (Italy) has implemented a management strategy for smart ports that supportsinnovation processes in the sustainable and safe management of the port, combining environmentalprotection and the development of the port and logistics system (98). Similarly, for the case of the port of Tangier Med, Morocco, it is mentioned that the digital transformation in correlation with flow planning andits impact on the improvement of international trade to address the case of container terminals, identifies the processes and necessary elements; as well as the difficulties of port terminals (99). Therefore, it is said that logistics control can increase quality by taking advantage of information technologies; moreover, effective planning can be achieved according to the main strategic aspect of each particular port (6,97).

Likewise, it should be noted that the port of Guadalupe is located in the Caribbean Sea and will become animportant logistic center in the region as a result of the expansion of the Panama Canal, which is why it seeks to integrate itself to the fast port logistics; and thanks to the implementation of intelligent technologies, it has demonstrated a development in the field of maritime transportation in the Caribbean. In contrast, it is a threat to other territories in this area and could impact jobs in the shipping industry in the English-speakingsector and affect the standard of living of people in the region (100).

On the other hand, it is important to highlight the importance and influence of the impact of the coronaviruspandemic on international trade, mainly on maritime transport and the logistics chain. In Hong Kong, first and foremost, it was analyzed that the consumption and movement of goods have had an effect on world trade due to the pandemic and above all had consequences on the logistics sector network, where the difficulty of contracts of transport, organization and return of containers, combined with the traditional problems of the port and shipping industry, increased, generating a worldwide crisis and a slowdown of normality in the entire supply chain (101).

However, Wuhan is evaluating the proposal to promote the construction of a smart port, optimizing the inland port system, developing the multimodal transportation business of Wuhan International Port, with the implementation of technologies that can comprehensively improve the efficiency of port operations, andrealize the

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modernization of port infrastructure and equipment, intelligent automation of port production and operation that will bring numerous benefits to international trade operations (98,102). However, smartports must have facilities with sufficient capacity to load and/or unload export and import goods in a timelymanner as required by the customer for maximum throughput (103). With this, an effective intelligentapproach must be implemented to support and ensure its validity, so that a port has public relations, innovation, human capital, investment, trade and governance that enhance the competitiveness of the national economy (17,96).

In general, smart ports focus on building a smart logistics platform and a smart port development zone thatwill trigger the development of digital construction in order to generate the integration of technical digitization tools to achieve greater reliability and reduce the risk of failures spreading to the connection box (102). For this reason, a number of protection functions must be implemented to support each Smart Port and its associated instrument (17,96).

Conclusions

A bibliometric analysis of publications in Scopus on Smart Ports up to 2022 was carried out using tools such as Bibliometrix and Vosviewer. This quantitative study addressed various aspects, from the volume and types of publications to highlighting countries, authors, areas and research trends. A significant and increasing concentration of publications was observed until 2022, representing 28.71% of the total, and the predominant areas were engineering and computer science. Conference Papers and Articles were the most prominent categories, accounting for 47.37% and 42.11% respectively. China led in the origin of publications, followed by Spain and Italy. Five main authors accounted for approximately 30.42% of the publications, evidencing their influence. Key trends were identified, highlighting port sustainability, supply chain management and the adoption of emerging technologies. In addition, the relevance of conference series such as “Lecture Notes in Computer Science” and leading journals such as “Journal of Physics Conference Series” was highlighted. This comprehensive analysis highlights the dynamic, global relevanceand interdisciplinary nature of Smart Port research.

The research highlights the application of technologies in smart ports, focusing on usefulness and benefits,with special attention to logistics 4.0. Common approaches are discussed: technologies used, the relevanceof sustainability and specific case studies. Sea transport is fundamental to global economic growth and in recent years is undergoing a significant transformation thanks to the adoption of emerging technologies. The implementation of the Internet of Things in smart ports stands out as a key catalyst for addressing operational challenges. The interconnection of sensors, integrated systems and technologies such as big dataand artificial intelligence form the basis of these ports of the future. International trade is driven by the construction and adaptation of automated terminals, which raises the need for planning and improved systems integration. In addition, artificial intelligence, blockchain and IoT are revolutionizing efficiency and connectivity in ports, optimizing logistics and supply chain management. However, the transition to smart ports represents challenges, especially in terms of cyber-security, where protection against cyber- attacks becomes crucial to ensure safe and continuous operations.

doi: 10.25100/iyc.v26i1.12814

The world's leading port terminals are adopting innovative strategies to improve efficiency and logistics management. The implementation of emerging technologies, such as the Internet of Things, is becoming key to optimizing information distribution, managing cyber risks, reducing costs and times in the supply chain, and minimizing environmental impacts. Technological evolution has led to a high optimization of shipping processes, control of sailing times, transport efficiency and reduction of storage costs. In addition,the connection between companies, cities and ports has improved significantly, contributing to the competitiveness of port terminals. Supply chain security is enhanced by preventing cyber-attacks and eliminating manual errors, while automation streamlines operations and reduces time and resources. The integration of connectivity systems and the development of data technologies have improved the capacity and performance of port terminals, increasing their competitiveness. However, proper risk management andconsideration of specific variables are essential to avoid vulnerabilities in technological systems.

Technological progress in ports is closely linked to the pursuit of sustainability and environmentalprotection. The implementation of management models for smart and sustainable ports is crucial today, requiring the collaboration of local stakeholders in pursuit of common improvements in port activities. Theadoption of technologies not only optimizes operations, but also reduces emissions, highlighting the importance of smart ports in speeding up the transfer of goods, tracking ships, statistical transparency improving port quality and capacity, and reducing costs, all from a green perspective. Sustainability becomes an essential axis, addressing issues such as energy efficiency, the application of renewable energysources, emissions control and pollution reduction in various aspects. In addition, the consideration of economic, social, environmental and institutional variables through databases contributes to a more comprehensive assessment. The implementation of sustainable technologies not only benefits ports, but also the surrounding communities, mitigating negative impacts and promoting environmentally friendly practices.

Therefore, the implementation of technologies in smart ports is essential for the optimization of processes in the supply chain and the efficient management of information. Globally, several ports stand out for theirinnovative and competitive approach, such as Shanghai, Rotterdam, Hamburg, Chile, Salerno, Huanghua, Ravenna, Tanger Med, Guadeloupe and Wuhan, which have adopted smart technologies to improve automation, sustainability, operational efficiency and coordination among port stakeholders. The coronavirus pandemic has had a significant impact on international trade and the logistics chain, highlighting the importance of technological adaptation to face crises and guarantee the continuity of port operations. In this context, the construction of smart ports is positioned as a key strategy to boost economicdevelopment, competitiveness and safety in maritime transport.

Research on smart ports has identified several lines of future study. In addition to focusing on specific technologies and its usefulness, additional areas of interest are highlighted. Cyber-security emerges as a priority, exploring measures to protect port technology infrastructure. Interconnection and standardization are presented as fundamental issues to facilitate communication between smart ports. It also

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addresses the socioeconomic impact of these technologies, evaluating their influence on employment and local development.

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