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Innovation in Smart Ports: Future Directions of Digitalization in Container Ports

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Abstract: New digital Industry 4.0 solutions and smart applications are being adopted in many industries, also in the most advanced ports in the world. Still, it is not clear in which directions digitalization in ports will develop in the future. Building on the research literature and the state-of-the-art in major container ports, this research characterizes smart ports and Port 4.0 with three key focus areas: automation, sustainability and collaboration. Following the scenario building theory, this article constructs four alternative scenarios for future smart ports and shows the ways in which these alternative scenarios will lead to different prioritization of digital innovations between automation, sustainable development and cooperation issues. This will have a big impact on what digitalization in ports will be like in the future.

Keywords: port; industry 4.0; digitalization; future; scenario; smart port; maritime

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1. Introduction

Ports are logistics and supply chain hubs with high requirements regarding costs, efficiency, security and sustainability [1]. Digital innovation related to cargo flows has been the main source for maintaining their competitiveness in the last few years [2]. Still, there is a lot of room for improvement, as approximately 80% of ports still rely on manual, legacy solutions such as whiteboards or spreadsheets to manage the most basic processes. At the same time, more advanced industries are starting to use digital solutions, named as Industry 4.0, which are characterized as solutions blurring the lines between the physical, digital, and biological spheres. The urgency to change is due to the need to take action against big societal problems such as climate change, resource shortage, and security. While in large ports such as Rotterdam and Antwerp, new digital 4.0 solutions are already emerging [3], it is far from clear what ports in general see as most important areas of innovation and how this development impacts the roles and power balance within maritime industry in future.

In this paper, we address the following research question: In which direction(s) will digitalization develop in ports? We build our research on the literature of smart ports and Port 4.0, and on the state-of-the-art in container ports. The research method applied is scenario analysis which helps us to foresee the future and build scenarios of smart ports.

We start by a short introduction to Port 4.0 and smart port. In Section 3 we explain our research method. Section 4 describes first the trends in maritime, and then provides literature review of smart ports as well as state-of-the-art analysis of innovation in ten selected ports. In Section 5, following the scenario building theory we create four scenarios on the ways in which the future development of ports might be shaped. The four alternatives have been chosen so that in each scenario port development is led by a different stakeholder. The article ends with discussion and conclusions.

This study contributes to the growing literature on digitalization in container ports, smart ports and Port 4.0, but also extends and complements the literature on Industry 4.0. We suggest that automation, sustainability and collaboration are the key ingredients of smart port. Moreover, the study presents multiple scenarios of future ports. Whereas

previous research suggests different maturity indexes for evaluating development of smart ports [3–5], our study aims to better understand why the ports end up using digitalization in very different ways.

2. Smart Port 4.0

In the past, port operations were mainly considered from the perspective of scale: quay length, number and efficiency of cranes etc. [6,7]. So far, ports and maritime sector have been considered to be lagging behind others in digitalization [2,8] but more recently Industry 4.0 technologies have been gaining more ground there [9,10]. Building on the impact of Industry 4.0 on other sectors, ports are also expected to see similar adoption of new technologies and new business models [11–13].

Industry 4.0 is defined in the literature as "the intelligent networking of machines and processes for industry with the help of information and communication technology" [14,15]. The term Port 4.0, in turn, is considered as the application of Industry 4.0 in the port environment. Scholars and practitioners also use the term "smart port" instead of Port 4.0. However, there is no clear difference between these two terms and they are used interchangeably [16]. Based on various descriptions provided in the literature [17–21], here, we define smart port as a port that is automated, collaborative and green.

Smart port can utilize various technologies. More than 1000 individual 4.0 technologies were identified in [22], and [23] categorized technologies into four groups: process technologies, such as robotics and additive manufacturing; interface technologies, such as IoT and visualization; network technologies, such as cloud, blockchain and cybersecurity, and data-processing technologies supporting analysis and decision-making, such as big data, machine learning and simulation.

The range of technologies is vast and each of them can be employed in various port operations. However, to see the big picture, we need to move away from individual development efforts and divert our attention to the higher-level goals and their impacts on the port ecosystem. For this purpose, this paper uses scenario analysis method to construct potential futures of ports.

3. Research Approach

In the scientific literature, building scenarios means speculating about the uncertainty surrounding the future and picturing a few different possible outcomes for the situation under scrutiny [24]. Scenarios are alternative stories that capture key ingredients of our uncertainty about the future and provide insight into drivers of change. Trends, expert predictions and visions are part of scenario-building exercises [25]. By identifying trends and uncertainties, we can construct scenarios which help to avoid overconfidence and too narrow vision in decision-making [26]. Scenarios can include, for example, projections of current trends but the value of scenarios comes from incorporating differing knowledge and in stimulating people to reassess their beliefs about the system.

The traditional approach to select the alternative scenarios is to have an optimistic and a pessimistic scenario. Later on, scholars increasingly utilize a scenario method which takes extreme positions in the spectrum and then add a middle position scenario. This is useful for generating radical ideas, but does not support participants in thinking plausibly. Instead, the most recent literature suggests adopting scenarios which look to multiple futures, discontinuous change or transformative viewpoints [27,28].

The first steps in the scenario building are about setting the scene, providing the definition of the purpose of the work and developing an understanding of the current situation [29]. In this paper, we first (a) identify the key trends, and thereafter (b) analyze the recent literature to recognize the important port innovation activities, as well as (c) analyze state-of-the art of smart port activities at ten smart container ports. The criterion for the selection was based on the availability of public information on the smart port activities in the ports. Reflecting the fact that publicly available information about smart port activities mostly comes from Europe, six of the selected ports are European. Outside

Europe, it was recognized that Singapore and Chinese ports are very much progressing with smart port development, striving heavily for automation. Therefore, we included three Chinese ports and the Port of Singapore. The data was collected from the web sites, news and press releases of the port authorities and major container terminal operators. We analyzed smart port activities related to automation, sustainability and collaboration in each port. The references to the full online sources (n = 241) are available from the authors.

As pointed out by [27], scenarios per se do not constitute "truths" or present the most probable developments but provide a set of plausible pathways in order to highlight the uncertainty and complexity of decision-making contexts. The author suggests specific means to improve plausibility:

(a) Clear structure of the scenarios: In our research, we followed the [28] scenario building theory and constructed our scenarios by first conducting a background analysis, which enabled us to identify and include drivers for change. The background research eventually led us to build the scenarios around different innovation leaders
(b) Internal consistency of the scenarios: We ensured consistency by analyzing the literature, state-of-the-art in ports and each scenario from three key viewpoints —automation, sustainability, collaboration.
(c) Scientific adequacy of the provided evidence and argumentation in the scenario: This paper provides evidence from scientific articles and from state-of-the art data. This background analysis was enhanced with several repeated nonformal discussions and interviews with maritime experts (port authorities, terminal operators, shipping lines and port technology providers) who collaborated in the same research project with the authors and whose feedback helped the authors to construct the smart port scenarios.

4. Background—Setting the Scene

4.1. Key Trends and Uncertainties

Global trade and shipping constantly face different shocks and disruptions as recently demonstrated by the COVID-19 pandemic or Brexit. It is evident that there will be changes to global trade, and the literature points out several uncertainties discussed below as potential drivers affecting the future of shipping and ports.

Since the 1970s, there has been a tendency to increase vessel size. While the shipping costs per container decreases, larger vessel size leads to peak demand for trucks, yard space and intermodal connections [30]. Large hubs are expected to grow in importance, and they have reported better performance and connectivity indicators [31]. As a response, many ports repetitively have to upgrade and optimize their operations [32] to also serve the larger vessels. However, the physical growth of the ports and waterways becomes even more difficult and, at some point, will reach its limits.

Effects of the COVID-19 pandemic have underscored the dependency of world trade on well-functioning sea transport. It has evoked long-term considerations, from changes in consumption to changes in structures of global supply chains. There are discussions related to having more local supply chains due to pandemics and of near sourcing versus higher inventories. The maritime industry was also hit hard by increased cyberthreats, increasing the need for better cybersecurity [33].

European industry has been leading the current development of maritime logistics. Recently, much emphasis has been placed on sustainability. The USA mostly shares the European views and has, for example, decided to adopt the European ISO standards. In the future, the East is expected to have more of a voice, and also the intra-Asian trade volumes are expected to grow [34]. China's strategy (referred to as Belt and Road) is to become a global leader in terms of national strength and international influence by 2050. Maritime policies play a vital role in support of that strategy and they direct investment to intensify maritime trade [35]. It has already invested in a vast number of overseas ports. A large part of the overseas port investments is carried out by state-owned companies.

Consolidation trend in the maritime sector has been strong: the container liner companies have already formed three alliances. On the other hand, the container terminals

and freight forwarding segments have not seen as much consolidation [36]. We also expect to see consolidation trend here. It may be horizontal integration, but it is also possible that container liners will integrate further with terminals and forwarders. Moreover, the platform economy is gaining ground in maritime logistics. Examples are the recently introduced Tradelens and GSBN utilizing block chain technologies [37]. Both platforms have the support from many shipping companies, and we will see the competition between platforms heating up. On the other hand, there could be potential for new value creation if these digital platforms are opened beyond the maritime industry, such as to financial sector.

Players outside maritime industry are entering the scene; e-commerce giants such as Amazon and Alibaba have become notable players in maritime logistics. In 2017, Amazon and Alibaba introduced new services where they expanded their business to freight forwarding and logistics provision. The aim is to provide simplified booking of door-to-door shipping, and by controlling the entire supply chain it can improve predictability. There are also indications that some customers want to have more visibility of goods locations and better estimation of arrival times. Sensors and IoT embedded in the containers would enable door-to-door tracking and monitoring. The impact on industry is the redistribution of profits; some freight forwarders and shipping agents will become obsolete, and other incumbents are worried for good reason.

4.2. Literature on Port 4.0 and Smart Ports

Only in recent years has smart ports or Port 4.0 received more attention in the literature. The authors of [38] found in their bibliometric, content and thematic analysis in the field of digitalization in maritime transport between 1990 and October 2021 in total 41 articles with keyword "port" and 15 articles with keyword "smart port". We, in turn, recognized 34 recent scientific articles which were published between 2017 and 2022 and focused on the characteristics of the innovation activities in ports (Table 1).

Based on the content analysis of these smart Port 4.0 articles, around half of the articles focused on current, and half considered the future of ports. For example, [36] presented scenarios for container transport. Three of the scenarios expected data and analytics to be a fundamental driver of value by automating the transport across the value chain. The fourth scenario was less optimistic where data and analytics were utilized only limitedly. In turn, [13] studied alternative futures of digitalization in Finnish seaports, and [12] explored the potential development of physical Internet at maritime ports.

Several articles present indexes for measuring the smartness of ports. In [4,5], it is suggested that the maturity index is organized around key activity domains of a smart port: infrastructure, operations (cargo handling and intermodal traffic), environment and energy, and safety, security and customs. The authors of [4] present an index consisting of 33 items divided into five areas: management, human capital, functionality, technology, and information. In turn, [39] lists a number of indicators of a green port, ranging from emission control to waste management and from noise control to control of odors.

Several authors, e.g., those of [40,41] point out that, in addition to digitalization, collaboration and environmental aspects are also important issues in future ports. For example, the authors of [13] point out the societal significance of ports in their home cities and importance of environmental efficiency. The authors of [1,42] emphasize the need for interconnectivity and collaboration.

On a whole, from the analysis, we can determine three central focuses of digitalization in future smart ports: automated, green and collaborative.

Table 1. Literature on Port 4.0 and smart ports (A= automated, S= sustainable, C= collaborative).

Article	Port 4.0 Issues/Focus	Time Horizon	Methodology	Focus		
Alahmadi et al., 2022 [43]	Blockchain integrated into port processes such as financial and document workflow	Present and future adoption	Review article discusses the adoption of blockchain in the ports and shipping industry	A		C
Alop, 2019 [44]	Human relations are the main challenges and barriers to the successful "smart shipping"	Present	Swot analysis			C
Ben Farah et al., 2022 [45]	Operations, environment, energy, safety and security, and human relations	Present—index for sustainable smart port	Literature review	A	S	C
Braidotti et al., 2020 [46]	The enhancement of the data collection and exchange systems among the involved parties is identified as a priority, as confirmed by the technologies deemed most relevant: Maritime transport chain, ETA, and Deliverables Planning	Present on the automation of ports and logistics chains in the Adriatic region	Desk research, innovation ranking and impact analyses			C
Camarero Orive et al., 2022 [47]	A tool for evaluating the degree of blue economy in port	Future—the emerging sectors in blue economy	Delphi panel		S	
Camarero Orive et al., 2020 [40]	Collaboration, decarbonization, transparency, technology and cybersecurity	Future—important issues at automated ports	Business observation tool to help automated terminals develop their strategies	A	S	C
Chang et al., 2020 [48]	Blockchain, collaboration	Present—identifies collaborative schema and future research directions for industry, government, and academia to jointly work together	Synthesis of the state-of-the-art			C
Cil et al., 2022 [49]	IoT	Present—Internet of Things enabled real time cold chain monitoring	IoT-enabled system developed for remote monitoring of temperature, humidity etc.	A		
Chu et al., 2018 [9]	Major barriers (in descending order of importance): capabilities of the workers, data quality, siloed operations, handling of exceptions.	Present—automation has become a trend. Barriers of reaping the benefits from automation at ports	Global survey, 40 participants from top ports, automation equipment and software suppliers, academia, port asset-management firms, and shipping companies	A		
De La Peña Zarzuelo 2021 [50]	Cybersecurity	Future—challenges of the industry and policymakers when transitioning to 4.0 world	Literature review	A		

Table 1. *Cont.*

Article	Port 4.0 Issues/Focus	Time Horizon	Methodology	Focus		
De La Peña Zarzuelo et al., 2020 [16]	Co-operation, integration, IoT, sensing solutions, big data and cloud computing, blockchain, drones, robotics and automation, augmented and virtual reality, artificial intelligence and machine learning, simulation and modelling, energy solutions, smart asset management, cybersecurity, connectivity, standards and federated database systems	Present—the state of the art of Industry 4.0 technologies at port and maritime industry	Systematic literature review	A		C
D'amico et al., 2021 [41]	Enabling factors (ecosystem, organization, data and security, policy and regulation, finance and funding, digital and technology), domains (mobility, environment, economy, telecommunications, safety and security, government, community) and goals (sustainable development and digitalization)	Present—the most recurring themes concerning smart and sustainable logistics initiatives within port cities	Systematic literature review	A	S	C
Fahim et al., 2021 [12]	Fully globally functioning physical, digital and operational interconnectivity through encapsulation, interfaces and protocols may not be reached by 2040	Future—design potential development paths of physical internet at maritime ports	A Delphi method	A		C
Fenton et al., 2018 [36]	Three of the scenarios expected data and analytics to be a fundamental driver of value; automation across value chain. One less optimistic scenario where data and analytics only an "overlay", gradual automation, especially landside (ports, rail, trucks)	Future—scenarios for container transport. Variables: economies of scale, flexibility, supply chain reliability and predictability, consolidation and integration, automation and productivity, environmental productivity	Interviewed over 30 industry leaders and experts, then a joint workshop with the TT Club Board members to further develop future scenarios	A	S	C
Frost & Sullivan Company 2019 [51]	Smart port technologies divided into five areas. Larger ports and ports facing intense geographically close competition faster to adopt new technologies	Present—technology export potential analysis. Analysis and comparison of nine ports	Overview on smart port technological contents and selected ports adoption	A		
Gonzalez-Cancelas et al., 2020 [1]	Collaboration evolvement and alignment for new partners; skills and practices; Transparency with, e.g., data exchange and control tools	Present and future—port digitalization	A SWOT Delphi study of 27 experts, both theorical and practical			C

Table 1. *Cont.*

Article	Port 4.0 Issues/Focus	Time Horizon	Methodology	Focus		
Heilig et al., 2017 [52]	Stages in IS evolution in ports: first, introduction of computerized data and systems; second, introduction of automated processes; third, since 2010, a shift to "smart" procedures including, e.g., more interorganizational interaction and real-time data analytics	Overview on digital transformation of ports	Retrospective analysis of events related to ports in general using IT-enabled business transformation framework	A		C
Heilig et al., 2017b [53]	Cloud computing and improved analyses open new opportunities. Simultaneously high requirements on IT/IS landscape and, e.g., integration of legacy systems	Present—the technologies in port information and decision support systems that have large role on information integration	Categorization	A		
Heilig and Voß 2017 [42]	Key features include: improved supply chain visibility through IoT; sensors and analytics; synchromodality as an ability to adapt plans real-time, and the need for interconnectivity and collaboration (where blockchain can become a trust-builder)	Future—technical vision paper on elements of intelligent supply chain	Industry news-based commentary	A		C
Hua et al., 2020 [54]	Port should focus on monitoring of energy consumption and pollutant emissions	Future—case study, governance strategy to determine the performance of Zhuhai Port in green port indicators	Fuzzy importance–performance analysis (FIPA) method		S	
Inkinen et al., 2021 [13]	The probable development pathway for port digitalization includes characteristics from all three scenarios. Key drivers: data standardization; logistic supply chain management, societal significance of ports in their home cities, environmental efficiency and Industry 4.0	Future—prospects of digitalization in Finnish seaports	Three digitalization scenarios (digital supremacy, business as usual, and digital failure) analyzed with SWOT and PESTEL	A	S	C
Jensen 2017 [55]	Four change drivers: digitization, transparency, supply chain dispersal and network optimization. Exception handling. Supply chains become more scattered rather than China-centered. Alliance swapping agreements are one tool for point-to-point	Future—liner shipping network logic	Expert view, technical vision paper on liner shipping	A		C

Table 1. *Cont.*

Article	Port 4.0 Issues/Focus	Time Horizon	Methodology	Focus	
Lind et al., 2020 [56]	Smart port information services provide value. Data and their sharing governance with big data intelligence are focal. Lighthouse ports refer to digital pioneers supporting holistically digitization of whole supply chain as a trusted environment	Future—smart port role for supply chains	Expert view, technical vision paper	A	C
Molavi et al., 2020 [4]	KPIs are organized around four key activity domains of a smart port: operations, environment, energy, and safety and security.	Present—smart port index (SPI)	Developed index is demonstrated by case studies	A	S
Montesinos and Guia 2019 [57]	Data belongs to different sensor owners, and beneficiaries of the data are diverse. Collaboration needed for integrating different hardware and communication technologies with, e.g., IoT platforms.	Present—smart port implementation requirements	Expert view, technical vision paper	A	C
Notteboom 2019 [58]	Port communities are determined to reduce the environmental footprint and to transition to a more energy-efficient and circular economy	Present and Future—evaluation of year 2019 and near future in European container ports	Expert view		S
Philipp 2020 [4]	Index consists of total 33 items divided into five areas: management, human capital, functionality, technology, and information.	Present	Constructs digital and Industry 4.0 readiness index and uses it to analyze five ports	A	
Rodrigo Gonzalez et al., 2020 [59]	Integrated digital merchandise management, mechanical systems automation, docking line efficiency, use of storage capacity, worker security, digitization of access security, digital interaction with client	Present—32 operational, social, political, environmental indicators for smart port in Spain. The aim is to rank Spanish smart ports.	Delphi study of 88 experts	A	C
Teerawattana and Yang 2019 [39]	Indicators of green port: CO_2 emission, energy consumption, waste management, water consumption and quality, carbon footprint, air quality, soil and sediment quality, noise control, pollution emission and odor	Present—case study of Laem Chabang port (LCP) to select the green port assessment criteria	Entropy analysis of environmental performance indicators of LCP based on secondary data (2011–2014)		S

Table 1. *Cont.*

Article	Port 4.0 Issues/Focus	Time Horizon	Methodology	Focus		
Tijan et al., 2021 [10]	Innovative technologies (such as Blockchain or autonomous shipping) fosters digital transformation, but uncertainty of business impacts and the lack of standards and cooperation among stakeholders hinders	Present—drivers, success factors and barriers to digital transformation in the maritime transport sector	Literature review	A		C
Triska et al., 2022 [5]	Suggest a maturity model for smart terminal	Present—investigates characteristics and relations between enablers, applications, and outcomes for smart port terminals	Conceptual literature study and application of the maturity model in two Brazilian container terminals	A	S	C
Wang et al., 2021 [60]	Development challenges of digital twin-driven management	Present—digital twin-driven management to realize visibility and traceability of on-site situations in real smart port	Investigates digital twin-driven applications	A		
Wang et al., 2019 [61]	International gate should aim for cost leadership, transshipment terminal is better with differentiation strategy. Close relationship with shipping lines or/and hinterland carriers is likely to increase automation	A multiple case study of 20 container terminals (archival sources + visits)	Container terminal process automation	A		C
Yau et al., 2020 [62]	IoT platform, greenhouse gases emission, energy efficiency, container management, use of AIS data for operation efficiency, resource management to reduce congestion	Present and Future—discussion of mainstream literature	Literature analysis enhanced with web sources	A	S	

4.3. State-of-the-Art in Major Contained Ports

The following ten smart ports were included into the internet-based data collection (Table 2). We gathered information from online sources about the innovation activity in the selected ports.

Table 2. Analyzed ports.

Port	Volume 2020 Million TEU	
Antwerp, Belgium	12.04	Top 2 Container port in Europe; city-owned port authority promotes smart port activities and port as an innovation platform for new technologies. Terminal operators: PSA, DP World, both with joint ventures.
Barcelona, Spain	3.50	Fast growing port in Europe; government-managed port authority promotes smart port. Terminal operators: APM Terminals, Hutchison.
Felixstowe, UK	3.78	Top 8 Container port in Europe; privately operated port authority and terminal operator Hutchison has a smart port strategy.
Gothenburg, Sweden	0.76	Largest container port in Scandinavia; city-owned port authority's main values are co-operation, sustainability, innovation and reliability. Terminal operators: APM Terminals.
Hamburg, Germany	8.70	Top 3 Container port in Europe; port authority promotes smart port philosophy and has started a smartPORT project focusing on logistics and energy. Terminal operators: HHLA, Eurogate.
Hong Kong, China	17.95	Top 8 Container port in the world; port is governed by the local government but does not have traditional port authority. Most of the port facilities are privately owned and operated. The Port of Hong Kong refers mostly to a group of independent terminals operating under Hong Kong Special Administrative Region's governance. In 2021, governmental authorities formed a task force to trigger a drive toward a smart, green port, although the task force is not equal to port authority. Terminals operators: Modern Terminals, Hongkong International Terminals (HIT), COSCO-HIT Terminals), Goodman DP World and Asia Container Terminals.
Rotterdam, Netherlands	14.35	Top 1 Container port in Europe; city- and partly state-owned port authority. Well-known smart port, first in the world to have successfully developed an unmanned automated terminal and unmanned crane quay. Terminal operators: APM Terminals, RWG (joint venture including DP World, ECT-Hutchison).
Shanghai, China	43.50	World Top 1 Container port; the world's largest automated container terminal; government-lead smart port development; port authority Shanghai International Port Group is owned by Shanghai government and it also the exclusive operator of all the public terminals. It will develop a new port and container terminal at the Yangshan Port.
Shenzhen, China	26.55	Top 4 Container port in the world; Port of Shenzhen is a group of ports and terminals along the coastline of Shenzhen. The local administration is in charge of port planning and policies, whereas local port corporations are responsible for the construction and operation of port facilities, as well as have partly the role as port authority. Regulatory authority is national. Terminals are mix of private and joint ventures between local state-owned port corporations and private companies. Yantian International Container Terminal is the biggest and operated by Hutchison. China Merchants Group, a state-owned corporation, is developing three other port terminals, of which Mawan intelligent port is one.
Singapore, Singapore	36.60	Top 2 Container port in the world; government-led port authority MPA and terminal operator PSA inaugurated the first phase of the new Tuas port in Sept 2022 which is planned to become world's largest fully automated port.

In Table 3, the listed smart port activities are first categorized into three core activities (automation, sustainability and collaboration) and then further into subcategories based on the general goal, purpose or value for which the specific activity has been implemented.

From the listed smart port activities, the following general observations were made. First, there were three activities that were found in all ten ports: port call data sharing platform (in automation category), hybrid, electric or fossil-free fuel terminal equipment (in sustainability category) and container tracking systems (in collaboration category). These activities can be defined as near to a de-facto industry standard for a large modern container port and confirm our proposition that smart ports develop their operations especially towards improved automation, sustainability and cooperation.

Table 3. Smart port activities at selected ports (T = terminal operator, A = port authority).

Category		Innovation Activity	Antwerp	Barcelona	Felixstowe	Gothenburg	Hamburg	Hong Kong	Rotterdam	Shanghai	Shenzhen	Singapore
Automation	Terminal Operations	Equipment remote operations			AT			T	T	AT	T	AT
		Terminal automation	T	T			T	T	T	AT	T	AT
		Container yard and handling optimization					T	T		AT	T	AT
	Seaside Traffic Optimization	Automated mooring/seaside equipment							A			
		New sensor data	A	A			A		A	AT		AT
		Port call data sharing platform	A	A	AT	A	AT	T	AT	AT	T	AT
		Advanced Traffic Management (IoT, predictive analytics)		A			AT	T	A		T	AT
	Hinterland Traffic Optimization	Digital customs process	A	A			T	A	AT	AT	AT	AT
		Vehicle booking system/ETA estimates	T	A	AT		T	T	AT	AT	T	AT
		Automated gates	T	T		T		T	T	AT	T	AT
		Intermodal route planning tool	A		AT		T			AT		AT
	Safety and Cybersecurity	Cargo release/cargo quality process (e.g., blockchain)	A		AT			T	A	AT	T	AT
		Cybersecurity top positions or projects					A		A			AT
Sustainability	Energy	Onshore power for ships	A	A		A	A		A	AT	T	
		Solar power installations	A	T	AT	T	A	T	A	AT		T
		Wind power	A				T		A			
		Hybrid, electric or fossil-free fuel terminal equipment	T	T	AT	T	T	T	T	AT	T	AT
	Other	Sustainability certificates/qualifications		A	AT	A	T	T	AT		T	T
		Air quality sensor	A	A	AT	A	A	T	A	AT		T
Collaboration	Co-Creation and Innovation Services towards stakeholders	Innovation Funding		A			T		A			AT
		Innovation Ecosystem Programs	A	A	AT		A		A		T	AT
		Different organizations' platform integration/Data sharing APIs	A		AT	AT		T	A	AT	T	AT
		Container Tracking Systems	AT	AT	AT	T	T	T	AT	AT	T	AT
		Container monitoring equipment					T	T	A	AT	T	AT
		Hackathons/Innovation challenges	AT	A			T		AT			AT
	Technology Pilots and tests	5G	A	AT	AT		A	T	A	AT	T	AT
		Blockchain	A	A		T	A	T	AT	AT	T	AT
		AI/machine learning					T	T	A		T	AT
		Carbon capture	A			A			A			AT
		Digital twin/IoT platform	A				A	T	A	AT	T	AT
		Hyperloop					T		A			
		Hydrogen	A				A		A	AT		A
		Autonomous vessels	A				A		A			AT
		Autonomous trucks			AT	T	T	T	A	AT		AT
		Drones	A				A		A		T	AT
		3D metal printing					T		A			AT

Second, in Europe, port authorities are clearly more active smart port actors than terminal operators. European port authorities perform a higher number of activities and their scope is also broader, while terminal operators focus on fewer issues. Facilitating "smart" has become one of the port authorities' obligations to the port community. Terminal operators' activities, especially with land traffic, suggests that some development tasks are also directed vertically along their respective supply chains with the cargo owner as the final customer. In Asia, the division of activities between the port authorities and terminal operators is not as clear. For instance, in Shanghai, the port authority is also the public terminal operator and is leading the port development. Singapore is somewhat similar to Shanghai, although the port authority and terminal operations are separated into two companies. In Hong Kong and Shenzhen, so far, mostly the terminal operators are active in introducing the smartness into port operations. It should be noted that in the examined Asian ports, the port authorities are under governmental control and, similarly, some of the major terminal operators are state-owned either directly or via state holding companies. This brings a special flavor to smart port development. An example of this is a statement from China Merchant Port group—which is investing, among others, in the Shenzhen port—that the company is a crucial means to implement the Belt and Road Initiative promoted by China.

Finally, the highest level of activity within the selected ports is found in Rotterdam, Singapore and Hamburg, and the activity list supports their reputation as frontrunner hubs. What makes them different is their high level of communication activity, gaining new partners and investments in exploring long-term technologies.

In the next subchapters, we will analyze each of the smart Port 4.0 key areas, automation, sustainability and collaboration, in more detail.

4.3.1. Automation

Digitalization by automating is seen as the main way to enhance the productivity in future smart ports [36,42,51,52,56,57,63]. In addition to large ports [61], ports facing intense geographically close competition are faster to adopt new automation and analytics solutions [51], which helps them to improve the efficiency of terminal operations as well as make traffic towards hinterland and seaside more fluent [46].

Terminal operations and automation. Innovations in terminal operations usually aim for improved efficiency, for example, by increasing movement frequency or reducing unwanted cargo handling. Typical means are automation of terminal equipment and analytics to optimize the container handling moves in a terminal yard. Smart port development here is often driven by equipment manufacturers' innovations or terminal operators' internal development.

Ports utilize automated equipment in ship-to-shore and yard operations, ground transportation and gate automation, for instance. The technology is relatively mature for many solutions. This kind of equipment makes operations run more consistently and decreases downtimes. However, investment costs are high.

Today, there are about 40 semi- or fully-automated container terminals in operation around the world. Furthermore, in Europe and the APAC region, we recognize a growing trend in the semi-automation of existing or new ports. One example of remote operation comes from Shanghai, where port cranes can be remote controlled from a center 100 km away from the port.

Automation makes operations smoother and provides more information for decision-making. The downside is that the lack of interface standards makes integrating many systems hard [9]. A rapidly emerging trend is new performance-based business models for retrofitting, leasing, sharing, learning and collaborating, where automated technology is applied with new innovative ways to the already existing terminals. Combining automated technologies and the expertise of people has been the key within most advanced cases in Singapore, Rotterdam, Hamburg, Qingdao and Nagoya for better productivity, safety, security and performance, as well as for meeting environmental factors and customer

expectations. Together, these determine the extent of automation and shape the design considerations.

One machine learning application example comes from Hamburg terminal operator HHLA which implemented a machine learning solution for container dwell time prediction. "Dwell time" means the period which a container stays at the terminal. Deep learning approach was applied to identify hidden patterns from historical data of container moves and now the real-time operational system obtains improved data predictions for container outbound mode of transport and subsequently improved dwell time predictions.

Seaside traffic optimization. Port call is the core of whole port operations, and a number of services relate to the port call both for ocean and inland vessels. Several large projects such as Sea Traffic Management and its predecessors or Port Call Optimization Task Force have explored ways to improve vessel–shore communication and interaction and, for example, enable more accurate ETAs about port calls, as up-to-date real-time-information on port calls is very valuable for synchronizing and coordinating different services on correct time and with correct resources and infrastructure and avoiding exceptions. Achieving that requires joint information systems with different stakeholders and agreed data sharing actions [46].

The basis for the development so far are the port community systems (PCS) and the national single windows (NSW). Basic data can originate from such platforms, but it can also be enhanced, for example, with additional data from weather sensors, or machine vision analyses of video camera streams on incoming ships. Using additional data sources, it is possible to improve accuracy of the information and/or help to detect exceptions.

Already managing to share and update the static relevant data is a large collaboration effort overall. In a more advanced form, port vessel traffic is actively managed, prioritizing safety but also different efficiency perspectives, e.g., slow steaming, just-in-time arrival or terminal resourcing considerations. Vessel traffic is one of the broadest smart port application areas usually driven primarily by the port authorities and involving many a broad set of stakeholders.

As an additional example, the Port of Rotterdam is committed to becoming the first digital port by 2030. Among many initiatives there is one for IoT and AI to analyze real-time data from sensors throughout the expansive dock facility about weather and sea state. The port has "Digital Dolphins," smart quay walls and sensor-equipped buoys. Separately, any of these data sources do not necessarily have much impact, but combined with algorithms, they can enhance traffic management.

Hinterland traffic optimization. Ports are claimed traditionally to overemphasize the seaside, even though the hinterland can have a large effect on the port's performance. Even in the fully automated terminals, the benefits are lost if the cargo is not transferred from/to the hinterland on schedule. From that perspective, port traffic is also highly interlinked with their respective cities' traffic and transportation.

The essential goals for truck and rail are avoiding congestion and streamlining the traffic flows in an effective and stable manner [64]. One of the most common tools is to coordinate truck arrivals to port via a mobile app for truck drivers. The app communicates a recommended time slot for each truck so that their entries to port are distributed into a longer time span thus avoiding high peaks. That is also one of the earliest smart port activities that have been launched. Another important development area is supporting intermodal traffic where a large share of cargo is moved forward by rail or inland vessels. International trade also often involves a lot of document handling and in many cases digitalized custom practices are under development. Recently, at least 7 out of the 10 analyzed ports are experimenting with autonomous trucks transporting containers from/to port. Overall, improving collaboration and integration both between different transport modes and between different parts of the supply chain relates to the goal of synchromodal logistics [65].

The driving actor in the development of land traffic is often the terminal operator. Any improvement in traffic flows improves the terminal traffic flows and helps to control the

peaks immediately during vessel port calls. Truck and rail carriers, gate system providers, port authorities and cities also support these innovations.

Examples of the activities include gate automation solutions which integrate actual physical gates, traffic lanes and lights, automatic container code recognition, license plate recognition and container damage inspection system. Digitized support functions make port entry faster and reduce errors.

Safety and Cybersecurity. Cybersecurity has gained interest since the outbreak of the COVID-19 pandemic [40,45,50,59] as maritime industry overall suffered a manyfold increase in cyberattacks. The importance of cybersecurity increases the more digitalized and the more collaborative and shared the information systems become. Still, safety, security and cybersecurity seem to be some of the least communicated smart port activities. Organizations probably tend to want these projects to attract less public attention and curiosity so as to protect critical processes and practices. Nevertheless, safety and security are very crucial for ports. Moving machinery, valuable equipment and cargo, business continuity and supply availability, border control and customs are just a few of dozens of perspectives. Digitalization can offer more efficient ways to supervise areas, identification of objects and individuals, analyze threats and so on. All actors in ports need to contribute so that operations are safe for all employees, cargo stays safe and is not stolen, and that no intentional harm is done to port operations.

The development towards Port 4.0 is centered on the interconnectivity and on the introduction of new technological enablers, such as cloud computing, big data, and IoT. This digital transformation has also led to a change in the sector's cyber risk profile demonstrated by increasing number of cybersecurity incidents in ports over the past few years, one extreme example being the 2017 world's most devastating cyberattack against Maersk.

Credible cybersecurity within ports requires attention to people's behavior and capabilities, the physical machines and equipment, and information and communication technology. The European Union Agency for Cybersecurity [66] takes these aspects into account in its suggestions for good practices for cybersecurity implementation. It points out that it is crucial to ensure clear governance, raise awareness of cybersecurity, use network segregation and password protection, security by design and enforce detection and response capabilities to react as quickly as possible.

Two kinds of issues were detected from the news articles in recent years that fit such goals. Several ports took part in the development of a blockchain-based cargo release process. For instance, the Port of Antwerp has collaborated in a start-up to enable full authentication by utilizing strengths of the blockchain approach. Having more tools to ensure that the right container is released to the right truck driver supports the prevention of errors and crime. Another example of the importance of cybersecurity was identified in the Port of Rotterdam appointing a Chief Cybersecurity Resilience Officer.

4.3.2. Sustainability

Second central dimension for smart Port 4.0 is sustainability [13,39,54,62]. Especially European port communities are determined to reduce the environmental footprint of their activities and transition to a more energy-efficient and circular economy [58]. As overall more public attention has been paid to environmental goals, the ports have started to react to the discussion. Ports, as connection points for many traffic forms and often in close connection with densely populated cities, highlight sustainability topics. For example, traffic peaks and congestion agglomerate emissions in the port areas, which raises concerns for cities that are increasingly emphasizing sustainability. In addition, cargo owners and carriers raise expectations in terms of green supply chains.

Sustainability goals to reduce emissions, favoring renewable fuel over fossil fuels and **decreasing energy consumption**, take various forms in the port environment. To improve sustainability of port operations, the adoption of innovative technology appears to be of importance in achieving the transition from carbon-intensive fuels to a low-carbon

port model [67]. Ports, especially container ports, have three functional areas: quayside, yardside and landside. In quayside, the working energy consumption is a function of the number of moves per hour and the energy consumption during (un)loading. Meanwhile, the nonworking energy consumption is due to auxiliary units and lighting. In yardside, the planning is mainly about the transport and stacking of containers. It is important to note that efficiency-orientated activities to optimize vessel or truck traffic also have sustainability impacts. At the port gates, even slight changes in truck arrival times can significantly reduce energy consumption and truck emissions [68]. Synchromodal logistics aims, for example, to increase the share of rail and inland vessel traffic, improving both overall efficiency and environmental impact [69]. As additional examples, reducing idling in operations, energy-aware scheduling of equipment, slight postponement of duty cycles, reduction in simultaneous lifting and limiting maximum energy use can also bring about energy cost reductions. In some ports, a sizeable part of the energy consumption comes from reefer containers. Ports can improve energy distribution, design better power plans and implement many other methods for reefer containers [67].

Other activities are more specifically aligned with sustainability. In all the analyzed ports, at least four different sustainability activities have committed to making sustainability improvements everyday targets for ports. Onshore power systems for ships in berth, renewable energy production, air quality measurements and hybrid or electric equipment are common measures. Many port authorities and some terminal operators have an environmental management system in use (ISO 140001 or PERS). It appears that in a port environment, there are several applications where cost reductions and sustainability goals can be achieved simultaneously, which supports sustainability innovations (and communicating about them).

4.3.3. Collaboration

The last category's goals relate to collaborative innovation, including networking and partnering, that ensure keeping up with technology and operational development and exploring potential new solutions. Increased collaboration and related issues, e.g., interaction, integration, transparency is a central aim in Port 4.0 [1,40,42,52,55,57,59]. The ports strive to improve the operations stretching over several organizations which requires collaboration and sharing of data between the ecosystem players [56]. This relates to the aforementioned consolidation trend and also to the entrancement of new players from outside of the maritime industry. The hard decision is to select collaborators and decide upon the alternative directions to put most effort into.

Customer and stakeholder services are related to answering various different information needs of a variety of port and supply chain stakeholders that are not actively taking part in actual container handling; for example, a typical case would be a cargo owner or recipient calling different port actors to obtain information on a certain container's location, the reason for delay or an arrival estimation or similar. In addition, forwarders, logistic service providers and container depots might be other information users. This is a slightly different need to actual cargo handling actors who need to track containers for operational reasons such as for ensuring the right container is loaded on the right vessel. Those actors are familiar with the port in question. However, responding to external stakeholders' information needs can actually be characterized as customer service. Transmitted information naturally needs to be true and reliable but also be transmitted quickly and via an easy method. This is realized in the form of various container tracking apps and online tools for each port actor. All ports offer a container tracking function, as do major ocean carriers themselves. The lesson learnt here is that a port does not include any single database for its containers, but rather different actors' information systems or digital platforms are integrated together with APIs if possible. Users and their needs are different, and a truck driver may receive a selected piece of information on their mobile app, whereas a forwarder uses the same information in a broader form through a different portal. A good example of API use is with APM Terminals, which opened an online API store for its customers

and partners. Different APIs enable users "to track import availability at container level, including container data, estimated time of arrival and date of discharge from the vessel, the status of the container, any holds on the container, and whether a truck appointment has been made". This kind of approach opens up customization opportunities for diverse needs, ultimately reducing the need for phone calls, investigations and other burdens.

Co-creation and Innovation. Both short-term and long-term co-creation is needed. Short-term co-creation aims to improve processes and solve practical problems, but in the long-term, co-creation aims to keep up with potential game-changing technologies. For example, radical breakthroughs in 3D printing could in theory shift transportation structures from finished goods to bulk. On many occasions, smart port development is connected to piloting different technologies, but often the primary incentive of the pilots relates to developing technological capabilities for the longer term. Changes to actual core operations are usually brought in only step-by-step.

There are multiple stakeholders operating within the physical port area, and in some operational areas they share similar development interests. Some new digital innovations are linked to an even wider environment that surpasses the port boundaries into the supply chain through both horizontal and vertical collaboration. One example is improvement in traffic flow in ports and between port and cargo destinations—it is of interest to port authorities and operators, terminal operators, shipping lines, logistics companies, cargo owners, rail operators and barge operators [16]. Each actor needs to weigh up with whom they should collaborate with. Depending on each actor's goals, they need to evaluate what kind of balance they are aiming for—whether it is between a select small group of close partners or a broad and versatile set of more distant collaborators.

The vision of the Port of Rotterdam and the British Port Association provides glimpses into the way they see the collaboration. Their vision divides port digitalization into four maturity layers: (1) single ports striving to develop and digitalize their own processes; (2) port communities and companies operating in the vicinity of the port and integrating their operations with the help of data sharing; (3) ports actively sharing information with regard to hinterland logistics; (4) ports becoming networked with each other, creating highly detailed on-demand transport chains. Whereas the above maturity model sees the four distinctive scenarios as steps towards increased digitalization, the Smarter Ports Manifesto published in March 2021 makes the competition and power play between stakeholders more visible. For instance, it suggests that vertically integrated logistics chains led by the carrier alliances and global digital integrators aim for increased transparency. This strengthens the position of shipping line alliances, which already dominate the chain, and large terminal operators, which have also started to join in. Moreover, it acknowledges that e-commerce giants such as Amazon and Alibaba have the power to vertically integrate with local service providers, effectively cutting out many incumbents.

Our analysis argues that port authorities have a strong motivation to led "green" or sustainable development and connecting their ports with the local authorities and the surrounding city. On the other hand, shipping lines could take the leading role in connecting logistics operations of ships and terminal operators into a more coherent one. An even more comprehensive approach could be taken by some large cargo owner, such as Alibaba or Amazon, or a freight forwarder with a focus on making the logistics chain from the factory all the way to the end customer more efficient and predictable.

All this points out that the key factor impacting the future direction of digitalization is the party who has the leading role in the innovation activity at the port.

5. Scenarios: Focus of Digital Innovations in Future Ports

Based on the literature analysis and scanning of current R&D activities in the previous section, we propose four scenarios on the digital innovation in ports, especially in container ports. The formulation of the scenarios has been made based on the key factor likely impacting the future direction: the main distinguishing factor between the scenarios is the

initiator(s) pushing and controlling the development. The characteristics of the scenarios are presented in Table 4.

Table 4. Port Digitalization Scenarios.

Name	Fragmented Innovation	Port Ecosystem	Logistic Chain Alliance	Global Closed Platforms
Led by	No clear leader. Every organization does this for itself and mainly keeps the development under their own control	Port authority primarily	Shipping line	Large player outside maritime industry such as Amazon, Alibaba or other high-volume cargo owner
Rationale	Aims at cost reduction	Aims at fulfilling local political and social objectives	Aims at improving efficiency of sea logistics with larger volumes and better global coverage	Aim at predictable door-to-door deliveries
Collaboration	Collaboration is superficial and opportunistic. Terminals and other actors in ports are striving to develop their own processes	Active collaboration within the port community, city and companies nearby	Shipping line creates stronger alliances with terminals, and increasingly with inland logistics companies	Collaborate with own terminal or with selected contracted terminals
Sustainability	Meets the requirements of the local laws	High incentives to improve due to political and social demands	Meets the requirements of the local laws. Most activities focus on improving energy efficiency of sea voyage	Two diverse outcomes are possible: Ports are selected so that they (a) minimize the sustainability requirements, or (b) meet the potentially increasing sustainability demands set by customers
Automation	Focus on digitalization of company internal processes. Port 4.0 development leads towards group of intelligent, but loosely connected systems	Focus on collaborative ICT between the parties. Port 4.0 development leads towards integrated operations and shared data	Focus on digitalization of the port–ship–port operations. Port 4.0 development leads towards open solutions and platforms for sharing data on cargo	Focus on the exchange nodes within the logistics chain, improving their predictability. Development towards own closed, tightly controlled and optimized logistic pipes and systems

5.1. Fragmented Innovation

In this scenario, each party seeks only to streamline its own internal operations. The main goal is likely to be cost reduction. However, competition forces organizations to implement some digital innovations to enhance services to customers. For example, terminal operators can try to provide attractive value propositions to shipping companies, such as fast port calls.

Cooperation with other actors is superficial and opportunistic. Individual relationships may work well if successful communication and marketing departments take as much advantage as possible from the collaboration. Sustainability is not very high on the list, but necessary actions are taken to meet the requirements of the local laws.

This scenario results in a group of individual digitalized intelligent systems. The sum of the systems, however, does not function particularly well. The parties are independently developing their own systems and putting money into their own systems, trying to build bridges to others using APIs, some working better and some less so. Lots of effort is put

into discussion and agreeing on interfaces between the different IT systems of parties, and these are also tested in a variety of projects and experiments with varying results.

This scenario represents a status quo situation, where no fundamental changes are needed to the current situation at ports. It will not lead to fast or radical changes in the ports. There is no one to take the lead on digital development, because even the big players do not have the means to redirect the development. It also raises a question whether intelligent development of ports is not worth the effort, and instead better results can be achieved with smaller investments in the development of supply chain operations outside ports.

5.2. Port Ecosystem

In this scenario, the local port community becomes a major hub. The aim is to create an intelligent, digitalized platform joining the actors together around a physical port. We expect the port authority to take the leading role. Other key players include terminal operators, port service providers, customs and public authorities.

The political and social objectives are of importance. The port is seen as an elemental part of the nearby city, because it provides work, well-being and wealth to the community. Sustainable development (less pollution, noise, light), optimal use of space, and reduction of traffic congestion both on the seaside and towards the hinterland are high on the agenda [70]. The employment impact of a port can also be an important issue.

The intelligence covers the whole port area. Situational awareness within the port is one important focus area. The parties are integrating automation and share data as far as possible. Port control centers and towers would consist of the real-time data, decision-making tools, digital platform and interfaces to the port community and customers. Advanced analytics and machine learning are required. Ideally, the control tower would coordinate and optimize the management of the entire port. Some information is also shared in the supply chain, but then through APIs between separate systems. In general, supply chain integration is still lacking, i.e., there is only partial sharing of information with trucking, forwarding, shipping, cargo owners or consumers.

The development of common interface standards is a prerequisite for efficient information sharing. At best, parties agree to the adoption of Industry 4.0 standards, which allows the integration of systems within the port, but also towards other potential Industry 4.0-compatible parties.

Local and national policy is certainly in favor of this scenario. Port authorities are showing strong interest. On the other hand, in larger ports, there are usually several operators, and the question remains whether they would be willing to collaborate and even use joint systems, and whether authorities would allow commercial operators to use the same systems.

5.3. Logistic Chain Alliance

In this scenario, shipping companies want closer cooperation with the terminal. The port–ship–port chain is better synchronized. The emphasis in terminal development is on more efficient and predictable services for the vessels, and possibly also inland transport companies.

The most powerful shipping line alliances led the development, perhaps with the help of IT companies (think, for example, about the Maersk and IBM collaboration, Tradelens). The shipping alliances and their preferred terminal operators are developing common practices and information exchange. Standardization has been one of the drivers in logistics chain alliances. Digital innovations are mainly focused on the exchange points within the logistics chain, improving their predictability. One important focus area is to improve estimated arrival times, loading/unloading and delivery times. Otherwise, each party manages their own plot, perhaps sharing experiences and jointly agreeing on workable solutions.

Sustainability is perhaps not among the most important issues when thinking about the activities in ports. Most activities will focus on improving energy efficiency of sea

voyage. This scenario can also lead to development towards logistics marketplaces, where the shipper can obtain information about different transport options and their prices, for example. Then, there could also be pressure to improve sustainability, as demonstrated by the news from the world's largest shipping company that it is going to phase out the use of fossil fuels in its new ships.

The development of shipping alliances has been a very strong trend for a long time, and there is nothing to prevent it from spreading to cover terminals as well. On the other hand, shipping alliances do not appear to utilize their potential power at present, and it may be that such cooperation is developing only in a few ports used by the largest shipping companies.

5.4. Global Closed Platform

In this scenario, true end-to-end transportation chains are established. The initiative is likely to come from outside traditional port operators looking to drive significant change—a total digital solution. The most likely candidates are large global cargo owners, such as Amazon and Alibaba. Here, ports are considered as transit points and even small inefficiencies in individual processes can be allowed if the whole end-to-end logistics chain is improved.

Regarding sustainability issues, we see two diverse outcomes as possible. The leading cargo owner may select its collaboration ports in such a way that they have minimum sustainability requirements, but if their customers start to demand greener transportation, these increased demands will be passed on to the collaborating ports and require them to make sustainable choices.

In extreme cases, the cargo owner owns the port terminals, or there is some other subordination relationship in place. The cargo owner might bring their own digital systems to ports as well, or at least on their terms. In the long run, particular shipping companies would almost be forced to react to this development somehow, but it is hard to say how.

Now, for the first time, land-based actors are big enough, have the courage, resources and even the strategies to make big changes in global logistics. Clearly, Amazon and Alibaba are moving towards this goal. Currently, no one else is able or willing to solve the problem of complex transport chains. Moreover, it should be remembered that China's Silkroad strategy supports Alibaba's expansion to global logistics. On the other hand, we can question whether large cargo owners have an interest in owning terminals, considering capital needs, unions, etc. In some parts of the world this might happen (e.g., in China), but in other parts of the world it may go differently. Thus, this scenario can also be realized on a smaller scale, perhaps regionally, such as in selected transport pipelines within Asia, or it may only affect the logistics of consumer goods. There is plenty of transportation of intermediate products that is taken care of by other (probably smaller) ports and terminals. Port authorities will certainly oppose this because it will take power away from them, and they may fear that the sources of revenue will also diminish.

6. Discussion and Implications

Based on the findings from this study, we discuss next managerial and policy implications, as well as theoretical implications.

6.1. Managerial and Policy Implications

Our analysis shows that currently, terminal operators mainly invest in digitalization of terminal operations and using fossil-free energy sources. They are less active in interorganizational development, except only in narrowly focused issues. Typically, the business models of their customers—the shipping companies—rely on scale economies using large vessel sizes. As a response, the container terminals serve them best by unloading and loading the vessels as efficiently as possible. There is a danger that their digitalization efforts focus on improving efficiency by simple automation. Thus, it seems that terminal operators are not willing to take a leading role in smart port ecosystem development. This

may result in "Fragmented Innovation", where port digital innovation activity is low and only necessary innovations are implemented.

The leading global ports show an increased activity in smart port ecosystem development, especially in integrating information systems and so on. These actions are typically initiated by port authorities and are usually targeted towards the immediate port community and close stakeholders. To respond to current local and national policies driving sustainability, many of the development activities relate to sustainability goals and improved energy efficiency, but also to experimenting with new technology. This means a substantial emphasis on digitalization which improves environmental and energy efficiency and makes ports "green". Thus, if sustainable development goals are considered important, policy guidance should encourage towards the "Port Ecosystem" scenario in particular.

Terminal operators seem to be more eager to innovate if the need comes from the shipping lines. This supports the probability of "Logistic Chain Alliance" being the scenario where smart ports utilize analytics to serve the logistics chain. Terminal operators consider shipping lines having the key role in setting the direction for future port development. The "Logistics Chain Alliance" scenario builds on the assumption that shipping companies want full integration with the terminals and land carriers. There are two potential outcomes for terminal development: either the focus is on improving the efficiency and cost-effectiveness, or, alternatively, if shipping lines start to provide faster or more flexible shipping services, they may want to have more visibility of (and control over) the activities at terminals, added smartness in the containers, and differentiated handling of cargo at terminals depending on the priority group, for example. This requires the use of data analytics and the sharing of data/knowledge between stakeholders.

The logistics chains may be disrupted by players coming from outside the maritime industry. The most likely candidates are large cargo owners, such as Amazon and Alibaba, of which the latter is supported by China's strategy. The Chinese Belt and Road infrastructure programme and e-commerce growth are signaling that China-led digital trade might shape the transportation playing field and threaten the status of incumbent carriers and logistics service providers. This would restructure the business more radically. The giants are likely to introduce in-house and very centralized IT systems, analytics and operation management tools also covering port terminals.

The authors consider all four scenarios possible, and they may in fact be realized simultaneously. We see that the alternative scenarios are not mutually exclusive, but it may well be so that in the future, they coexist simultaneously in different ports around the world. This means that there will be many differing smart concepts and definitions with differing development emphases.

6.2. Theoretical Implications

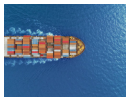
Building on scientific literature and state-of-the-art analysis of innovation activities at selected ports, this article proposes four alternative directions for digital innovation at container ports. It supports findings of previous analyses [13,36] that digitalization is a central mean in development of future ports. Our study contributes to the scientific discussion by presenting scenarios where the focus of digitalization differs depending on who is the party leading the innovation activity. While we found automation, sustainability and collaboration to be the main innovation areas, the ports in differing scenarios significantly differ in their emphasis on these areas. As a result, in the future, ports may be highly digitalized, but still look very different, some excelling, e.g., in green innovations, and other in efficiency of sea logistics.

This also has theoretical implications for the research on future smart port indexes [3,4,39]. These indexes could be developed further, so that they would show the variety in directions of digitalization utilization in port innovation.

7. Conclusions

This research discusses the development of container ports towards smart ports. According to our findings from the literature and state-of-the-art analysis, innovation is directed towards digitalization making the ports more automated, green and collaborative. The ports are paying attention to cargo operations, traffic management, safety and cybersecurity, energy and other environmental issues, as well as services towards stakeholders and collaboration and innovation with partners.

However, ports are constellations of several interdependent actors with varying interests and power within the ecosystem. This has an effect on the way the future development of ports might be shaped. We suggest that the main factor determining the scenarios, i.e., the direction of digitalization in ports, is the party leading the innovation activities. Building on our findings from the analysis, we constructed four potential scenarios for Port 4.0 (Figure 1).



	FRAGMENTED INNOVATION	PORT ECOSYSTEM	LOGISTIC CHAIN ALLIANCE	GLOBAL CLOSED PLATFORM
Lead by:	No clear leader	Port authority	Shipping line	Large player outside maritime industry
Collaboration:	Superficial and opportunistic	Active within the port community, city and companies nearby	With selected terminals and maybe with inland logistics companies.	With terminals it owns or with selected contracted terminals
Rationale:	Cost reduction	Political and social objectives, e.g. sustainability	Efficiency of sea logistics	Predictable door-to-door deliveries
Port4.0 development leads towards::	Group of intelligent - but loosely connected – systems.	Integrated operations and shared data.	Open solutions and platforms for sharing data on cargo.	Own closed, tightly controlled and optimised logistic pipes and systems.

Figure 1. Four Potential scenarios of Port 4.0.

In the first scenario, port development is slow and only necessary digital innovations are implemented. In the second scenario, the innovation leader is the port authority, and the focus is especially on political and social objectives such as environmental issues. Third scenario assumes that a shipping alliance takes the lead on R&D. It creates stronger cooperation with large terminal operators with an aim to use digitalization for efficiency improvement of sea logistics. In the last scenario, a large player outside the maritime industry, such as Amazon and Alibaba or other high-volume cargo owner, uses global digital platforms to create their own predictable logistics pipes. All these scenarios have their own characteristics and led towards different kinds of manifestations of digital innovation in ports.

National and international politics certainly have a major impact on the direction the future takes. For example, the current European blue economy policy supports the port ecosystem scenario where innovation is led by the port authority and where sustainable development goals are considered important. On the other hand, the Chinese Belt and Road infrastructure programme supports other scenarios where Chinese companies have the possibility to gain better control of the global logistics chains.

Having said that, we do not see the alternative scenarios as mutually exclusive, but it may well be so that in the future they coexist simultaneously in different ports around the world.

Our study contributes to the scientific discussion on digital innovation in ports. Automation, sustainability and collaboration are found to be the main innovation areas. However, depending on the leader of the innovation, the ports end up utilizing the digitalization very differently. We suggest that research on smart port indexes could be developed further, towards measuring and visualizing the direction taken by the ports.

Like any research, this study has its limitations. This paper provides evidence from scientific articles and from state-of-the art data. Perhaps the biggest downside is that the scenarios were ultimately constructed by the researchers. Here, the credibility of the results could be improved by collecting more quantitative data and by collecting feedback from experts. Moreover, we should be aware of the uncertainty of forecasting, where unexpected events may have significant disruptive impacts. Thus, several opportunities for further research arise from our study. The logical next step would be to systematically collect feedback on the scenarios. They could be substantiated with empirical studies in container ports to understand the relevance and boundary conditions, as well as with theory-based research focused on explaining their mechanisms. The study might also be replicated in other types of ports, to better understand smart port concept and its emergence in maritime sector.

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References

1. González-Cancelas, N.; Molina Serrano, B.; Soler-Flores, F.; Camarero-Orive, A. Using the SWOT Methodology to Know the Scope of the Digitalization of the Spanish Ports. *Logistics* **2020**, *4*, 20. [CrossRef]
2. Vanelslander, T.; Sys, C.; Lam, J.S.L.; Ferrari, C.; Roumboutsos, A.; Acciaro, M.; Macário, R.; Giuliano, G. A serving innovation typology: Mapping port-related innovations. *Transp. Rev.* **2019**, *39*, 611–629. [CrossRef]
3. Philipp, R. Digital readiness index assessment towards smart port development. *Nachhalt. Manag. Forum* **2020**, *28*, 49–60. [CrossRef]
4. Molavi, A.; Lim, G.J.; Race, B. A framework for building a smart port and smart port index. *Int. J. Sustain. Transp.* **2020**, *14*, 686–700. [CrossRef]
5. Triska, Y.; Frazzon, E.M.; Silva, V.M.D.; Heilig, L. Smart port terminals: Conceptual framework, maturity modeling and research agenda. *Marit. Policy Manag.* **2022**, 1–24. [CrossRef]
6. Yeo, G.T.; Roe, M.; Dinwoodie, J. Measuring the competiti'eness of container ports: Logisticians' perspectives. *Eur. J. Mark.* **2011**, *45*, 455–470. [CrossRef]
7. Güner, S. Incorporating value judgments into port efficiency measurement models: Insights from Turkish ports. *Marit. Econ. Logist.* **2018**, *20*, 569–586. [CrossRef]
8. Acciaro, M.; Ferrari, C.; Lam, J.S.L.; Macario, R.; Roumboutsos, A.; Sys, C.; Tei, A.; Vanelslander, T. Are the innovation processes in seaport terminal operations successful? *Marit. Policy Manag.* **2018**, *45*, 787–802. [CrossRef]
9. Chu, F.; Gailus, S.; Liu, L.; Ni, L. The Future of Automated Port, Mckinzey. 2018. Available online: https://www.mckinsey.com/industries/travel-logistics-and-transport-infrastructure/our-insights/the-future-of-automated-ports (accessed on 5 December 2022).
10. Tijan, E.; Jović, M.; Aksentijević, S.; Pucihar, A. Digital transformation in the maritime transport sector. *Technol. Forecast. Soc. Chang.* **2021**, *170*, 120879. [CrossRef]
11. Acciaro, M.; Renken, K.; El Khadiri, N. Technological Change and Logistics Development in European Ports. In *European Port Cities in Transition*; Carpenter, A., Lozano, R., Eds.; Springer: Cham, Switzerland, 2020; pp. 73–88.
12. Fahim, P.B.; Rezaei, J.; van Binsbergen, A.; Nijdam, M.; Tavasszy, L. On the evolution of maritime ports towards the Physical Internet. *Futures* **2021**, *134*, 102834. [CrossRef]
13. Inkinen, T.; Helminen, R.; Saarikoski, J. Technological trajectories and scenarios in seaport digitalization. *Res. Transp. Bus. Manag.* **2021**, *41*, 100633. [CrossRef]

14. Kagermann, H.; Wahlster, W.; Helbig, J. Securing the Future of German Manufacturing Industry—Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0, Final Report of the Industrie 4.0 Working Group. 2013. Available online: https://www.din.de/blob/76902/e8cac883f42bf28536e7e8165993f1fd/recommendations-for-implementing-industry-4-0-data.pdf (accessed on 5 December 2022).
15. Reischauer, G. Industry 4.0 as policy-driven discourse to institutionalize innovation systems in manufacturing. *Technol. Forecast. Soc. Chang.* **2018**, *132*, 26–33. [CrossRef]
16. De la Peña Zarzuelo, I.; Freire Soeane, M.J.; López Bermúdez, B. Industry 4.0 in the port and maritime industry: A literature review. *J. Ind. Inf. Integr.* **2020**, *20*, 100173. [CrossRef]
17. Jun, W.K.; Lee, M.K.; Choi, J.Y. Impact of the smart port industry on the Korean national economy using input-output analysis. *Transp. Res. Part A Policy Pract.* **2018**, *118*, 480–493. [CrossRef]
18. Botti, A.; Monda, A.; Pellicano, M.; Torre, C. The re-conceptualization of the port supply chain as a smart port service system: The case of the port of Salerno. *Systems* **2017**, *5*, 35. [CrossRef]
19. Buiza-Camacho, G.; Cerbán-Jiménez, M.; González-Gaya, C. Assessment of the factors influencing on a smart port with an analytic hierarchy process. *DYNA* **2016**, *91*, 498–501. [CrossRef]
20. Ferretti, M.; Schiavone, F. Internet of Things and business processes redesign in seaports. The case of Hamburg. *Bus. Process Manag. J.* **2016**, *22*, 271–284. [CrossRef]
21. Yang, Y.; Zhong, M.; Yao, H.; Yu, F.; Fu, X.; Postolache, O. Internet of things for smart ports: Technologies and challenges. *IEEE Instrum. Meas. Mag.* **2018**, *21*, 34–43. [CrossRef]
22. Chiarello, F.; Trivelli, L.; Bonaccorsi, A.; Fantoni, G. Extracting and mapping industry 4.0 technologies using Wikipedia. *Comput. Ind.* **2018**, *100*, 244–257. [CrossRef]
23. Culot, G.; Orzes, G.; Sartor, M.; Nassimbeni, G. The future of manufacturing: A Delphi-based scenario analysis on Industry 4.0. *Technol. Forecast. Soc. Chang.* **2020**, *157*, 120092. [CrossRef]
24. Martelli, A. Scenario building and scenario planning: State of the art and prospects of evolution. *Future Res. Q.* **2001**, *17*, 57–74.
25. Peterson, G.D.; Cumming, G.S.; Carpenter, S.R. Scenario planning: A tool for conservation in an uncertain world. *Conserv. Biol.* **2003**, *17*, 358–366.
26. Schoemaker, P.J. Scenario planning: A tool for strategic thinking. *Sloan Manag. Rev.* **1995**, *36*, 25–50.
27. Schmidt-Scheele, R. 'Plausible' energy scenarios?! How users of scenarios assess uncertain futures. *Energy Strategy Rev.* **2020**, *32*, 100571. [CrossRef]
28. Walton, S.; O'Kane, P.; Ruwhiu, D. Developing a theory of plausibility in scenario building: Designing plausible scenarios. *Futures* **2019**, *111*, 42–56. [CrossRef]
29. Hussain, M.; Tapinos, E.; Knight, L. Scenario-driven roadmapping for technology foresight. *Technol. Forecast. Soc. Chang.* **2017**, *124*, 160–177. [CrossRef]
30. Notteboom, T.; Pallis, A.; Rodrigue, J.-P. *Port Economics, Management and Policy*; Routledge: New York, NY, USA, 2021.
31. UNCTAD. Review of Maritime Transport 2020. *United Nations.* 2020. Available online: https://unctad.org/system/files/official-document/rmt2020summary_en.pdf (accessed on 5 December 2022).
32. Bierwirth, C.; Meisel, F. A follow-up survey of berth allocation and quay crane scheduling problems in container terminals. *Eur. J. Oper. Res.* **2015**, *244*, 675–689. [CrossRef]
33. Ivanov, D. Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case. *Transp. Res. Part E Logist. Transp. Rev.* **2020**, *136*, 101922. [CrossRef]
34. Savelsberg, E. Part One: Our Industry, PTI 100th Edition Video Interview of Eva Savelsber, Senior Vice President of Inform. 17 September 2020. Available online: https://www.youtube.com/watch?v=L_uENdP9Ttc (accessed on 18 November 2022).
35. Lee, P.T.W.; Hu, Z.H.; Lee, S.; Feng, X.; Notteboom, T. Strategic locations for logistics distribution centers along the Belt and Road: Explorative analysis and research agenda. *Transp. Policy* **2022**, *116*, 24–47. [CrossRef]
36. Fenton, C.; Storrs-Fox, P.; Joerss, M.; Saxon, S.; Stone, M. Brave New World? Container Transport in 2043. TT Club & McKinsey & Company. 2018. Available online: https://www.mckinsey.com/~{}/media/mckinsey/industries/travel%20transport%20and%20logistics/our%20insights/brave%20new%20world%20container%20transport%20in%202043/brave-new-world-container-transport-in-2043.pdf (accessed on 18 November 2022).
37. Pu, S.; Lam, J.S.L. Blockchain adoptions in the maritime industry: A conceptual framework. *Marit. Policy Manag.* **2021**, *48*, 777–794. [CrossRef]
38. Jović, M.; Tijan, E.; Brčić, D.; Pucihar, A. Digitalization in Maritime Transport and Seaports: Bibliometric, Content and Thematic Analysis. *J. Mar. Sci. Eng.* **2022**, *10*, 486. [CrossRef]
39. Teerawattana, R.; Yang, Y.C. Environmental performance indicators for green port policy evaluation: Case study of Laem Chabang port. *Asian J. Shipp. Logist.* **2019**, *35*, 63–69. [CrossRef]
40. Camarero Orive, A.; Santiago, J.I.P.; Corral, M.M.E.-I.; González-Cancelas, N. Strategic Analysis of the Automation of Container Port Terminals through BOT (Business Observation Tool). *Logistics* **2020**, *4*, 3. [CrossRef]
41. D'Amico, G.; Szopik-Depczyńska, K.; Dembińska, I.; Ioppolo, G. Smart and sustainable logistics of Port cities: A framework for comprehending enabling factors, domains and goals. *Sustain. Cities Soc.* **2021**, *69*, 102801. [CrossRef]
42. Heilig, L.; Voß, S. Information systems in seaports: A categorization and overview. *Inf. Technol. Manag.* **2017**, *18*, 179–201. [CrossRef]

43. Alahmadi, D.H.; Baothman, F.A.; Alrajhi, M.M.; Alshahrani, F.S.; Albalawi, H.Z. Comparative analysis of blockchain technology to support digital transformation in ports and shipping. *J. Intell. Syst.* **2022**, *31*, 55–69. [CrossRef]
44. Alop, A. The main challenges and barriers to the successful "smart shipping". *TransNav Int. J. Mar. Navig. Saf. Sea Transp.* **2019**, *13*, 521–528. [CrossRef]
45. Ben Farah, M.A.; Ukwandu, E.; Hindy, H.; Brosset, D.; Bures, M.; Andonovic, I.; Bellekens, X. Cyber security in the maritime industry: A systematic survey of recent advances and future trends. *Information* **2022**, *13*, 22. [CrossRef]
46. Braidotti, L.; Mazzarino, M.; Cociancich, M.; Bucci, V. On the Automation of Ports and Logistics Chains in the Adriatic Region. In *International Conference on Computational Science and Its Applications*; Springer: Cham, Switzerland, 2020; pp. 96–111.
47. Camarero Orive, A.; González-Cancelas, N.; Vaca Cabrero, J.; Parra Santiago, J.I. Use of a Delphi Panel to Determine the Degree of Implementation of Blue Economy in Spanish Ports. *J. Mar. Sci. Eng.* **2022**, *10*, 1573. [CrossRef]
48. Chang, Y.; Iakovou, E.; Shi, W. Blockchain in global supply chains and cross border trade: A critical synthesis of the state-of-the-art, challenges and opportunities. *Int. J. Prod. Res.* **2020**, *58*, 2082–2099. [CrossRef]
49. Cil, A.Y.; Abdurahman, D.; Cil, I. Internet of Things enabled real time cold chain monitoring in a container port. *J. Shipp. Trade* **2022**, *7*, 9. [CrossRef]
50. De la Peña Zarzuelo, I. Cybersecurity in ports and maritime industry: Reasons for raising awareness on this issue. *Transp. Policy* **2021**, *100*, 1–4. [CrossRef]
51. Frost & Sullivan. Supporting Business Finland to Drive Exports by Improving Its Insight on Trends: Smart Ports. 2019. Available online: https://www.businessfinland.fi/49e303/globalassets/finnish-customers/02-build-your-network/digitalization/smart-mobility/191211---fs---smart-ports-final-report.pdf (accessed on 18 November 2022).
52. Heilig, L.; Schwarze, S.; Voß, S. An Analysis of Digital Transformation in the History and Future of Modern Ports. In Proceedings of the 50th Hawaii International Conference on System Sciences, Waikoloa Village, HI, USA, 4–7 January 2017. [CrossRef]
53. Heilig, L.; Lalla-Ruiz, E.; Voß, S. port-IO: An integrative mobile cloud platform for real-time inter-terminal truck routing optimization. *Flex. Serv. Manuf. J.* **2017**, *29*, 504–534. [CrossRef]
54. Hua, C.; Chen, J.; Wan, Z.; Xu, L.; Bai, Y.; Zheng, T.; Fei, Y. Evaluation and governance of green development practice of port: A sea port case of China. *J. Clean. Prod.* **2020**, *249*, 119434. [CrossRef]
55. Jensen, L. *Liner Shipping 2025: How to Survive and Thrive*; Vespucci Maritime Publishing: Copenhagen, Denmark, 2017.
56. Lind, M.; Lehmacher, W.; Haraldson, S.; Fu, X.; Zuesongdham, P.; Huesmann, R.; Fich, S. Smart ports as lighthouse nodes of supply chain networks. Port Technology. 2020. Edition 104. Technical Paper. Available online: https://www.porttechnology.org/technical-papers/smart-ports-as-lighthouse-nodes-of-supply-chain-networks/ (accessed on 18 November 2022).
57. Montesinos, M.; de la Guia, J.G. Smart Port—A System of Systems Approach. Port Technology. 2016. Edition 69. Technical Paper. Available online: https://www.porttechnology.org/technical-papers/smart_port_a_system_of_systems_approach/ (accessed on 18 November 2022).
58. Notteboom, T. The European container port scene 2019 and outlook for 2020. *Port Technol. Int.* **2019**, *92*, 8–10. Available online: https://www.porttechnology.org/wp-content/uploads/2019/12/NOTTEBOOM.pdf (accessed on 18 November 2022).
59. Rodrigo González, A.; González-Cancelas, N.; Molina Serrano, B.; Orive, A.C. Preparation of a Smart Port Indicator and Calculation of a Ranking for the Spanish Port System. *Logistics* **2020**, *4*, 9. [CrossRef]
60. Wang, K.; Hu, Q.; Zhou, M.; Zun, Z.; Qian, X. Multi-aspect applications and development challenges of digital twin-driven management in global smart ports. *Case Stud. Transp. Policy* **2021**, *9*, 1298–1312. [CrossRef]
61. Wang, P.; Mileski, J.P.; Zeng, Q. Alignments between strategic content and process structure: The case of container terminal service process automation. *Marit. Econ. Logist.* **2019**, *21*, 543–558. [CrossRef]
62. Yau, K.L.A.; Peng, S.; Qadir, J.; Low, Y.C.; Ling, M.H. Towards Smart Port Infrastructures: Enhancing Port Activities Using Information and Communications Technology. *IEEE Access* **2020**, *8*, 83387–83404. [CrossRef]
63. Zhou, C.; Ma, N.; Cao, X.; Lee, L.H.; Chew, E.P. Classification and literature review on the integration of simulation and optimization in maritime logistics studies. *IISE Trans.* **2021**, *53*, 1157–1176. [CrossRef]
64. Zhang, X.; Zeng, Q.; Yang, Z. Optimization of truck appointments in container terminals. *Marit. Econ. Logist.* **2019**, *21*, 125–145. [CrossRef]
65. Giusti, R.; Manerba, D.; Bruno, G.; Tadei, R. Synchromodal logistics: An overview of critical success factors, enabling technologies, and open research issues. *Transp. Res. Part E Logist. Transp. Rev.* **2019**, *129*, 92–110. [CrossRef]
66. ENISA. Port Cybersecurity. Good Practices for Cybersecurity in the Maritime Sector, European Union Agency for Cybersecurity (ENISA). 2019. Available online: https://www.enisa.europa.eu/publications/port-cybersecurity-good-practices-for-cybersecurity-in-the-maritime-sector (accessed on 18 November 2022).
67. Iris, Ç.; Lam, J.S.L. A review of energy efficiency in ports: Operational strategies, technologies and energy management systems. *Renew. Sustain. Energy Rev.* **2019**, *112*, 170–182. [CrossRef]
68. Chen, G.; Govindan, K.; Golias, M. Reducing truck emissions at container terminals in a low carbon economy: Proposal of a queueing-based bi-objective model for optimizing truck arrival pattern. *Transp. Res E Logist Transp. Rev* **2013**, *55*, 3–22. [CrossRef]
69. Dong, C.; Boute, R.; McKinnon, A.; Verelst, M. Investigating synchromodality from a supply chain perspective. *Transp. Res. Part D Transp. Environ.* **2018**, *61*, 42–57. [CrossRef]
70. Beškovnik, B.; Bajec, P. Strategies and approach for smart city–port ecosystems development supported by the internet of things. *Transport* **2021**, *36*, 433–443. [CrossRef]