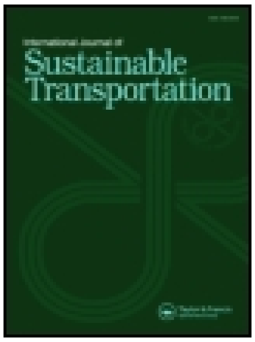

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A framework for building a smart port and smart port index

Anahita Molavi[a], Gino J. Lim[a], and Bruce Race[b]

[a]Industrial Engineering, University of Houston, Houston, TX, USA; [b]College of Architecture and Design, University of Houston, Houston, TX, USA

ABSTRACT

Ports and harbors are facing stiff competition for market share and delivering more effective and secure flow of goods worldwide. High-performing ports are implementing smart technologies to better manage operations meeting new challenges in maintaining safe, secure, and energy efficient facilities that mitigate environmental impacts. In this context, a new concept has emerged which is called *smart port*. However, a unified definition of a smart port has not been well documented. This article attempts to develop a framework for a smart port and a quantitative metric, smart port index (SPI), that ports can use to improve their resiliency and sustainability. Our proposed SPI is based on key performance indicators (KPIs) gathered from the literature. These KPIs are organized around four key activity domains of a smart port: operations, environment, energy, and safety & security. Case studies are conducted to show how one can use SPI and to assess the performance of some of the busiest ports in the world. Our methodology provides a quantitative tool for port authorities to develop their smart port strategies, assess their smartness, and identify strengths and weaknesses of their current operations for continuous improvement. Our study reveals that smart port initiatives around the world have different levels of comprehensiveness. The results of this study also suggest that government policies and region-specific variables can impact SPI value.

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Smart port index; maritime transportation; key performance indicators; resilience; sustainability

1. Introduction

Ports are regional multimodal intersections of global supply chains. They function in the context of complex infrastructure, business transactions, and regulations. With the global economy demanding maritime transportation, ports have faced increasing pressure to optimize their performance in terms of economic, environmental, energy, and functional challenges that impact their sustainability.

Key elements and associated issues include operations (e.g. congestion, delays, operating errors, and lack of information sharing; Braveboy, 2015), environment (e.g. air, water and noise pollution, waste disposal, construction, and expansion activities; Lam & Notteboom, 2014), energy (e.g. increasing energy consumption, increasing energy costs, and energy disruption impacts on the port activities; Abbasi, Barati, & Lim, 2019; Buiza et al., 2015), safety (e.g. berthing impacts, vessel collisions, and striking while at berth; Cho, Lim, Biobaku, & Kim, 2018; Pak, Yeo, Oh, & Yang, 2015), and security (e.g. armed robbery, cyber security issues, unlawful acts, stowaways, drug smuggling, use of ports as conduit for moving weapons, and terrorist attacks; Biobaku, Lim, Bora, Cho, & Parsaei, 2016; Lim, Cho, Bora, Biobaku, & Parsaei, 2018; International Maritime Organization, 2016b). These issues may persist if preventive and corrective actions are not planned and performed in a timely manner. In response to the existing problems, ports are adopting technology-based solutions, as well as new approaches to port operations planning and management. Implementation of such solutions to mitigate recent problems is known to be switching to smart ports.

Our comprehensive literature review reveals two different perspectives of a smart port. One perspective is that the smartness of a port relates more to the ideology rather than technologies and physical infrastructures. In other words, policy decisions and the smart use of resources are more important than the implementation of technologies. Another view of smartness is related to the utilization of recent technologies in order to improve the port performance or provide solutions for energy and environmental issues (PortTechnology, 2016).

Literature review reveals that current smart port initiatives around the world can be categorized into two groups: multipurpose initiatives and targeted initiatives.

1.1. Smart port multipurpose initiatives

This category includes those practices with comprehensive long-term plans and strategies covering various aspects of port activities. These are primarily being conducted by large ports or associations. As a first step, port authorities have detected and evaluated current and possible future problems and have identified solutions for eliminating or avoiding

CONTACT Gino Lim ginolim@uh.edu Department of Industrial Engineering, University of Houston, Engineering Bldg 2, Rm E206, 4722 Calhoun Rd, Houston 77204-4008 TX.
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them. One major common goal is to develop efficient operations and logistics through automation and technology propagation or by modifying strategies and policies (Hamburg Port Authority, 2016b; MedMaritime SMART PORT, 2016; Port of Rotterdam, 2016). Topics related to environment and energy have formed other pillars of these initiatives such as implementing renewable energy, reducing energy consumption, and improving operations to be environmentally friendly (Hamburg Port Authority, 2016a; MedMaritime SMART PORT, 2016; Port of Rotterdam, 2016). This category includes MedMaritime SMART-PORT (MedMaritime SMART PORT, 2016), Port of Rotterdam Smart Port (Port of Rotterdam, 2016), Port of Hamburg Smart Port (Hamburg Port Authority, 2016a, 2016b), Erasmus Smart Port Rotterdam (World Port Hackathon, 2016), and Port of Amsterdam Smart Port (Amsterdam Smart City, 2016; Port of Amsterdam, 2017).

1.2. Smart port targeted initiatives

Smart port targeted initiatives seek to eliminate specific obstacles in ports. These initiatives are largely focused on special-purpose information and communication technology (ICT) applications and regulation-based approaches in the setting of smart ports. ICT contributes significantly to the trend toward smart ports. Ports can take advantage of ICT for improving knowledge sharing and information analysis to increase operations and energy efficiency as well as environmental sustainability.

The City of Hamburg has adopted the SmartPort Solution by AGT International™ (AGT International SmartPort Solution, 2013). This solution includes a port-wide Cisco Wi-Fi real-time locating system (RTLS), which detects RFID tags continuously in the port. This technology recognizes and traces barges in real time. SmartPort Platform is another tool which has a distributed architecture and performs data collection of the port sensors, data visualization, and data analysis. This platform facilitates the processing of big data volumes from the sensors that register environmental parameters and dynamic parameters about the vessels (Fernández et al., 2016). In the private sector, companies such as Kalmar Smart Port and Arelsa Company (Arelsa Co, 2016; Kalmar Global, 2018) offer automation solutions for smart ports. As another instance of technology-dependent solutions, ABB organization (Lama, 2016) markets shore to ship power (onshore power supply) and other reliable, green, and efficient electrification solutions.

The Port Authority of Cartagena has adopted the Posidonia SmartPort application to share instant information about vessel situation, movements, operations, traffic history, and forecasts (Montesinos, 2016). The Port Authority of Singapore (MPA) has employed mobile technology and wireless connectivity to improve efficiency, communications, and crew satisfaction in the Port of Singapore (The Maritime Executive, 2015).

Malaysian and Singaporean ports have implemented Integrated Port Management System (IPMS) which incorporates multiple ports on a single platform (Ngcobo, 2015; The Maritime Executive, 2015). The Kenya Ports Authority (KPA) has automated processes such as time management and payroll functions. Moreover, the KPA runs a security management system that automates all entry and exit points for vehicles and passengers and facilitates yard management with sensors to gain full transparency on the location and movement of containers (Magyar, 2015). In addition to adopting existing technologies, the Port of Singapore and the Port of Rotterdam have held hackathons separately to discuss possible future projects and existing ideas in the area of smart ports (Smart Port Hackathon, 2017; World Port Hackathon, 2016).

In the context of smart ports, there exist regulation-based approaches from the United Nations Conference on Trade and Development (UNCTAD), International Maritime Organization (IMO), and European Union (EU) (The Motorways of the Sea Digital Multi-Channel Platform, 2015). These legislations aim to improve port sustainability, motivate the implementation of new technologies, and provide standards for assessing port performance. Similarly, the U.S. Department of Homeland Security introduced the Smart Port Security Act, which enhances risk-based security measures to prevent threats from reaching the ports (Homeland Security Committee, 2012). Table A.1 shows the overview of smart port practices grouped into two categories of multipurpose and targeted initiatives (see Appendix A).

Despite the recent emergence of the smart port concept, a unified definition of a smart port and its associated key activity domains have not been well addressed in the literature. Therefore, this article aims to propose a smart port definition and its activity domains based on the provided literature and stimulate a path toward smarter ports by providing a formal definition of smart port and its quantitative measure "smart port index" for port authorities. Therefore, this article addresses three research questions:

1. What are a smart port and its activity domains?
2. How are ports performing to meet a typical smart port's objectives?
3. What are the leading factors of the current smartness state of ports?

The remainder of this article is organized as follows. The next section defines a smart port based on the classified literature and identifies its activity domains. Section 3 proposes a collection of KPIs for ports' smartness assessment, develops a smart port index (i.e. SPI), and evaluates major international ports with regard to the definition of a smart port. Note that there were limitations on data availability and we experienced that not all ports publish the required data for calculating all KPIs being discussed in this article. Hence, it was necessary for us to modify the index measurement approach to deal with this limitation for the numerical experiments. However, this should not affect the development of the SPI index.

Section 4 investigates the effect of region-specific variables on the ports' performances by analyzing and decomposing SPI, identifies weaknesses and strengths of each port,

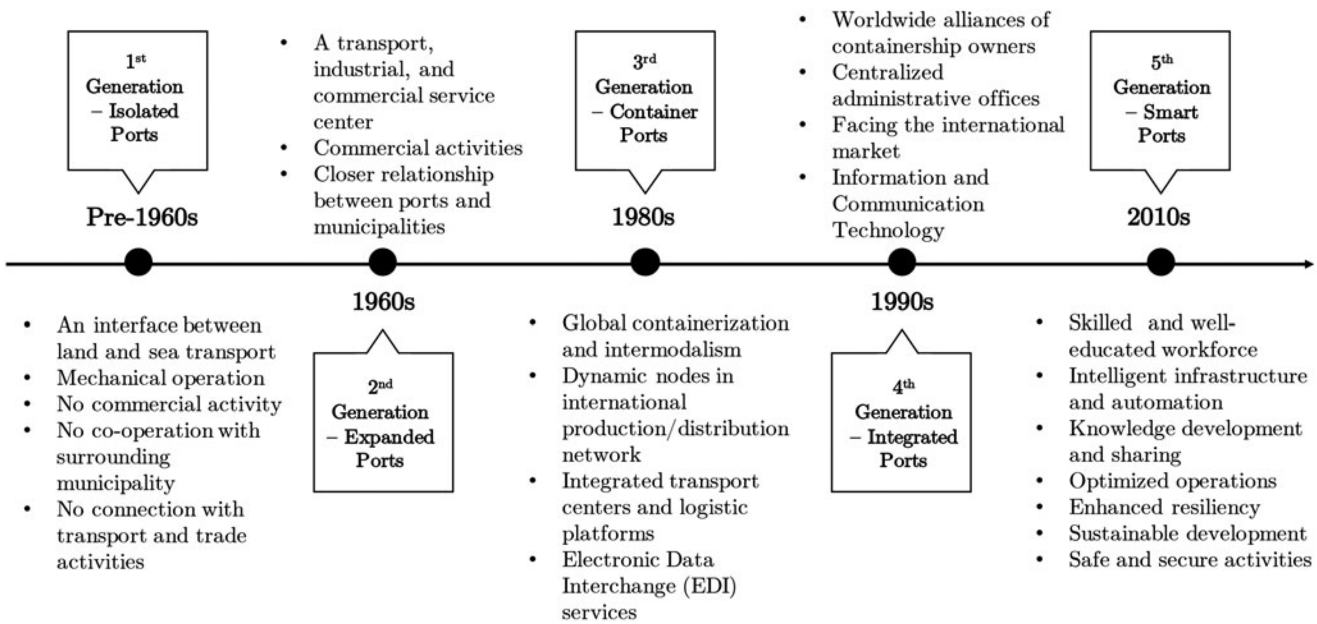

Figure 1. Ports development throughout the history (Barros & Barros, 2013; The Motorways of the Sea Digital Multi-Channel Platform, 2015; UNCTAD, 1992, 1999).

and suggests possible solutions to overcome deficiencies they may have. Finally, Section 5 concludes this article and provides possible future research directions.

2. Smart port: Definition and activity domains

2.1. Smart port definition

Sporadic efforts have been made for developing a smart port. However, an internationally accepted and standard definition for the word "smart" does not exist in the context of ports and maritime industry. Tracking the genealogy of the word "smart" in similar areas assists us in the understanding of why this term has emerged.

In the technology setting, smartness refers to the automatic computing principles such as self-configuration, self-protection, self-healing, and self-optimization (Spangler et al., 2010).

In the urban planning field, smart growth emerged during the 1990s as a potent government- and society-driven reaction to exacerbating trends in the loss of open space, air pollution, obliteration of historic places, traffic congestion, and increasing public facilities cost (Nam & Pardo, 2011). The term "smart growth" refers to an approach (public or private) to managing development that leads to economic advancement without the congestion and environmental degradation. Smart City maximizes services to citizens while monitoring and integrating critical infrastructures, planning preventive maintenance actions, optimizing resources, and monitoring security aspects (Hall et al., 2000). Governments and public agencies at all levels are embracing the notion of smartness to characterize their new policies aiming for sustainable development, sound economic growth, and better quality of life for citizens. Being smart involves strategic directions and is associated with achieving policy success (Center on Governance, 2003). Smart homes, buildings, airports, hospitals, and ports are equipped with mobile terminals, embedded devices, sensors, and actuators (Moss Kanter & Litow, 2009).

Additionally, comparing the application of potential alternatives to the word "smart" clarifies that it is the right choice to thoroughly describe the concept. Borrowing the word choice philosophy from the Smart City field (Nam & Pardo, 2011), we can say that the digital port describes a connected port that combines broadband communications infrastructure, flexible and service-oriented computing infrastructure, and innovative services to meet demands. An intelligent port has all the infrastructure and info-structure of information technology and the most recent technologies in telecommunications, electronic, and mechanic. A knowledge port is designed to encourage the nurturing of knowledge. A humane port has multiple opportunities to utilize its human potential and lead creative processes.

However, the port that we have in mind entails all the above aspects as well as the traditional port services and specifications (Figure 1). A smart port gathers better-educated individuals, skilled workforces, intelligent infrastructures, and automation to facilitate knowledge development and sharing, optimize the port operations, enhance the port resiliency, lead a sustainable development, and guarantee safe and secure activities. It is sensible that the term "smart port" has prevailed among the public and private sectors to describe the trend. In what follows, we present the activity domains of a smart port that we have identified by classifying the smart port initiatives (Table 1). These domains and subdomains categorize and include different smart port initiatives covered so far and the associated smart port initiative is referenced in the right column.

2.2. Smart port activity domains

According to Table 1, a smart port consists of four main activity domains: operations, environment, energy, and

Table 1. Classification of a smart port activity domains and subdomains.

Domains	Subdomains	Description	References
Operations	Productivity	The extent to which the port operations are carried out efficiently within the limits of time, budget, space, and available facilities	MedMaritime SMART PORT (2016), Hamburg Port Authority (2016b), Port of Rotterdam (2016), and Port of Amsterdam (2017)
	Automation	Automation is the use of various control systems (set of devices that manages the behavior of other devices or systems) for operating equipment with minimal or reduced human intervention.	MedMaritime SMART PORT (2016), Hamburg Port Authority (2016b), Kalmar Global (2018), and Magyar (2015)
	Intelligent infrastructure	Intelligent infrastructure means the use of technologies, both hardware and software, in the port with the aim to increase efficiency and sustainability.	MedMaritime SMART PORT (2016), Hamburg Port Authority (2016b), Port of Rotterdam (2016), Arelsa Co (2016), Montesinos (2016), The Maritime Executive (2015), The Motorways of the Sea Digital Multi-Channel Platform (2015) and Fernández et al. (2016)
Environment	Environmental management systems	Environmental management systems (EMS) are means to help organizations to improve their environmental performance. This aim is achieved through observing and controlling port operations with regard to their environmental impacts.	MedMaritime SMART PORT (2016) and Hamburg Port Authority (2016b)
	Emissions and pollutions control	Port activities and shipping industry can cause three major types of pollution: emissions to air, noise pollution, and water pollution.	MedMaritime SMART PORT (2016), Hamburg Port Authority (2016a), Hamburg Port Authority (2016b), and The Motorways of the Sea Digital Multi-Channel Platform (2015)
	Waste management	Ports receive a noticeable amount of waste, sources of which are port activities and vessels.	MedMaritime SMART PORT (2016), Hamburg Port Authority (2016a), Hamburg Port Authority (2016b)
	Water management	Water is a vital resource for both human and other species health, so monitoring and controlling the water quality should be part of port plans and strategies.	MedMaritime SMART PORT (2016), Hamburg Port Authority (2016a), Hamburg Port Authority (2016b)
Energy	Efficient energy consumption	Several factors influence the energy consumption of a port. These elements could be divided into two categories, direct and indirect energy users. For both groups, saving possibilities should be identified.	MedMaritime SMART PORT (2016), Hamburg Port Authority (2016a), Hamburg Port Authority (2016b)
	Producing and use of renewables	Renewable energy is replenishable energy that is generated from natural processes. There are significant possibilities of renewable energy implementation in the ports. This assists in partially or totally covering the port energy demand and significantly reduces pollutions.	MedMaritime SMART PORT (2016), Hamburg Port Authority (2016a), Hamburg Port Authority (2016b), and The Motorways of the Sea Digital Multi-Channel Platform (2015)
	Energy management	Ports should identify energy management strategies and activities to make efficient use of the available energy.	MedMaritime SMART PORT (2016), Hamburg Port Authority (2016a), Hamburg Port Authority (2016b)
Safety and security	Safety management systems	Safety Management System (SMS) is a comprehensive business management system designed to administer safety principles in the workplace.	MedMaritime SMART PORT (2016) and The Motorways of the Sea Digital Multi-Channel Platform (2015)
	Security management systems	A security management system identifies potential threats to the port and establishes, implements, monitors, reviews, and maintains all appropriate actions to provide assurance for the effective handling of security risks.	MedMaritime SMART PORT (2016) and The Motorways of the Sea Digital Multi-Channel Platform (2015), and Homeland Security Committee (2012)
	Integrated monitoring and optimization systems	Establishing an integrated monitoring and optimization system based on the most recent software and hardware facilitates achieving enhanced security and safety in the port area.	Magyar (2015)

safety and security. One can assess the port performance in those domains by studying measurable elements which we call "subdomains" of a smart port and we explain them in more detail.

2.2.1. Operations

Ports receive different types of vessels including containerships, cruise vessels, tankers, RoRo ships, auto carriers, bulk carriers, and refrigerated vessels (reefers). The main operation of the port is to load and unload these vessels and handle the process of transporting the cargo to warehouses or other destinations. A smart port utilizes technologies along with adopting innovative and efficient management models to increase the productivity of port operations and minimize associated costs. Subdomains of smart port operations include productivity, automation, and intelligent infrastructure (Table 2).

2.2.1.1. Productivity. The global containership fleet capacity will increase by 1685187 TEUs or 8% by 2019, which as a high growth rate clarifies the vitality of improving port

Table 2. Operations: smart port activity subdomains.

Smart operations		
Productivity	Automation	Intelligent infrastructure
Berth productivity	Automated stack	Integrated information systems and software
Infrastructure productivity	Automated path	Hardware
Land productivity	Automated rail	
Size and use of maximum capacity	Automated lift	
Lines calling at the port	Automated trucks	
Capacity for receiving large vessels	Automated quay	
Level of intermodality		

productivity which affects country's productivity to a large extent (Statistia, 2017). The productivity of a port operation could be assessed through measuring productivity in seven areas: berth productivity, infrastructure productivity, land productivity, capacity for receiving large vessels, size and use of maximum capacity, the level of intermodality, and lines calling at the port (MedMaritime SMART PORT, 2016).

2.2.1.2. Automation. Automatized machinery can replace the human workforce in ports and reduce existing human errors, safety issues, port congestions, and turnaround time as well as increasing operations efficiency (MedMaritime SMART PORT, 2016).

2.2.1.3. Intelligent infrastructure. Intelligent infrastructure (both hardware and software) in ports can increase efficiency and sustainability by real-time data collection, processing, and sharing. Information regarding traffic flow of both vessels and hinterland transportation vehicles, closure times of movable bridges and other infrastructure information, the situation at the container terminals and other major operations (e.g. empty container depots), and parking facilities should be available to port users (Hamburg Port Authority, 2016b). The fast and easy flow of this information facilitates wise and well-informed decision making by port authorities and port customers. This ultimately brings increased productivity, fewer costs, high market competition ability for the port, less emission, energy efficiency, and green logistics. With reference to the current smart port's best practices, implemented intelligent infrastructures in the ports are: sensors, GPS/DGPS, RFID/OCR/LPR, GNSS, DGNSS, TOS, Bluetooth, WLAN, mobile devices, the Cloud, port community systems, port monitor system, port road management system, intelligent railway, smart maintenance, vessel traffic management, parking space management, and gate management.

2.2.2. Environment

Ports can be the source of environmental pollution through land and sea transportation and industrial activities. For the purpose of this research, we focus on the following environmental impacts of port activities: emissions to air, noise pollution, water pollution and consumption, and waste generation. These environmental issues reduce social welfare and pose a threat to the survival of living creatures; thus, they cause critical challenges for port managers and menace the ports' endurance in the future competitive era. Smart ports seek solutions to existing environmental problems. We can evaluate the port efficiency in this domain by investigating the port environmental management systems (EMS), pollution reduction activities, and water & waste management.

2.2.2.1. Environmental management systems. Environmental management systems (EMS) offer a framework for evaluating, monitoring, and reducing port environmental impact. The International Organization for Standardization (ISO) has developed the most commonly used framework for an EMS, the ISO 14001 standard. According to ISO 14001, the five main stages of an EMS are as follows: commitment and policy, planning, implementation, evaluation, and review (The United States Environmental Protection Agency, 2016). Two well-known EMS examples include EU Eco-Management and Audit Scheme (EMAS) and Environmental Review System (PERS). EMAS was developed by the European Commission as a means for every organization and organization type to evaluate, report, and improve their environmental performance (European Commission, 2017). PERS is a port-specific environmental management standard developed by EcoPorts. PERS incorporates the main requirements of well-known environmental management standards (e.g. ISO 14001) as well as the specificities of ports (EcoPorts, 2018).

2.2.2.2. Air emission control. The main air pollutants from port activities are CO_2, SO_2, NO_x, Particulate Matter ($PM_{2.5}$ and PM_{10}), HC, CO, and VOC. Air pollution damages the natural environment and can cause harm to human health and other living species. Shipping-related particulate matter (PM) is one of the most dangerous air pollutants and was responsible for approximately 60,000 cardiopulmonary and lung cancer deaths in 2007 (Corbett et al., 2007). In addition, increasing amounts of greenhouse gases can lead to climate change, ozone layer disruption, and more acid rain. There exist many solutions to decrease emissions such as implementing alternative fuels and zero emission technologies for vessels and land transportation means in ports.

2.2.2.3. Noise pollution reduction. Noise pollution in ports is generated from ferries, ships, industrial activities, shipyard activities, and auxiliary services. This noise pollution can negatively impact the natural eco-system and the urban population (Schenone, Pittaluga, Repetto, & Borelli, 2014). Hence, effective actions should be designed and performed for evaluating, monitoring, and reducing noise pollution at ports.

2.2.2.4. Waste management. Ports receive a noticeable amount of waste, sources of which are port activities and vessels. Categorization of ship-generated waste has been established by IMO in the MARPOL 73/78 Convention. According to this convention, six major types of wastes are produced by the vessels: oily waste, bulk chemical waste, noxious substances, packaged form, sewage, and garbage.

Table 3. Energy: smart port activity subdomains.

Smart Energy		
Efficient energy consumption	Use of renewables	Energy management
Energy consumption by containers	Wind energy	Energy management systems
Energy consumption by fleet	Solar power	Monitoring and optimization of energy consumption
Energy consumption by lighting	Biomass energy	
Energy consumption by terminal equipment for movement of containers	Wave and tidal energy	
Energy consumption by offices and companies	Efficient use of solar and electric transportation	

The same categories can be considered for grouping the port-generated waste (Olson, 1994). Each of the mentioned types of waste can have environmentally harmful effects if action plans are not devised for handling, recycling, reception, and reducing them to standard amounts.

2.2.2.5. Water management. Wastewater from port activities is one of the major environmental concerns since seaports are often situated near residential communities or environmentally sensitive locations. High organic concentration in wastewater assists the growth of different types of bacteria. Wastewater assessment and reduction methods should be implemented in order to reduce the amount of pollutants in the water. In addition to wastewater handling, another issue is the high water consumption of port activities, such as the cooling process. This water is either drawn directly by the port companies themselves (from surface, ground, or rain water) or supplied by the water companies. Limited sources of water and rising costs have led to the idea of reducing water consumption.

2.2.3. Energy

The port and its logistics are large consumers of energy. Along with the development of ports, the rise in the demand for maritime transportation, and the increase in industrial activities in ports, the demand for energy further increases. Taking into account the limitation of energy sources and port budget, smart port considers approaches to decrease energy consumption. It also suggests the use of renewable energies to both reduce emissions and become independent in terms of energy sources (Port of Rotterdam, 2016). The subdomains consists of the use and production of renewable energy, efficient energy consumption, and adopting energy management systems (Table 3).

2.2.3.1. Efficient energy consumption. Energy consumers in ports can be divided into two categories: direct and indirect energy consumers. Direct consumers of energy include the lighting system of the port terminal area, offices and other facilities, the office buildings, and the facilities of the garage. Indirect consumers are those with more seasonal consumption patterns. In other words, they depend on the volume of port activities. Indirect consumers include cranes, the internal fleet of the port, and the reefers (MedMaritime SMART PORT, 2016). Improving the processes and equipment to require less energy and avoid energy loss leads to more efficient energy consumption and lower costs.

2.2.3.2. Production and use of renewables. Possibilities of implementation of renewable energies are huge in the ports. This assists covering partially or totally the port energy demand. Sources of renewable energy that can be developed in ports are wind technology (off-shore or installed in the terminal area for electric cranes and forklifts), small wind (incorporated in buildings to satisfy the energy demand of offices, garage facilities, and electric vehicles), photovoltaic technology (incorporated in buildings to satisfy the energy demand of offices, garage facilities, and electric vehicles), biodiesel (to provide fuel to internal fleet), and marine technologies (wave and tidal energy conversion to electricity for electric cranes and forklifts) (MedMaritime SMART PORT, 2016).

2.2.3.4. Energy management. Energy management systems provide ports with a systematic approach to achieve continuous improvement in energy performance. In this regard, ISO 50001, an international standard for energy management systems, specifies the requirements for designing, applying, maintaining, and enhancing an energy management system. Implementation of ISO 50001 can result in energy performance improvement and energy costs reduction (International Maritime Organization, 2016a). In addition to energy management systems, ports can optimize energy consumption by continuous monitoring and controlling energy consumption of different activities. An integrated information processing and visualization system in the port assists with reaching this goal.

2.2.4. Safety and security

Ports are vulnerable to several safety and security issues, which can potentially cause a loss in terms of benefits, port reputation, and the efficiency of operations (Fabiano, Curro, Reverberi, & Pastorino, 2010). Direct attacks by terrorists, utilization of ports as a conduit for the movement of weapons (Altiok, 2011), natural hazards, and inherent risks in the port activities associated with safety and security are the prominent issues in this area. For example, ports can be exposed to both high-frequency low-severity events (occupational risk) and low-frequency high-severity events (major accident risk) (Mokhtari, Ren, Charles, & Wang, 2012; Vairo, Quagliati, Del Giudice, Barbucci, & Fabiano, 2017). Smart port uses solutions such as regulations, standards, employee training, periodic control of facilities, risk assessment, proper designs, and monitoring systems to detect any security issue, increase port preparedness, and improve

Table 4. Information on the collected KPIs.

	Study				
Category	MedMaritime SMARTPORT	Anto, P. et al.	Maigret, A. et al.	Perera, M. A. P. et al.	Total number of KPIs
Operations	✓	✗	✗	✓	29
Environment	✓	✗	✓	✓	27
Energy	✓	✗	✓	✓	17
Safety and Security	✓	✓	✗	✗	15

resilience. Overall port performance in this sense is measurable through exploring port safety management systems, security management systems, and integrated monitoring and optimization systems.

2.2.4.1. Safety management systems. Safety management system (SMS) is a systematic and comprehensive process for managing safety risks and is composed of policy, organizing, designing, applying, assessment, and improvement. The system also contains manuals, training, and standards. SMS is applicable to port activities and vessel operations. As another approach to ensure safety at ports, IMO has developed the International Safety Management Code (ISM). In addition to this code, IMO requires all international passenger ships, oil tankers, chemical tankers, gas carriers, bulk carriers, and cargo ships of 500 gross tons or more to implement a SMS.

2.2.4.2. Security management systems. Security management systems identify potential threats to the port and establish, implement, monitor, review, and maintain appropriate actions to effectively handle security risks. Implementation of a security management system will ensure resilience in the face of danger and optimization in terms of cost and loss. Ports need to identify both their assets and possible external and internal threats, perform risk analysis and risk management, and increase the preparedness and awareness of employees. In the meanwhile, steady monitoring and policy evaluation is required to have an up-to-date security management system. International Ship and Port Facility Security Code (ISPS) is introduced by IMO for enhancing security at the ports.

2.2.4.3. Integrated monitoring and optimization systems. Establishing an integrated monitoring and optimization system based on the most recent software and hardware enhances security and safety in the port area. This includes mainly connecting hardware such as cameras, wireless technology, sensors, RFID tags, and software for data gathering, visualization, analysis, and optimization. Storing the data and analyzing it brings several benefits: real-time information sharing among different port sectors, identification of preventive actions, increased preparedness, effective decision making in the face of unpredicted events, and hence, the resiliency of the port operations.

3. Smart port index (SPI)

In this section, we introduce a methodology to assess the smartness of a port and develop a rubric as a single index value to capture the port smartness. First, we reviewed the existing key performance indicators (KPIs) in the literature for evaluating the port performance. Four indices were found to be important for measuring smart port performance in its activity domains: operations, energy, environment, and safety and security. Thus, our proposed SPI is a convex combination of these four indices. The SPI can facilitate early detection of deficiencies in any of the four measurement areas to make correctional actions, or help expedite the improvement of port performance. Furthermore, ports can use the SPI to evaluate themselves and know where they stand in comparison to other ports. They can also use the outcome measures to develop strategic and operational decisions to stay competitive in the global market of maritime transportation.

3.1. Key performance indicators

The first step toward measuring the SPI is to identify a comprehensive set of KPIs for quantifying port performance in each smart port activity domain. Tables A.2–A.5 show the KPIs we collected from the literature for measuring port performance (see Appendix A). We have adopted KPIs from several sources, as shown in Table 4 (Antão et al., 2016; Maigret, 2014; MedMaritime SMART PORT, 2016; Perera & Abeysekara, 2016). We borrowed all the 68 KPIs of MedMaritime Smart Port: 26 KPIs related to SOI subdomains, 2 KPIs for SSSI, 16 KPIs for quantifying SEgI, and 24 KPIs related to SEnI. Then, we selected and added the remaining KPIs from other related sources to enhance the capability of the SPI in measuring all the smart port domains and subdomains.

3.2. SPI formulation

The performance of a smart port is quantifiable through four indices we present here: Smart Operations Index (SOI), Smart Energy Index (SEgI), Smart Environment Index (SEnI), and Smart Safety and Security Index (SSSI). Because the range of values can be quite different from one KPI to the next, the values must be rescaled so that the KPI values are comparable in the combined SPI. Standardization and normalization are the two common approaches for rescaling the data. In normalization, the data are modified to take values between 0 and 1 (Equation (1)). Normalized data are calculated by Equation (1) in which x is the original data, $x_{\min}$ is the minimum x value in the data set, and $x_{\max}$ is the maximum x value.

$$x_{\text{normalized}} = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \tag{1}$$

The normalization maps the data to positive values, while standardization may result in negative values. In this article, the normalization equation (Equation (1)) is used to transform the original data. The KPIs can be modified in such a way that if a higher KPI value is preferred, the normalized value can be used as is. But, if less value for the KPI is preferred, the KPI value can be multiplied by −1 (see Equation (2)). For instance, higher values of port productivity (e.g. annual throughput) and lower values of air emission (e.g. total annual air emission) are more desirable. So, we keep positive the productivity value but we multiply the air emission value by −1. As a result, the positive productivity value increases the total SPI while the negative emission value reduces it. Each of the four indices (SOI, SEgI, SEnI, and SSSI) is calculated as a function of the relevant KPIs (Equations (3)–(6)). For instance, in Equation (3), α_i's take positive values and the summation of them should be equal to 1. Hence, SOI is calculated as the convex combination of the modified KPIs. Equations (4) through (6) have the same structure as Equation (3). Finally, SPI is quantified using Equation (7). Note that j refers to the smart port activity domains, i.e., $j \in \{1\text{: operations, } 2\text{: energy, } 3\text{: environment, } 4\text{: safety and security}\}$, the rescaled value of ith KPI of j^{th} category is k_{ij} (n_i is number of KPIs for measuring port performance in i^{th} smart port activity domain) and the signed value of i^{th} rescaled KPI of j^{th} category is k'_{ij}.

$$k'_{ij} = \begin{cases} -k_{ij}, & \text{lower values of } k_{ij} \text{ are preferable} \\ k_{ij}, & \text{higher values of } k_{ij} \text{ are preferable} \end{cases} \quad (2)$$

$$\text{SOI} = \sum_{i=1}^{n_1} \alpha_i k'_{1i}, \quad \sum_{i=1}^{n_1} \alpha_i = 1, \quad \alpha_i \geq 0, \forall i = 1, \ldots, n_1 \quad (3)$$

$$\text{SEgI} = \sum_{i=1}^{n_2} \beta_i k'_{2i}, \quad \sum_{i=1}^{n_2} \beta_i = 1, \quad \beta_i \geq 0, \forall i = 1, \ldots, n_2 \quad (4)$$

$$\text{SEnI} = \sum_{i=1}^{n_3} \gamma_i k'_{3i}, \quad \sum_{i=1}^{n_3} \gamma_i = 1, \quad \gamma_i \geq 0, \forall i = 1, \ldots, n_3 \quad (5)$$

$$\text{SSSI} = \sum_{i=1}^{n_4} \delta_i k'_{4i}, \quad \sum_{i=1}^{n_4} \delta_i = 1, \quad \delta_i \geq 0, \forall i = 1, \ldots, n_4 \quad (6)$$

$$\begin{aligned} &\text{SPI} = \lambda_1 \text{SOI} + \lambda_2 \text{SEgI} + \lambda_3 \text{SEnI} + \lambda_4 \text{SSSI}, \\ &\sum_{i=1}^{4} \lambda_i = 1, \quad \lambda_i \geq 0, \forall i = 1, 2, 3, 4 \end{aligned} \quad (7)$$

Each of the SPI indices mentioned above (Equations (3)–(7)) requires the values for weight parameters, e.g. $\alpha, \beta, \gamma, \delta, \lambda$. These values must be provided to the equations beforehand, and they can be determined by expert opinions. Analytic hierarchy process (AHP) or Analytic network process (ANP) are two common methods to calculate the weight parameters and this calculation is beyond the scope of this article (Ben-Arieh, 2002; Saaty, 2013; Velasquez & Hester, 2013).

Since KPIs are normalized as in Equations (1) and (2) for the purpose of index calculations, each resulting KPI can take a value between −1 and 1. According to Equations (3) through (6), all indices are convex combinations of the associated scaled KPIs; hence, they also range between −1 and 1. As a result, the SPI values are in the range of [−1,1].

4. Using SPI to evaluate and compare international port performance

4.1. Comparison of fourteen international ports

Fourteen ports are selected among the world's busiest ports in terms of numbers of annual TEUs. The selection of the ports is based on two criteria: the availability of the data from the related port authority website and diversity in terms of ports locations.

4.1.1. Data collection and SPI measurements

We have collected relevant data for fourteen ports from their websites to illustrate the use of the proposed method. We have experienced that not all ports publish the necessary data to calculate all KPIs discussed in this article, but we were able to obtain publicly available data to compute 8 KPIs (see Appendix, Table A.2, KPIs 1, 3, 5, 7, 9, 11, 22, and 23). These KPIs are all related to measuring *Productivity*, SOI. Thus, we modified the index measurement approach presented in the previous section to quantify other activity domains as follows: if the port has stated and explained related activities to each smart port activity domain in the port website, we have assigned the value of 1 to the subdomain index value, and for those areas that are not mentioned in the website, we have not assigned any value. For instance, for measuring SOI, we can calculate the *Productivity* by KPIs (e.g. annual throughput (TEU/meter of container quay)), but the data is not available for quantifying the *Automation* and *Intelligent Infrastructure*. So, if the port website mentions ongoing activities in these two areas, we assign the value of 1 to each. For increasing the preciseness of this modified approach, we divided *Intelligent Infrastructure* into two categories of *Software (IIS)* and *Hardware (IIH)*. We also divided *Integrated Monitoring and Optimization Systems* into two categories of *Integrated Monitoring Systems for Safety* and *Integrated Monitoring Systems for Security*.

There are four categories ($n_1 = 4$) in calculating SOI (*Productivity, Automation, IIS, and IIH*) in Equation (3). By assuming equal weights among these categories, the value of α_i is 1/4, for $i \in \{1, 2, 3, 4\}$. For computing SEgI (Equation (4)), there are three categories (i.e., low energy consumption, producing/use of renewables, and energy management); hence, $n_2 = 3$ and $\beta_i = 1/3$ for $i \in \{1,2,3\}$. Categories included in Equation (5) are environmental management system, emissions and pollution control, waste management, and water management; $n_3 = 4$ and $\gamma_i = 1/4$ for $i \in \{1,2,3,4\}$. Regarding safety and security index quantification (Equation (6)), there are four categories (i.e. safety management system, security management system, integrated monitoring system for safety, and integrated monitoring system for security); $n_4 = 4$ and $\delta_i = 1/4$ for $i \in \{1,2,3,4\}$. Putting these all together, the SPI index is calculated as in Equation

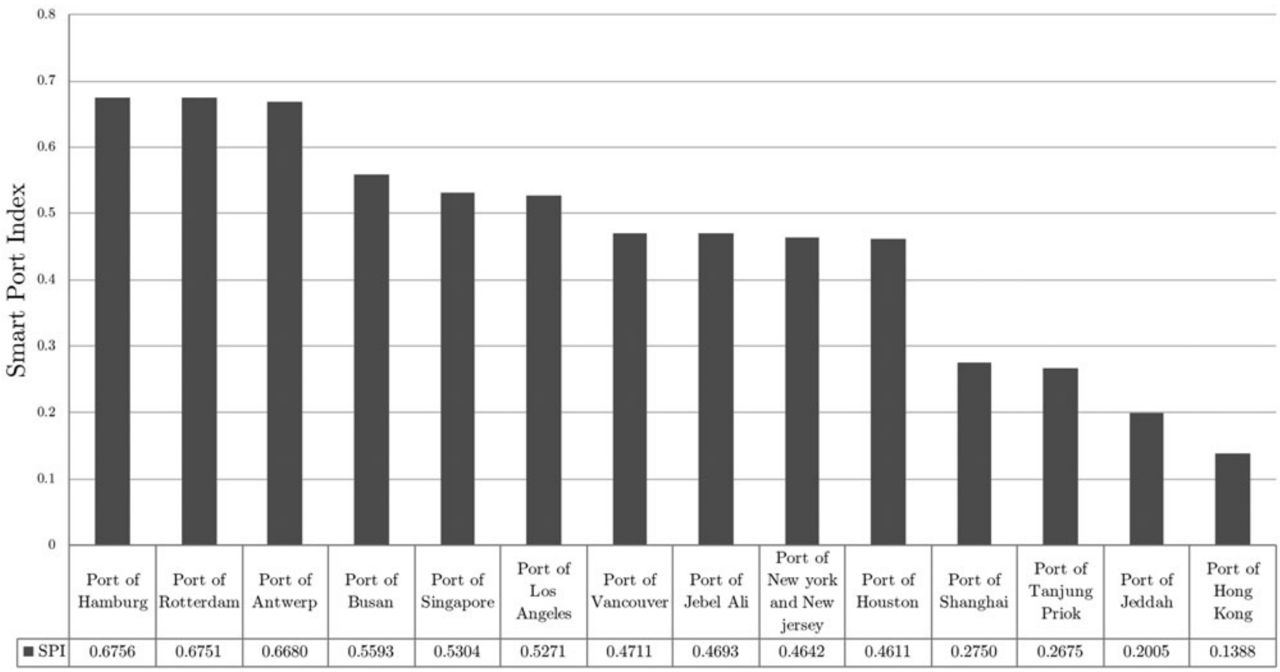

Figure 2. Comparison of Smart Port Index for 14 ports.

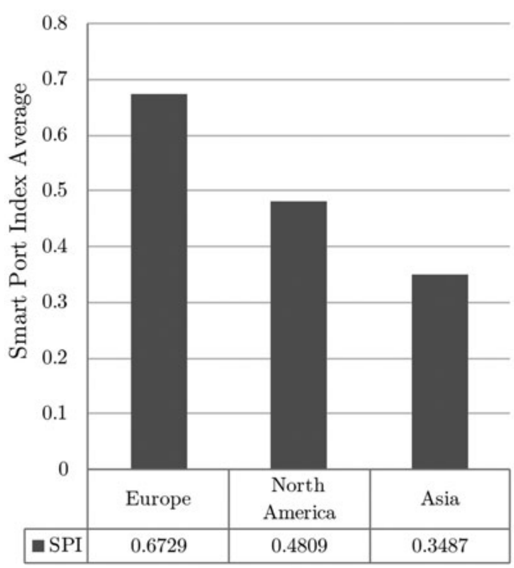

Figure 3. SPI by region.

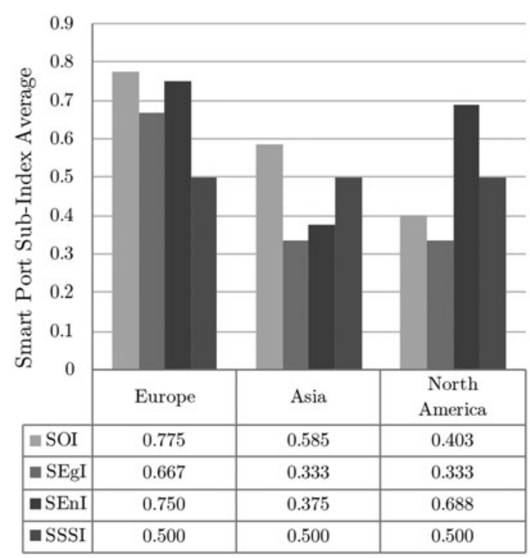

Figure 4. Smart subindices by region.

(7) by assuming equal parameter weights. The other measurement steps in this example are the same as the approach outlined in Section 3 and SPI values take values in the range of [−1,1].

4.1.2. Effects of region-specific variables on the smartness of the ports

The data analysis in our study has three objectives: to calculate and compare index values of the selected ports, to analyze why a port received the associated score, and to make suggestions for improving port performance. In this numerical example, the Hamburg Port Authority received the highest SPI value of 0.6756, while the Port of Hong Kong received the lowest SPI value of 0.1388 (Figure 2). Moreover, our approach reveals that ports have paid different levels of attention to each smart port activity domain (see Appendix A, Figure A.1). For instance, the Port of Singapore has initiated and declared more smart actions in the port operations than the environment, while in the Port of Jeddah, smart actions have penetrated more in safety and security than in operations.

The second step of the empirical study is to find the causes of the varied index values. We analyzed the impact of the geographical (Figures 3 and 4), economic, political, and energy-related factors on the port smartness (Table 5). On average, European ports seem to be more conscious about factors included in the SPI calculation as compared to Asian ports (Figures 3 and 4). We can observe that there exists a meaningful correlation between the smart port interventions

Table 5. Regression analysis showing the effect of region-specific variables on SPI ($\alpha = 5\%$).

Variable	GDP per capita ($ thousands/ # of inhabitants)	R&D expenditure (% of GDP)	Energy intensity of the economy (kg of oil equivalent/GDP)
Coefficient	0.0086	0.0026	−0.0019
p-value	0.0129	0.0196	0.0003
R-square	0.5154	0.4715	0.7904

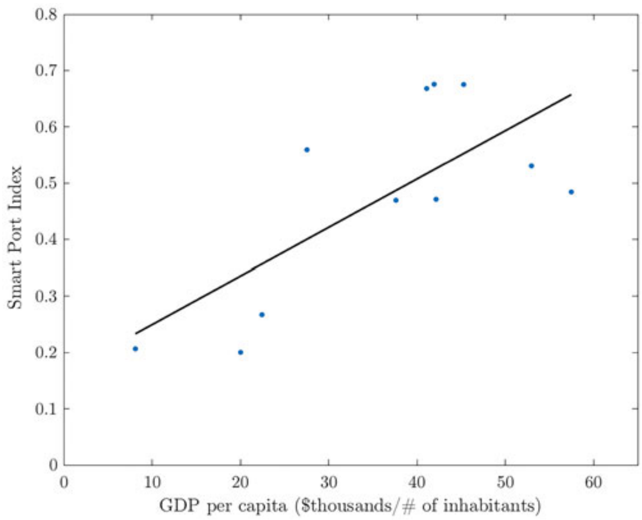

Figure 5. GDP effect on SPI value.

in environmental and energy-related aspects and geographical variables; European ports have expressed greater interest in eliminating port environmental and energy-related issues than Asian and North American ports. Asian ports have high SOI values and have shown greater tendency to increase the productivity and enhance port operations compared to the other smart port activity domains (Figure 4).

To measure the effect of economic and energy-related factors on the SPI value, we considered country gross domestic product (GDP) per capita, R&D expenditure per capita, and energy intensity of the economy. The selection of these variables was based on data availability (data source: The World Bank (2017)). We performed linear regression analysis to study the correlation between each variable and the SPI value. Positive regression coefficients show the positive correlation between the variable (and so the factor) and SPI. On the other hand, negative coefficients indicate a negative correlation between them.

Figures 5–7 visualize the effects of GDP, R&D expenditure, and energy intensity of the economy on the SPI values by linear regression. In Figure 5, we observe that there is a positive correlation between port SPI value and country GDP per capita. This indicates that ports located in wealthier countries have higher SPI values. Figure 6 shows a positive correlation between country R&D expenditure per capita and the port SPI value. We can interpret that if a country is more open to innovation and higher education systems, then the country's ports are more interested in the implementation of new technologies and innovative approaches. Figure 7 visualizes a negative correlation between the amount of energy consumption in the country

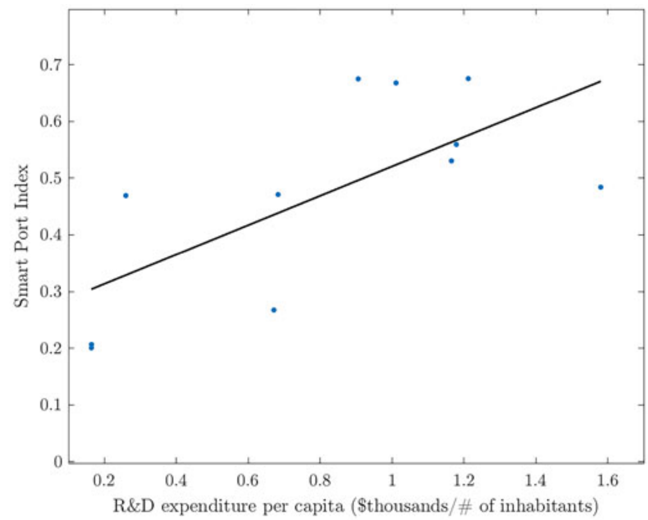

Figure 6. R&D expenditure effect on SPI value.

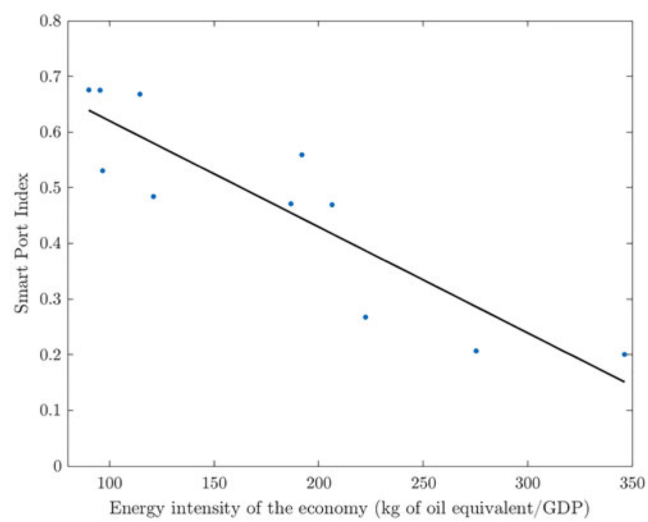

Figure 7. Energy intensity of the economy effect on SPI value.

per GDP and SPI. Higher energy intensity values indicate that higher industrial output and effort were required for production and service. This means either the industries in the country are not productive or energy efficient. We can observe how SPI value reduces as the energy intensity increases in Figure 7.

5. Conclusion

Smart port is a wide concept that encompasses various aspects of port activities. However, it has so far received limited attention from academic researchers. Despite the recent growing interest in the topic, efforts are required to identify benchmarks at the international level and to find improvement opportunities in ports. In this scenario of limited empirical evidence and hype on smart ports, this article can be considered the first attempt to provide a comprehensive definition of a smart port and an empirical assessment of current trends at the international level. To this end, four main activity domains (i.e. operations, energy, environment, and safety and security) and the related subdomains of a smart port were identified based on smart port best practices; afterward, the Smart port index was developed as the convex combination of the subindices.

Index calculation is achieved mainly through measurement of the KPIs collected from the literature. The numerical example included the study of 14 ports selected among the top 100 busiest ports in the world in terms of the total number of annual TEUs. Note that we have experienced limited availability of data for some KPIs described in this article. Port selection criteria were the availability of data given on the ports websites and diversity in the location of the ports. After index measurements, an analysis was conducted in order to understand the relationship between the geographical, governmental, economic, and energy-related variables, and the dependent SPI variable. It was noticed that regional variables and government policies can affect the port performance and that in general, ports located in countries that are wealthier, open to innovation, environmentally-friendly, and energy efficient have higher SPI values.

In the process of achieving the above results, the article explains two issues. First, current smart port initiatives have different pillars, some of which overlap. Some of the ports are conducting multipurpose projects, while the others have targeted special areas such as ICT penetration into the port operations. It has been noticed that European ports have relatively comprehensive approaches and they are more conscious about port environmental and energy aspects in comparison to the other ports. This can be traced back to the environmental standards that the European Union mandates different organizations to follow (European Union, 2017). In this study, we attempted to conceptualize a smart port that includes various aspects of port activities and incorporates important areas of concern such as the environment or energy.

Second, adequate information and data for quantifying ports smartness are not available. This is due to either port policies and their reluctance to share the detailed information or the lack of focus on some smart port activity domains. We reduced the impact of this limitation on the results by selecting ports with the highest level of data availability and modifying the indices computation approach.

For future research, one can investigate other possible activity domains to be included in the smart port concept such as sustainability, human resources (e.g. knowledgeable employees, creativity, training opportunities), and institutional aspects (e.g. corporate governance, harmony with the community, supply chain partnerships). Moreover, if one has access to more comprehensive data for computing more KPIs, the empirical research can be extended to enhance the analysis presented in this article. Furthermore, there is a need to further explore both the barriers of implementation and impacts of a smart port on the related matters; for instance, we can target topics such as the impact of smart ports on traditional institutional and human factors and the influence of smart ports on cities and the surrounding municipalities.

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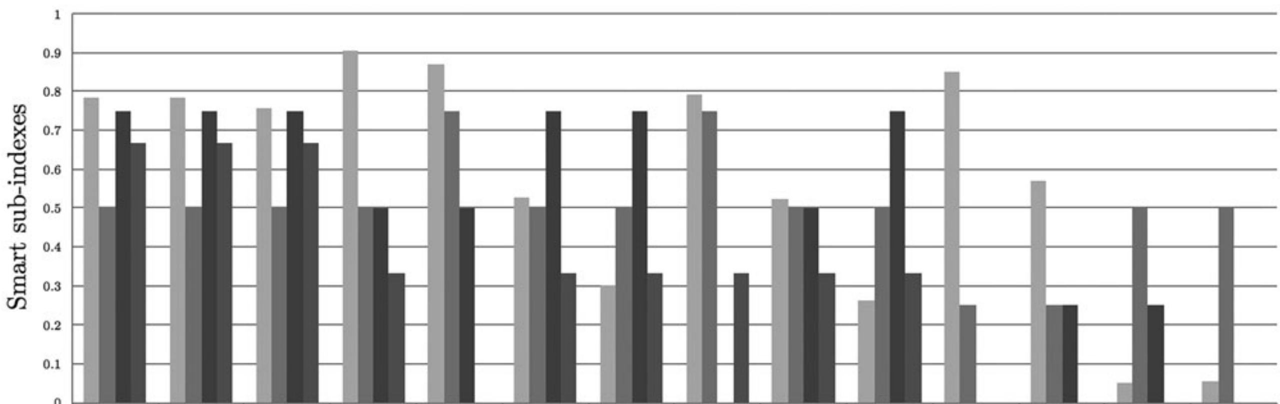
A. Appendix

(See Figures A1 and Tables A.1–A.5)



	Port of Hamburg	Port of Rotterdam	Port of Antwerp	Port of Busan	Port of Singapore	Port of Los Angeles	Port of Vancouver	Port of Jebel Ali	Port of New york and New jersey	Port of Houston	Port of Shanghai	Port of Tanjung Priok	Port of Jeddah	Port of Hong Kong
SOI	0.786	0.784	0.755	0.904	0.871	0.525	0.301	0.794	0.523	0.261	0.850	0.570	0.052	0.055
SSSI	0.500	0.500	0.500	0.500	0.750	0.500	0.500	0.750	0.500	0.500	0.250	0.250	0.500	0.500
SEnI	0.750	0.750	0.750	0.500	0.500	0.750	0.750	-	0.500	0.750	-	0.250	0.250	-
SEgI	0.667	0.667	0.667	0.333	-	0.333	0.333	0.333	0.333	0.333	-	-	-	-

Figure A.1. Comparison of the sub-indices (activity domain indices) for 14 ports, data unavailability is marked with (—).

Table A.1. Literature review on the smart port initiatives and the related studies.

Category of approach	Initiatives and studies	Description
Multipurpose initiatives	Mediterranean Maritime Integrated Projects	Three major elements: operations, environment, and energy, 23 criteria and 68 KPIs for smartness of a port
	Hamburg Port Authority	Smart logistics: infrastructure, smart traffic flow, smart trade flow Smart energy: use of renewable energies, increasing energy efficiency, and mobility
	Port of Rotterdam	Integration of knowledge exploration and knowledge exploitation with the motto of connecting knowledge. Five road maps: future proof port infrastructure, smart energy, smart logistics, world port city, and smartest port
	Erasmus Smart Port Rotterdam	A cooperation between the Port Authority of Rotterdam and port-related scientists from Erasmus University Rotterdam, five themes: operational excellence in ports and networks, drivers for green port-related operations, governance for a sustainable port, ports in global networks, and visibility for connected port
	Port of Amsterdam	Smartly promoting growth, innovation, sustainability, use of physical space, and caring about energy and environment
Targeted initiatives	Maritime Port Authority of Singapore	Use of mobile technology and wireless connectivity to improve communications, efficiency, and crew satisfaction: 4G broadband access, free Wi-Fi services, launch of myMaritime@SG mobile application
	Singapore Smart Port Hackathon	Discussions on innovative ideas embracing challenges in three areas: maritime services value chain, maritime logistics supply chain, and cruise/ferry terminal operations
	World Port Hackathon	Discussions on challenges in areas of infrastructure & logistics, energy & climate, disrupt the port in Rotterdam
	Port Authority of Cartagena	Adoption of Posidonia SmartPort application
	Kalmar Smart Port	Automation solutions: Smart Path, Smart Stack, Smart Lift, Smart Rail, Smart Trucks, Smart Quay, Smart Lane, Smart Fleet
	Arelsa Smart Port	Offering Smart Port solutions and services: software platform, mega yacht panels, Citiport pedestals, and Smart Port System for remote controlling and service management
	United Nations Conference on Trade and Development	Specification of smart port: ITS port, logistic community, connection to smart city and smart hinterland, providing multimodal services, and being sustainable
	European Union	Regulations on transport, energy, and ICT
	International Maritime Organization	E-navigation and conventions: MARPOL-ISPS-ISM-PSC-SECA
	Integrated Port Management System	A web-based integrated system that incorporates the logistics around the vessel traffic services, rail logistics, marine and terminal operations, and provides real-time reporting ability in the port.
	SmartPort platform	Big data analysis, visualization, and management tool for sensors' data collected in ports
	Kenya Ports Authority	Security management system and automated processes
	Smart Port Security Act	Legislation from Homeland Security regarding maritime security

Table A.2. KPIs for quantifying sub-domains in "Operations" category.

	Operations
1.	Annual throughput (TEU/Meter of container quay)
2.	Annual TEUs/Total terminal area
3.	Annual TEUs/Total storage or yard area
4.	Annual TEUs/Total storage or yard area plus total hinterland storage area
5.	Annual TEUs/Number of container terminals
6.	Annual TEUs reefers/Total number of electrical outlets for reefers (static capacity)
7.	Annual throughout (tonnage/meter of container quay)
8.	Annual cargo tonnage/Total terminal area
9.	Annual cargo tonnage/Total storage or yard area
10.	Annual cargo tonnage/Total storage or yard area plus total hinterland storage area
11.	Annual cargo tonnage/Number of container terminals
12.	Length of quay with +14 m depth/Total quay length
13.	Annual TEUs/Capacity of the container terminals (static capacity)
14.	Average annual number of hours (that container terminals are working)
15.	Annual TEUs/Average annual number of hours (containers terminals are working)
16.	Number of ICT that the port and terminals operators use and offer to the port community
17.	Annual throughput in TEU per number of quayside cranes
18.	Percentage of automatized quayside cranes
19.	Annual throughput in TEU per number of yard gantries
20.	Percentage of automatized yard gantries
21.	Annual throughput in TEU per number of equipment for internal movements (trucks, shuttle, etc.)
22.	Percentage of automatized equipment for internal movements (trucks, shuttle, etc.)
23.	Total percentage of automatized quayside cranes, yard gantries and equipment for internal movements
24.	Use of the intermodality-railway option (Total TEUs transported by rail/Total TEUs)
25.	Use of the intermodality-road option (Total TEUs transported by road/Total TEUs)
26.	Total number of TEUs/Number of carriers (only carriers of maritime transport)
27.	Number of main lines (large intercontinental and inter-oceanic lines with large ships and tonnage arriving in port)/Total number of lines
28.	Total TEUs per number of vessels that stop in the port
29.	Total cargo tonnage per number of vessels that stop in the port

Table A.3. KPIs for quantifying sub-domains in "Environment" category.

	Environment
1.	Number of environmental management systems based on international standards (e.g. EMAS or ISO 14001) implemented by port authority and port operators/Total number of terminal operators
2.	Total hazardous wastes generated by the terminal operators disaggregated by sources per TEUs (Wastes from ships (i.e., MARPOL wastes) are not included.)
3.	Total wastes collected in a selective way from all port activities (organic, plastic, paper, wood, electronics, etc.) per total port area. (Wastes from ships (i.e., MARPOL wastes) are not included.)
4.	Total wastes generated that are intended to operations of reuse, recycling, and vaporization disaggregated per kind of wastes per total port area (Tons/m^2)
5.	Total water consumption by all port activities per total port area (m^3/m^2)
6.	Total water consumption by terminal operators per TEUs (m^3/TEUs)
7.	Total water consumed by ships per vessels stops (m^3/Vessels stops)
8.	Volume of water consumption that came from reuse operations (in all port area) per total volume of water consumed (%)
9.	Total wastewater generated by all port activities per total port area (m^3/m^2)
10.	Total wastewater generated by the terminal operators per TEUs (m^3/TEUs)
11.	Total volume of wastewater from all port activities that are treated for reuse per total volume of wastewater in the port (%)
12.	Port activities covered by environmental management systems (%)
13.	Number of waste management plans implemented by port authority and port operators/Total number of terminal operators
14.	Port activities covered by waste management plans (%)
15.	Total wastes generated by all port activities (Tons). Wastes from ships (i.e., MARPOL wastes) are not included per total port area
16.	Total wastes generated by terminal operators per TEUs (Tons/TEUs). The wastes from ships (i.e., MARPOL wastes) are not included.
17.	Total wastes generated by ships (MARPOL wastes) disaggregated per kind of wastes and per vessels stops (Tons/Vessels stops)
18.	Total hazardous wastes generated by all port activities disaggregated by sources per total port area. Wastes from ships (i.e., MARPOL wastes) are not included. (Tons/m^2) (CO2 equivalents Tons/m^2)
19.	Lden – noise pollution
20.	Lnight – noise pollution
21.	Total leaks and spills (Tons) of polluting substances at sea per vessels stops
22.	Number of monitoring systems to assess water quality (temperature, salinity, fecal coliform, etc.) in port area per total quay berth
23.	Number of monitoring systems to assess air quality in port area per total port area
24.	Greenhouse gas emissions from all port activities per total port area
25.	Total annual GHG emissions per TEU
26.	Total annual air emission
27.	Amount of recycled waste

Table A.4. KPIs for quantifying sub-domains in "Energy" category.

	Energy
1.	Total energy consumption (primary energy) by port authority per total port area (kWh/m^2)
2.	Total energy consumption (primary energy) by the container terminals per total terminal area (kWh/m^2)
3.	Total energy consumption (primary energy) per container per total TEUs (*kWh*/TEU)
4.	Total energy consumption (primary energy) by reefers per Total number of reefer TEUs (*kWh*/Reefer TEU)
5.	Total energy consumption (primary energy) by internal fleet per terminal area (kWh/m^2)
6.	Total energy consumption (primary energy) by office buildings per terminal area (kWh/m^2)
7.	Total energy consumption (primary energy) by lighting system (port terminal area, not office buildings) per terminal area (kWh/m^2)
8.	Total energy consumption (primary energy) by the terminals' equipment per total number of TEUs (*kWh*/TEU)
9.	Total energy consumption (primary energy) by the terminals' equipment per total terminal area (kWh/m^2)
10.	Total energy consumption (primary energy) by cranes per total number of cranes (*kWh*/crane)
11.	Percentage of heating fuels from renewable resources managed by the port authority
12.	Percentage of heating fuels from renewable resources managed by terminal operators
13.	Percentage of energy from renewable resources managed by port authority
14.	Percentage of energy from renewable resources managed by terminal operators
15.	Number of energy management certificates or arrangements according to any standard (ISO 50001, etc. (by port authority and terminal operators)/Total number of terminal operators
16.	Port activities covered by energy management systems (%)
17.	Energy saved due to conservation and efficiency improvements

Table A.5. KPIs for quantifying sub-domains in "Safety & Security" category.

	Safety & Security
1.	Number of safety and security arrangements and certificates
2.	Scope of the safety and security arrangements and certificates (port activities covered by the safety and security management systems)
3.	Annual number of nautical accidents (significant or incidents in areas under the jurisdiction of the port authorities)
4.	Number of failures to comply (port regulations, industry safety standards, etc.)
5.	Number of spills (nautical or industrial)
6.	Number of fires and explosions (nautical or industrial)
7.	Number of foundering
8.	Investment in safety
9.	Number of port security incidents (different types of breaches-e.g. access without authorization, thefts and claims, jobs without authorization, etc.)
10.	Number of security drills
11.	Investment in protection (maintenance and investment)
12.	Compliance with ISPS requirements
13.	Percentage of employees trained in the organizations anti-corruption policies and procedures
14.	Number of Security meetings (police forces and authorities, private security and technological measures firms, shipping companies, shipping agents, and foreign consulates)
15.	Number of port security inspections