Smart Port Concept: Strategic Development, Best Practices, Perspectives of Development

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Abstract Seaports play an important role in the maritime supply chain. In recent years, the need for process optimization and automation solutions has increased, not least due to growing challenges regarding the complexity of processes. This is due to the growth in ship size and space restrictions in ports. The use of new technologies offers opportunities to meet these challenges. Large ports are increasingly implementing automated process solutions to meet these challenges. Science is also developing new approaches to optimize processes and to better connect the maritime supply chain. In the context of the chapter, solution approaches from science and practice are presented to give an insight into the current developments in ports to become smart ports. Different aspects such as the networking of logistics partners, automation and artificial intelligence, processes and environmental aspects are addressed.

1 Introduction

Increasing global trade and megatrends such as Industry 4.0 and the increasing demand for individualized products in combination with shorter product life cycles are leading to a change in logistics chains. This results in a global division of labor, decreasing logistics costs and the opening of new markets. These trends also have an impact on seaports (Philipp, 2020).

Seaports play an important role as interfaces in global maritime supply chains. In addition to transshipment between the different modes of transport, storage, as well as pre- and post-processing of goods, ports offer various types of value-added logistics services. However, seaports have to deal with different challenges in order to stay competitive or to maximize the efficiency of the maritime supply chain. Especially increasing ship sizes, geographically limited growth opportunities and increasing pressure on the productivity of seaports are current challenges. At the

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same time, the demands to reduce emissions along the entire supply chain are becoming more important. These structural changes and challenges in the logistics chain need to be addressed. One possibility is digitization along the entire maritime supply chain, for example by integrating new information technologies and global networking. Seaports can benefit from the development of traditional ports into smart ports, increasing connectivity among the individual actors and improving their performance (Karas, 2020).

The chapter "Smart Port concept: strategic development, best practices, perspectives of development" is intended to provide an overview of what smart ports are and which innovative digital technologies are already being used both in science and in practice around seaports. First, a brief definition of a smart port is given in section 2 "Definition", followed by a presentation of the development stages of ports from simple loading and unloading ports to smart ports. In the following section, theoretical as well as practical innovative solutions from science and industry for reducing complexity in ports are presented. Finally, the chapter ends with a summary of all important findings and an outlook.

2 Definition

During the last decades, the function of a port has changed significantly, as can be seen in Fig. 1. In the first generation, ports were only loading and unloading nodes between waterside and landside modes of transportation. In the beginning, the ports' function was limited to services related to ships and the goods they handled. However, more and more manufacturing industries settled around the ports. Therefore, the second generation of ports is called "industrial port." After the 1980s, it can be seen that ports have become more than simple transshipment hubs. They also offering value-added services related to the distribution of goods, as well as data

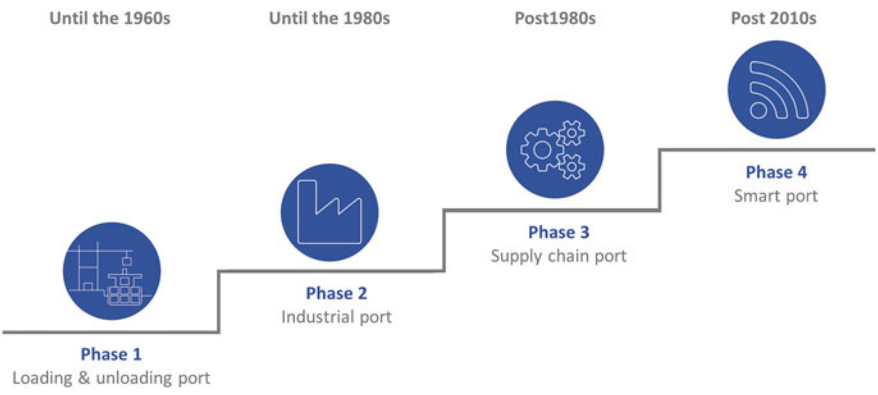

Fig. 1 Port development (based on Berns et al. 2017)

Fig. 2 A smart port uses innovative digital technologies to improve its performance (Saxe & Jahn, 2017)

processing and the use of telecommunications systems. Thus, they also called "logistics/supply chain ports" (Berns et al., 2017).

Nowadays, ports must become more and more service providers. New services are increasingly replacing traditional services. Regarding the changing requirements of the world trade, the need that the ports become more and more "intelligent" is getting a higher importance. Thus, currently the fourth generation of ports, the so-called smart ports, is born. A smart port uses automation and innovative technologies such as artificial intelligence, Big Data, Internet of Things (IoT), and blockchain to improve its performance. Thereby, innovative digital technologies can be used in different parts of the port and turn a conventional port into a smart port. Figure 2 shows some exemplary applications of smart technologies in the port environment, which can be used both on the water and on land (Saxe & Jahn, 2017).

In summary, the smart port concept is based on digitalization, automation of port and terminal processes and also on the interconnectivity of all actors in the maritime supply chain through the automated transmission of mobile data in real time. As a result, this concept aims to increase the overall competitiveness of ports and also contributes to the integration of the maritime supply chain (Douaioui et al., 2018).

By integrating different data sources and improving the use of data, added value can be generated. This creates many opportunities for the new generation of ports. For example, the integration of innovative new technologies into ports enables logistics actors to network safely and securely. In addition, the use of artificial intelligence makes it possible to automate tasks. Opportunities for synchronizing processes also arise from the transformation of ports into smart ports. There are opportunities for the emergence of new business models. The tasks of people in smart ports will shift. They will increasingly take on a supervisory role. And finally, solutions will be found to make processes more environmentally friendly. Many research and development projects in the academic or practical world are concerned with the development of innovative solutions to reduce complexity in ports with regard to the aspects mentioned above (Saxe & Jahn, 2017).

3 Interlink Logistics Partner

In addition to the planning, design, and control of material flows of sea-bound transports, the acquisition, storage, transformation, and transmission of information play a central role in the maritime supply chain. Thus, computer-based operational and inter-operational information systems are becoming increasingly important for the planning and control of cross-border flows of goods. For this purpose, it is necessary that the actors in maritime transport are comprehensively and cyber-securely networked in and between the ports. This networking is already taking place in many cases via commercial platforms, which are often developed and operated by companies in the port industry (Gimenez & Llop, 2020).

The widespread use of sensor and communication technology (Internet of Things) provides permanent real-time information about the location, condition of equipment, vehicles and cargo carriers (intelligent containers). Challenges in the design of information networks in the maritime transport chain arise, among other things, from many different peer-to-peer interfaces, the question of data sovereignty, data security issues, and lack of data exchange standards, among others (Saxe & Jahn, 2017).

Port community systems are an example of the successful networking of logistics partners along the maritime supply chain. They enable better and more transparency in planning and faster handling and reduce the frequency of errors. A global pioneer in port community systems is DAKOSY Datenkommunikationssystem GmbH, an operating company of a communication network for the storage, transmission, conversion, and distribution of logistics-relevant data. Among other things, DAKOSY operates the Port Community System for the Port of Hamburg. Via data interfaces, transport companies can link up with the loading and receiving industries as well as with the authorities relevant to the transport process (e.g., water police, customs). Intermodal hinterland processing is also integrated into the system (DAKOSY Datenkommunikationssystem AG, 2021).

Furthermore, there are current efforts in research to address the increase in the need for information to improve the coordination of the transport chain based on open IT platforms. One example is the research project “MISSION—Manage Information Seamlessly in Ports and Hinterlands” initiated by the Fraunhofer Center for Maritime Logistics and Services (Fraunhofer—Center for Maritime Logistics and Services CML, 2017).

MISSION aims to create a prototype for a non-discriminatory information network. The open infrastructure, in which as little data as possible is held centrally and data sovereignty remains with the provider, is very important part of the project. A key aspect of MISSION is the possibility for all participants to integrate their own services, such as truck routing and tracking services. The data is not held centrally, but remains with the owners of the data. To make this possible, an identification service is used to provide login information for the entire network. In addition to the possibility of single sign-on (one login for many connected services), this relieves the service providers in the network of user administration and enables secure data exchange. In addition, modules are being developed to support truck routing and tracking (Fraunhofer—Center for Maritime Logistics and Services CML, 2018).

4 Automate Tasks with Artificial Intelligence

In recent years, Big Data and artificial intelligence have increasingly become the focus of science and industry. In several areas of logistics, artificial intelligence and data analytics have enabled the introduction of automation, such as driverless transport systems. A higher degree of automation has a significant impact on operational efficiency and productivity. The use of artificial intelligence has the potential to reduce human error, speed up operations, and reduce emissions by analyzing the large number of available data in a specific way to optimize existing processes. In addition, big data analyses provide deep insights into logistical, economic, and technical correlations and forecasts (Schwerdtfeger, 2021).

Especially the larger ports, for example Singapore, Rotterdam, and Hamburg, are using artificial intelligence to improve their business processes. One example of the use of artificial intelligence in ports is the project "KIK Lee—Using artificial intelligence to reduce truck congestion." The aim of the project is to use artificial intelligence to provide utilization forecasts of track arrival rates and truck waiting times for an empty container depot. As part of the project, information will be generated and made available. The information will be used to enable container depot customers to avoid peak times. Furthermore, facility operators should be able to adjust to the expected workload. This will help depot operators to manage their resources more efficiently, support trucking companies in optimizing their routes, and reduce traffic congestion in the port. Based on an analysis of the information requirements, data collected by the container depot on incoming trucks and publicly available data (e.g., traffic data, data on ship arrivals) are combined. These are integrated into a real-time and AI-based forecast in order to be able to make predictions about capacity utilization during truck dispatch. The open data access is published on the data platform mCLOUD, which is operated by the German federal ministry of transportation and enables the generated information to be accessible and always updated for all actors involved in the empty container depot (Fraunhofer—Center for Maritime Logistics and Services CML, 2020).

Another example of the use of artificial intelligence in ports is the research project "Cookie—Container Services Optimized by Artificial Intelligence." At up to 40%, empty containers account for a significant share of the total number of containers transported on land. This underlines the relevance of reducing the workload in empty container logistics as well as the fastest, most efficient, and resource-saving temporary storage, repair, cleaning and finally delivery to the place of loading. The repair of empty containers is an essential service to support the performance of seaports. In the process flow at the empty container depot, manual activities and a lack of digitization result in delays that reduce the plannability of the processes for associated actors in the maritime supply chain. With Cookie, the use of artificial intelligence in the context of services of an empty container depot is being researched. The goal is to help make the processes in the depot more efficient by making reliable forecasts about container availability, optimizing the cleaning process in a way that conserves resources, and implementing automated identification and assessment of damage cases. In this way, intelligent systems using AI methods will help to eliminate inefficiencies in container service processes and to achieve optimized control of empty container processes across all actors, which in turn will facilitate optimized planning of empty container transports in the port (Fraunhofer—Center for Maritime Logistics and Services CML, 2019).

5 Synchronize Processes

Along the maritime supply chain, uncertainties in the arrival times of ships complicate the planning reliability of the actors involved. These can be caused by various influences, such as unfavorable weather conditions, high traffic volumes, or bottleneck situations. The same applies, for example, to landside delays of external trucks in terminals or fluctuations in handling times at logistics nodes. These factors can have a strong impact on the resource and capacity utilization of the various actors. A better networking of the actors in international trade processes, e.g. importers and exporters, transport companies, port authorities, terminal operators, customs, freight forwarders, etc. allows a better coordination of material and information flows. Thus, logistic processes can be organized more efficiently and long waiting times at the various nodes of the maritime supply chain can be reduced (Ascencio et al., 2014). This is where IT networks and IoT create end-to-end transparency in the logistics chain, so that the relevant actors are familiar with the location, condition, handling of the goods, as well as other upcoming processes and their options. This enables synchronized logistics chains and more efficient use of existing logistics resources and infrastructures.

One example of successful coordination of different actors and efficient process design is the Port of Hamburg. It is one of the most efficient universal ports in the world. Spread over 43 km of quay walls for vessels and 300 berths, the port has almost 7500 ship calls per year. On land, more than 1300 freight trains and countless trucks are handled every week. In 2020, around 126.3 million tons were handled across the quayside in Hamburg, with a large proportion of the goods reaching the port in containerized form. This makes Hamburg the third largest container port in Europe. Hamburg ranks 18th on the list of the world's largest container ports (Port of Hamburg, 2021).

One of the most important factors for efficient operations is seaward accessibility. High accessibility results in shipping companies deciding to use a port. Likewise, poor accessibility and inefficient processes ensure that a port loses its attractiveness for shipowners, thus worsening its competitive position. In order to coordinate the inflow, flow between terminals if necessary and outflow to and from the Port of Hamburg, the Port of Hamburg has created a central, inter-company coordination office for large ship, feeder and inland waterway vessel traffic, the Hamburg Vessel Coordination Center (HVCC). In addition, the HVCC acts as the central communication interface to the Hamburg Nautical Center and to the pilotage fraternities. In this way, the HVCC links different partners and their data. All actors involved benefit from this, because the Elbe River area and the Port of Hamburg can be used efficiently. In addition, the resulting reduction in emissions and lower energy consumption protect the environment (HVCC Hamburg Vessel Coordination Center GmbH, 2021).

6 Enable New Business Models

The need for sustainable and efficient supply chain processes means major challenges in terms of developing new business models. The current demands on maritime supply chains are great. The aim is to protect natural resources, avoid environmental pollution, and increase safety requirements. At the same time, the supply chain must be competitive. This requires development of new intelligent business models to meet all the requirements. AI-based data generation, analysis, and use, as well as automation, will help to support the development of new business models and new operating concepts for technical systems (Zijm et al., 2016).

One possibility to open up new business sectors for (maritime) logistics is the use of drones or unmanned aerial vehicles. Although the drone industry is still rather young, it offers great potential. Thus, the use of drones is also becoming increasingly important in logistics and industry, and new applications are added every day. Drones help to reduce the time spent by inspectors and minimize the risk of accidents. At the same time, they can be deployed quickly and flexibly. In the maritime environment, they can monitor the conditions of bridges, locks, and various buildings in the port and thus support their maintenance. Figure 3 shows a drone during a bridge inspection in the area around the port (Saxe & Jahn, 2017).

Drones are already being used in ports today. For example, the drones are used for inspection tasks on the facilities in ports. One field of application is the regular inspection of ship-to-shore gantry cranes. In particular, the inspection involves checking the weld seams for signs of fatigue. In this way, the time during which the ship-to-shore gantry cranes are out of service can be reduced to a minimum. Another area of application for drones in ports is checking the transponder surfaces of AGVs on the terminal. In addition, the use for automated control flights to monitor track systems and gantry cranes is being investigated (Saxe & Jahn, 2017).

Further potential can be seen in the automation of ships. Concepts for unmanned or autonomous ships have been developed since the early 1980s. However, most (partial) automation projects before 2010 focused on functions such as asset monitoring and predictive maintenance rather than the vision of an unmanned, autonomously deciding and acting ship (Saarni et al., 2018).

Although there are more and more small remote-controlled or autonomous ships that have been used for various purposes in ocean research since 2017, there are still

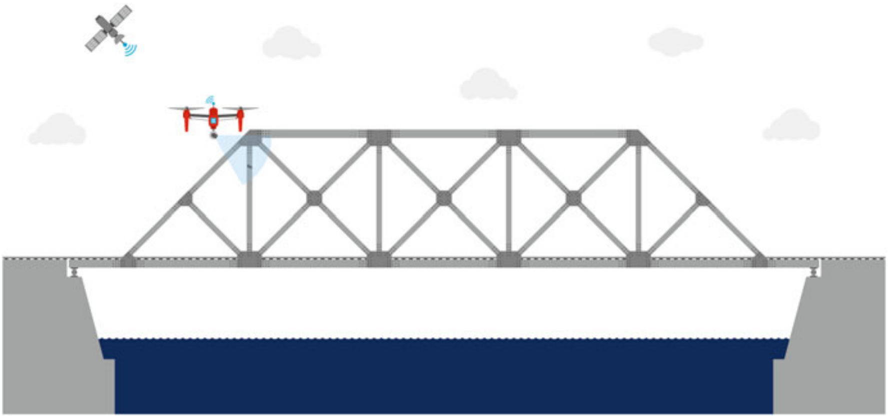

Fig. 3 Flight drones (Saxe & Jahn, 2017)

no large autonomous ships in daily operation (Lloyd's Register, 2017). Despite major technological advances, for example in data processing and networking as well as in the operational concepts of autonomous ships, there are so far only field trials or individual construction projects for autonomous ships, but no regularly deployed solutions. This is mainly due to the fact that there are still obstacles to the introduction of autonomy in maritime shipping, both due to unresolved safety issues and in the area of legal foundations (Levander, 2017). Nevertheless, automation of shipping opens up new opportunities to address existing as well as future challenges in the areas of competitiveness, safety, and sustainability (MUNIN, 2016a). For example, autonomous ships can operate even in conditions where manned ships cannot. On the other hand, autonomous systems allow for a more frequent cycle and in this respect ensure a competitiveness of shipping compared to land transport (Bruhn, 2017). Furthermore, a changed cost structure, for example due to personnel savings, can be counted among the motivations (Willumsen & Simonsen, 2018). In conventional shipping, liner services for small transport units are often uneconomical due to disproportionate transport costs. For such trips, autonomously operating ships could be an economical alternative (Bruhn, 2017).

Regular inspection of ships and port infrastructure is an unavoidable responsibility. This is the only way to ensure safety at sea and in coastal areas. Such responsibilities are traditionally assumed by professional divers. The turbidity of the water in harbor basins in particular poses a risk for divers that should not be underestimated. The use of underwater drones is one way of making such tasks safer and more efficient in the future. The international research project "RoboVaaS—Robotic Vessels as a Service" is attempting to implement this. The idea behind the research and development project is to implement maritime, coastal services such as depth measurements, quay wall and ship hull inspections with the help of underwater drones (Fraunhofer—Center for Maritime Logistics and Services CML, 2021).

7 Human Center

Due to increased digitalization and automation of processes in the port, the job profile for the employees in this area is also changing. Routine physical activities are replaced by automation solutions or supported by cooperative robots. Human work focuses on complex maintenance tasks. Instead, human labor is increasingly focused on complex maintenance tasks. Thus, the need for qualified employees with IT-related profiles is growing. One example of the support of human tasks through the use of modern technologies is the implementation of visual appliances. These can provide additional information for employees. For this, employees working in the ports need to be trained and educated with regard to new tasks and work profiles (Saxe & Jahn, 2017).

New job profiles in the port are, for example, data scientist, multimodal traffic controller, shore-control-center operator, land-based crew, port energy manager, officer in the Port Authority's nautical command center, and port infrastructure manager.

At the port, large data sets are generated each day. On this basis it is not possible to forecast and make decisions. In order to make the data useful, data scientists analyze it using Big Data analytics, as shown in Fig. 4. Only this way the data can be used to increase the efficiency of a port by identifying complex causal chains and also uncovering data correlations that are not obvious. The analyzed data can then be used, for example, to optimize the management of transport and handling resources.

The multimodal traffic controllers work closely together with the data scientists. Their task is to optimize the entire transportation system. To do this, they use deep learning and big data analytics with the help of historical and real-time data. This enables them to organize the entire traffic system and not just individual traffic flows.

Fig. 4 New job profile—Data scientist in the port's data lab (Saxe & Jahn, 2017)

Fig. 5 New job profile—Energy Manager (Saxe & Jahn, 2017)

Fully autonomous ships usually run without a crew on board. Instead, the captain of an autonomous ship is located on land in a so-called Port Traffic Center. From here, he monitors the ship. Telemetry is used to display relevant information about the ship's condition and the current situation on board. For this, the shore control center monitors nautical information, the traffic situation at sea, weather and wave conditions as well as the operating status of the engines and aggregates on board. In case of a fault or a critical situation, a Port Traffic Center can take over control and navigate the ship safely.

In controlling and guarding such autonomously operating ships, the captain is supported by a specialized crew that is also based ashore. In many ways, land-based controlling and monitoring of ships is more attractive than on-board operations. This means that there are no long shifts with non-stop working hours and less difficult or dangerous working conditions (MUNIN, 2016b).

Another new job profile created by increased digitalization and automation of processes in ports is the energy manager, which can be seen in Fig. 5. The energy manager's task consists of collecting and analyzing information regarding electricity generation and consumption around the port. It is the manager's responsibility to match the energy available in the port with the electricity demand of the different stakeholders (e.g., terminal operators). For this, analyses of traffic peaks, ship arrivals, and operational shifts at the terminals must be taken into account. If necessary, additional energy required has to be purchased on the forward market.

Finally, there is the job as a port infrastructure manager, who is responsible for monitoring both mobile and stationary port infrastructures. In this job field, employees can use the latest technologies, such as flying drones, to fulfill their tasks.

8 Green Logistics

The logistics sector has a significant impact on global greenhouse gas emissions. In addition to greenhouse gases, the mobility and logistics sector also produces other emissions that are important parameters for making transportation more eco-friendly. These include noise, air pollutants, and particulate emissions. Thus, Green Logistics stands for environmental compatibility and resource efficiency along the entire logistics chain, i.e., for transport, intralogistics, and logistics buildings. Opportunities to reduce emissions can be realized, for example, by increasing transport efficiency, reducing transport volumes, optimizing routes, shifting transport to more environmentally friendly modes of transport, or using more energy-efficient vehicles. Overall, existing approaches to reducing emissions can be divided into technological approaches, operational approaches, and political approaches. An example of a technological approach is the development of new driving technologies. Personnel training is one of the operational approaches, and the introduction of speed limits is an example of a political approach (Fraunhofer-Institut für Materialfluss und Logistik IML, 2011).

Also, in the maritime sector, more and more technical systems are being used both on land and at sea that are designed to avoid emissions. The Hamburg Container Terminal Altenwerder uses a fleet of 90 so-called automated guided vehicles (AGV) to transport containers between the quay side and the yard. Until now, these automated container transporters were largely diesel-hydraulically and diesel-electrically driven. Since 2017, the AGVs at the terminal have been switched to lithium-ion batteries step by step. This should not only reduce CO_2 emissions at the terminal, but also reduce noise, particulate matter, soot and nitrogen emissions. The AGVs will be refueled during off-peak hours in order to withdraw excess energy from the power grid. At the same time, it is planned that AGVs can also feed energy back into the power grid as so-called primary control power. This is intended to smooth load peaks in the power grid and keep the network frequency stable. For the realization of this project, a sufficient number of charging stations have to be installed on the CTA. Therefore, a control software has to be developed that continuously determines the transport performance of the vehicles required for container handling and optimizes the charging strategies of the AGVs based on this (HHLA Hamburger Hafen und Logistik AG, 2021). At the beginning of 2019, the project "FRESH—Flexibility Management and Control Energy Provision for Heavy Goods Vehicles in the Port" started its research and development of the necessary control software. By the end of 2022, the terminal plans to complete the changeover to purely electrically powered AGVs (OFFIS e.V., 2021).

9 Conclusion and Outlook

The chapter has shown how ports have developed over time from simply being ports of loading and unloading to becoming increasingly automated and digitized. Approaches from science and practice were presented on how ports are trying to integrate the trend of digitalization into their daily processes. The aim is to make port processes more flexible, robust, and efficient. This enables better handling of complexity in terms of structural complexity, data complexity, product complexity, and complexity due to networking and e-commerce.

In summary, the concept of the smart port is the key to facing the upcoming challenges of ship size growth, space constraints, and the increasing pressure to increase productivity in ports. A wide range of digital technologies is now available to optimize processes and systems in ports. In this context, topics such as digitalization, automation, and emissions avoidance are having a significant impact on technology, infrastructure, and human labor in ports. A critical success factor on this journey will be bridging the gap between science and industry for the implementation of innovative digital solutions in the coming years. Implementation on the path to the smart port will only be successful if cooperative research projects can be launched. The overriding goal should not be to create individual smart ports, but to create a chain of smart ports. A success factor will thus be the global cooperation of port-relevant players to promote co-innovation and to lead the market-oriented digital transformation process in the maritime supply chain from the customer's front door to the customer's front door.

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