

This is an electronic reprint of the original article. This reprint may differ from the original in pagination and typographic detail.

Digitalizing maritime transport: digital innovation as a catalyzer of sustainable transformation

Tsvetkova, Anastasia; Gustafsson, Magnus; Wikström, Kim

Published in:
A Modern Guide to the Digitalization of Infrastructure

E-pub ahead of print: 01/09/2021

Document Version
Accepted author manuscript

[Link to publication](#)

Please cite the original version:
Tsvetkova, A., Gustafsson, M., & Wikström, K. (2021). Digitalizing maritime transport: digital innovation as a catalyzer of sustainable transformation. In J. Montero, & M. Finger (Eds.), *A Modern Guide to the Digitalization of Infrastructure* (pp. 123-148). (Elgar Modern Guides). Edward Elgar. Advance online publication.

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

This is a draft chapter. The final version is available in “A modern guide to the digitalization of infrastructure”, pp. 123-148, edited by J. Montero and M. Finger, published in 2021, Edward Elgar Publishing Ltd

<https://doi.org/10.4337/9781839106057>

The material cannot be used for any other purpose without further permission of the publisher, and is for private use only.

Digitalizing maritime transport

Anastasia Tsvetkova¹, Magnus Gustafsson^{1,2} and Kim Wikström^{1,2}

Abstract

This chapter provides a review of various digital innovations that directly or indirectly affect the maritime transportation sector. With a specific focus on port and fairway infrastructure management and efficient use, we also address a number of digital solutions for vessels and end-to-end logistic and supply chains. Given the fragmentation and a number of inefficiencies associated with maritime transport, we highlight the potential of digitalization to act as a catalyzer of its transformation towards more transparent and productive industry. We specifically discuss the changes in the respective business ecosystem that such transformation would bring and require. The discussion of challenges in terms of shifting power positions and the new requirements for secure data management are followed by the explication of required regulatory interventions. We conclude by summarizing the expected impact of a number of digital innovations described in this chapter on the efficiency and costs of maritime transportation.

Keywords

Maritime transport, sea logistics, ports, digitalization, maritime infrastructure, business ecosystem

1. Introduction

The transportation of goods by sea is the most prevalent mode of shipping due to its low cost and practically no capacity limitations. It remains the backbone of globalized trade and manufacturing supply chains as more than four-fifths of world’s merchandise trade by volume is carried by sea (UNCTAD 2019), and most end-to-end shipments include at least one sea leg. In this respect, maritime transportation is an integral part of logistic chains rather than one of competing modes of transport. In broad terms, it refers to the actual sea voyage and port calls, which include arrivals to ports and terminal operations (see Figure 1 for a more detailed representation of a logistic chain and maritime transportation).

One of the key challenges in maritime transportation and logistics in general is the high degree of fragmentation. As demonstrated in Figure 1, more than 15 different organizations can be involved in the export or import of foreign trade cargo from the point of origin to the final destination (Gustafsson et al. 2016). The multitude of involved participants in the transport chain translates

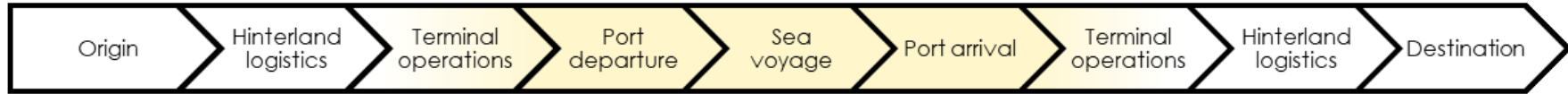
¹ Laboratory of Industrial Management, Faculty of Science and Engineering, Åbo Akademi University, Turku, Finland

² PBI Research Institute, Turku, Finland

into a high number of profit margins, which are included in the freight rate ultimately paid by the logistic service customers and end-users. In addition to increased 'margin on margin', the large number of actors that obstruct the flow of information in the transport chain also increase the risk for delays and disruption in the logistic chains. Every organizational interface means a delay and a possible obstacle – due to human or technical reasons – to information transmittal. Then, sometimes withholding information is in the best interests of actors that serve as intermediaries. In certain cases, not giving notice about a ship's delayed arrival may be economically advantageous for an individual actor such as a ship operator, even though the efficiency of the entire logistic chain is compromised (Gustafsson et al. 2015).

Logistic chain

Maritime transportation



Actors

Cargo shipper, seller or representative Freight forwarders	Hinterland transport operators Freight forwarders	Port authorities Stevedores Fuel suppliers Other terminal operators	Port authorities Port agents Customs brokers Pilotage companies Tug companies	Shipping lines Shipping companies Ship owners	Port authorities Port agents Customs brokers Pilotage companies Tug companies	Port authorities Stevedores Fuel suppliers Other terminal operators	Hinterland transport operators Freight forwarders	Cargo receiver, buyer or representative Freight forwarders
---	--	--	---	---	---	--	--	---

Activities

Production planning Logistic planning	Hinterland transportation by rail, roads, inland waterways	Cargo handling Bunkering vessels Warehousing	Customs clearance Mooring Tugging Pilotage Paperwork	Voyage execution	Customs clearance Mooring Tugging Pilotage Paperwork	Cargo handling Bunkering vessels Warehousing	Hinterland transportation by rail, roads, inland waterways	Production planning Logistic planning
--	--	--	--	------------------	--	--	--	--

Figure 1 Logistic chain and main activities and actors involved

The key considerations for improving the productivity of maritime transportation include streamlining end-to-end logistic chains and the efficient use of maritime infrastructure such as ports and vessels. Maximizing the capacity utilization of infrastructure has a direct impact on reducing both economic and environmental costs per unit of transported cargo (Gustafsson et al. 2016). This includes efforts to have vessels sail loaded to their maximum capacity, thus minimizing voyages in ballastⁱ, and decreasing turnaround time in ports, thereby allowing for more voyages for vessel operators and more port calls for port actors.

Digitalization has the potential to solve the mentioned problems if accompanied by respective changes in the business models and interactions among the business actors, that is, in the business ecosystemⁱⁱ. Firstly, digitizing the information flow along logistic chains can reduce the time spent on communication, submission of documents and organization of shipments (Inkinen et al. 2019). Secondly, real-time data on infrastructure availability and cargo movements allows for planning just-in-time vessel operations and efficient use of port infrastructure to eliminate unnecessary ‘wastes’ of time and capacity by various actors. Finally, the digitalization of end-to-end supply chains bears the potential to fundamentally change logistics and thus has implications on the future management of maritime infrastructure. Specifically, increased transparency and better understanding of cargo and vessel flow through ports is an input for smarter decisions regarding port infrastructure investments in the future.

Traditionally, the infrastructure required for maritime logistics includes man-made global maritime routes such as fairwaysⁱⁱⁱ and canals and port infrastructure required for handling cargo at ports and stowing it on vessels. There is a proposal to consider the floating deck of a vessel as part of the transport infrastructure since it is functionally comparable to road and rail infrastructure (Baird 2010). Thus, in this chapter, we discuss digital solutions that concern not only fairways and port and terminal infrastructure but also a number of relevant solutions for vessel operations. Moreover, since the efficient use of any fragment of maritime infrastructure depends on the functioning of the whole logistic chain, we also discuss digital solutions that address the functioning of logistic corridors and logistic chains and elucidate the effect they have on the management of maritime infrastructure.

Sea logistics is known to be the slowest to adopt digitalization technologies (Transport Intelligence 2019), and it still relies heavily on old communication and data exchange methods; thus, the potential benefits of aggregating and analyzing the data on maritime transportation are vast, and a number of various digital solutions are already implemented or under development.

2. Digital technologies for maritime transport and the data layer

In this section, we briefly overview current maritime digital technologies and those soon to be introduced which will affect the efficiency of sea logistics, particularly the management of maritime infrastructure. As noted earlier, the large number of actors involved in sea logistics is accompanied by the disruption in information flow and the lack of transparency, which ultimately leads to low efficiency in the logistic chain. Firstly, digitalization can serve as a means for timely information gathering, exchange and analysis. Second, digitalization is expected to drive the optimization of business operations and change existing business models in the maritime transportation sector based on the use of data collected throughout the logistic chains (Rantanen et al. 2019).

Due to the increasing availability of data received through various sensors installed on port equipment, vessels and even cargo carrying containers, maritime infrastructure has become

‘smart’. The notions of smart ports, smart vessels and smart fairways include combinations of technological and business model innovations, which can vary depending on the actor defining them (see Figure 2). The common feature, though, is the increasing volume of data regarding maritime infrastructure, as well as vessel and cargo flows, which can be collected and used to make operational and strategic decisions regarding maritime transport infrastructure and end-to-end logistics.

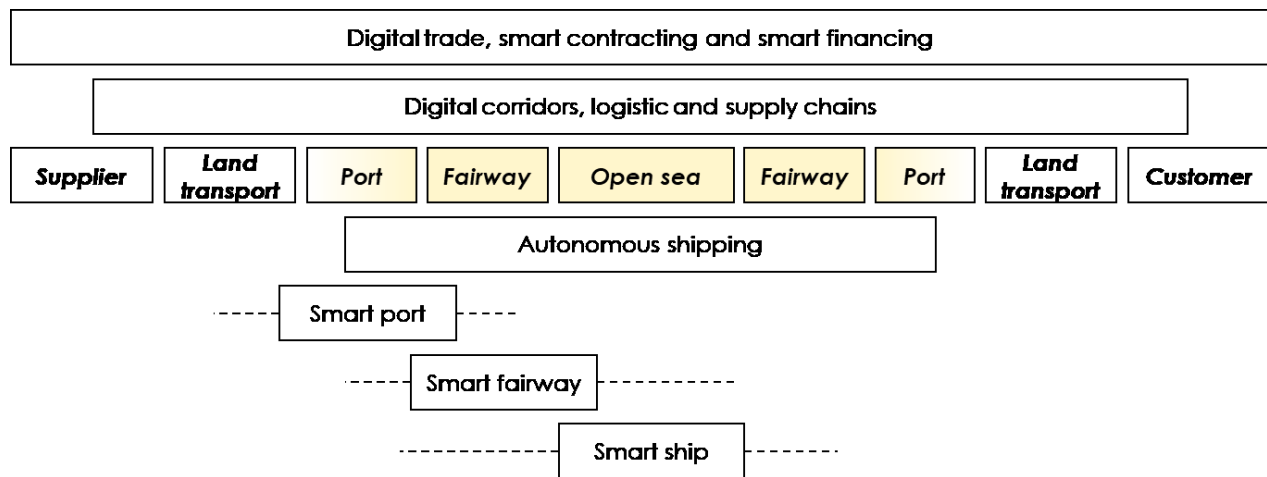


Figure 2 Digital solutions related to maritime transportation^{iv}

Regarding smart ports and fairways, there are a number of implemented digital solutions and others under development. The first type of solutions directly relate to the efficient operation and maintenance of maritime infrastructure, for example digital twins of port infrastructure and smart buoys that help identify the need for maintenance through predictive algorithms. The second type of solutions are service-related and aim to improve how the users utilize this infrastructure. These solutions include managing the throughput of traffic, cargo and vessel flows through ports so that maritime infrastructure is utilized efficiently, and the quality of service is maximized for cargo shippers, ship operators and other parties relying on port infrastructure.

The general trend is that various digital solutions help vessels become aware of their surroundings, which is often referred to as situational awareness (Andrade et al. 2017). The relevant data are collected on ships through various sensors such as radars and lidars^v. These data and respective algorithms for situational awareness (e.g. algorithms for combining data from different sensors and for prioritizing data) allow for creating a detailed picture of nearby vessels, obstacles and port infrastructure layout in order for vessels to navigate safely. The data on vessel position are available through automatic identification systems (AIS) that automatically provide information about a ship's GPS coordinates for other ships and coastal authorities. These data, combined with weather and sea information and the condition of ship systems' is the pre-requisite for many operational efficiency improvements, including voyage optimization, automation, remote operation and fully autonomous operations.

By combining the data related to maritime infrastructure and cargo flows, it is possible to achieve efficiencies on a larger scale – at a system level – ensuring a smart cargo flow through digital corridors and optimizing whole supply chains. For example, the transport of smart containers can be carried out depending on the respective availability of trucks, railcars, feeder ships or inland

waterway vessels (Fruth and Teuteberg 2017). Such synchronous modality can allow significant transport cost reductions and optimum utilization of transport infrastructure while adhering to the respective delivery conditions (Lee et al. 2016). Autonomous shipping can also be considered as system-level digital innovation because it relies on many service-related solutions such as voyage optimization and situational awareness, and it has the potential to change not only maritime transportation but also supply chain management and production planning on an industrial scale. Table 1 lists a number of digital solutions that affect the management and use of maritime transport infrastructure categorized by three layers. The impact on the cargo and vessel flow relying on this infrastructure is also marked in the table. These solutions are described in detail in the following sections.

Table 1 Digital solutions and their influence on the management of maritime transport infrastructure, vessel traffic and cargo traffic

		Digital solutions	Vessel traffic	Cargo traffic	Infra-structure
Infra-structure-related		Port infrastructure monitoring and management			x
		Digital twins of port infrastructure and BIM (Building Information Modeling)			x
		Smart fairways	x		x
Service-related	Smart port	Port community systems	x	x	x
		Queuing and slot booking system	x		x
		Traffic flow management in and to ports		x	x
		Cargo flow management in ports		x	x
	Smart ship	Situational awareness	x		x
Voyage optimization		x	x	x	
System-related		Autonomous shipping	x	x	x
		Cargo and vessel matching	x	x	x
		End-to-end logistic planning, synchro-modality	x	x	x
		Prediction and management of cargo flows	x	x	x
		Supply chain management and digital trade	x	x	x

It is important to mention that, unlike other types of infrastructure, maritime transport is characterized by low connectivity. Currently, the communication between vessels and the shore is done via radio^{vi} and satellite systems, such as Inmarsat20. All communication is normally done via the same satellite connection and is submitted through the same narrow bandwidth. Moreover, in remote areas like polar regions, satellite coverage is insufficient, congested or non-existing. The cost of satellite communication is also considered to be quite high (Rantanen et al. 2019). The expected increase in the volume of data that must be transmitted from ship to shore and back is a critical issue to be addressed.

To conclude, large amounts of data are currently gathered on ships and in ports, although most remain unused. The generation and collection of more data that would cover entire port networks and vessel fleets would lead to issues of choosing which data are relevant, how long they should

be stored and who should be allowed to access them. Nevertheless, consolidating and analyzing such big data bring opportunities to transform logistic chains in a sustainable manner.

3. Infrastructure-related digital solutions: Impact on design, construction and maintenance of maritime transport infrastructure

Infrastructure-related digitalization concerns the construction, management and maintenance of physical maritime transport infrastructure such as port infrastructure and fairways. We do not discuss the digital solutions that affect the design, construction and maintenance of vessels since the shipbuilding industry differs significantly from infrastructure construction and is thus out of the scope of this chapter.

Port infrastructure includes the port terminal infrastructure, that is, static structures such as buildings, docking areas, roads, warehouses and power supply; it also includes port operational equipment such as vehicles or machinery needed to provide port services that include, for example, towing and cargo stowage (Gibson et al. 2011).

Monitoring static terminal infrastructure to ensure safe and continuous operation is one of the main tasks of port authorities. Smart sensors, advanced computing and video analytics help port authorities to more efficiently monitor large and diverse infrastructures in port, including networks, roads, railways, restricted areas and warehouses, quays, banks, water depth and locks (Frost & Sullivan 2020). The condition of port infrastructure can be monitored through connected camera and computer image analytics that detect damaged land-based infrastructure. Since water depth and berth status are crucial in vessel moving and mooring within the port, sounding drones with ultrasonic sensors or cameras can constantly monitor the depth and berth and provide data for dredging and maintenance operations (Frost & Sullivan 2020). Based on these data and algorithms for predicting incidents, it is possible to automate the planning of control operations and maintenance actions, that is, to switch to prescriptive maintenance.

Following the same trend, predictive and prescriptive maintenance is also discussed and partly realized in the management of cargo handling equipment in ports. Sensor and reported information from the diverse parts of cargo handling cranes is analyzed in order to improve crane maintenance, repair and operations. The data analytics algorithms developed by cargo handling equipment suppliers can be further improved by collecting global crane data rather than focusing on individual pieces of equipment.

Following the development of the building construction sector, BIM can be applied in the design and management of port infrastructure, as well as in 3D models of assets and when enabling the assessment of collected data. In the process, an asset's current and historical data are gathered in order to enhance the infrastructure management, which is based on predictive maintenance, for example (Frost & Sullivan 2020). The development of digital twins for ports can also aid in the strategic planning of infrastructure investments, port design, and terminal capacity based on the analysis of cargo flow through ports (Lind et al. 2020). As a result, Capex can be reduced by 27–38% (McKinsey & Company 2017).

Regarding fairways, a recent innovation is to equip navigational aids such as buoys marking the navigable areas leading to harbours with remote monitoring and control technology^{vii}. Similar to the other types of infrastructure discussed earlier, the information of the location and state of the buoys is used to predict the maintenance needs, which improves the cost efficiency of

maintaining fairways (Port of Helsinki 2019). Other digital solutions related to ‘smart fairways as a service’ are discussed in the next section.

4. Service- and system-related digital solutions: Management of vessel and cargo flow

The service-related digitalization of maritime transport aims to improve the use of relevant infrastructure by its users – mainly cargo shippers and vessel operators. Thus, it is critical to improve the vessel and cargo flow throughput, for example by reducing the time that vessels spend in ports. This includes minimizing time used for mooring, cargo handling, bunkering and similar activities, eliminating idle time spent queuing to enter a port, and waiting for loading or unloading, for example, when cargo handling equipment is unavailable or when documentation exchange with authorities and trade parties is slow (Gustafsson et al. 2015). We present a number of digital solutions that address these and other relevant issues and group around the concepts of smart ports, smart ships and smart fairways. It is critical to note that in many cases, the effects of these solutions are intertwined; digitalization in port is impossible without complementary innovations on-board the ships. Finally, we discuss how various maritime digital innovations connect to the system-level digitalization of logistic corridors, supply chains and the global trade.

4.1. Smart port

Ports vary depending on their capacity, the type of cargo they can receive and their role in the logistic chain. For instance, there are larger ‘hub’ container ports and smaller final-destination or ‘hinterland’ ports. Nonetheless, one key criterion for port efficiency is vessel turnaround time. In 2018, a ship call had an average turnaround of around one day. Specifically, dry bulk carriers spent 2.05 days in port, and containerships spent 0.7 days on average (UNCTAD 2019). Ports generally aim to reduce vessel turnaround time to either increase earnings for port actors by serving as many vessels as possible or to be an efficient link in the longer supply chain and thus ensure its competitiveness. Smaller ports require a competitive edge as they do not have many ship calls to efficiently connect land and sea transport in order to guarantee the reliability and swiftness of the supply chains related to the hinterland industries they serve.

While some of the vessels’ time in port is used to load or unload cargo, a lot of time can be spent waiting, for example for berth or cargo handling equipment, customs clearance. Thus, the main areas of application for port-related digitalization first focus on improving port calls through better coordination and communication among multiple actors involved in sea transportation, port operations and land logistics. Second, there are digital innovations aimed at optimizing vessel and cargo flows through ports. While coordination requires data sharing, optimization requires data analysis such as predictive and prescriptive analytics to predict events and plan the optimal resource allocations (Lind et al. 2018).

There are a number of inefficiencies in how port calls are currently organized. Most ports apply the principle of ‘first come, first served’ for arriving vessels. This often leads to a ‘rush to wait’ situation, as vessels simultaneously arriving in the port area increase their speed in order to be first in line to approach the berth. Queuing in ports can also take several hours or even days if a vessel arrives outside of a port’s working hours (Gustafsson et al. 2016). This unproductive time could be avoided or otherwise used, for example for slow steaming^{viii}, through a timely exchange of information between different parties regarding the vessel’s estimated time of arrival (ETA) and availability of port quays and cargo handling equipment. For instance, studies show that reducing the nominal speed from 27 to 22 knots (by 19%) can result in bunker savings of approximately 58% (Gustafsson et al. 2015, 2016). Algorithms predicting vessel arrival times and

port infrastructure availability are the basis for real-time queuing and slot booking systems in ports that can help solve the ‘rush to wait’ challenge. However, in this case, technical solutions are not enough, so companies must change how they handle issues like work routines and contracts. Despite the availability of standard slow steaming and virtual arrival clauses developed, for instance, by a renowned maritime association BIMCO^{ix}, they are hardly used due to the potential arbitration complications and missing references cases.

Then, to facilitate the coordination necessary for efficient port calls, communication must be drastically improved between the multitude of actors involved. This includes port authorities, ship operators, shippers, port operators, port agents and many others. A vast number of different hardware and software systems from different time periods are currently being utilized to transmit data from ships to ports during a port call, often leading to lack of data sharing and interoperability (Inkinen et al. 2019). There are initiatives to solve this problem by digitizing information exchange, such as through the European Maritime Single Window (EMSA 2020) and the use of blockchain technology. Blockchain has been explored in Rotterdam and a few other leading ports globally due to its potential to flatten out multiple registration and control processes that can involve up to 25 separate entities in relation to a single transport transaction (Lambert et al. 2019). Their Port Community Systems (PCS) aim to solve bottlenecks in information exchange, such as slow communication techniques, large numbers of documents and messages, and incompatible working procedures. The advantages of these systems include decreased paperwork and errors, increased data transparency, easier planning, and faster reactions to disturbances (Rantanen et al. 2019).

To further decrease vessel turnaround time in ports, it is crucial to synchronize sea and land logistics by managing cargo flow to and in ports. Otherwise, the benefits of efficient ‘digital calls’ will be diminished due to delays in cargo stowage. Predictive algorithms based on things like data from container tracking sensors allow for improved planning of cargo arrival to ports, storage and loading on vessels. There are also specific digital solutions for managing traffic flow, which are especially relevant for handling vehicle traffic in RoRo and RoPax ports^x. For example, the Port of Tallinn implemented a smart gate solution based on automatic vehicle number plate recognition (Tallink Silja Line 2020). When a vehicle is recognized, barriers to port areas are open automatically, and electronic boards throughout the port guide drivers to the ships. This significantly reduces the costs of loading RoPax vessels and saves time for passengers.

Another solution to ensure smooth traffic flow and alleviate congestion caused by land transportation is based on installing sensors on the roads leading to ports. Combined with data from the drivers’ devices, it tracks travel times and adjusts traffic lights or signage to facilitate smooth traffic flows to ports.

Achieving synchronomodality in ports is a challenging endeavour due to significant differences in the logics of ship-to-port synchronization, port-to-port synchronization, and port-to-hinterland synchronization (Lind et al. 2018). Therefore, there is an increasing interest in platform-based digital solutions that collect data from various sources and actors involved in logistics and in providing custom analytics for specific actors to make informed decisions.

In this spirit, the Port of Rotterdam recently launched the company PortXchange to promote the Pronto digital platform service offered to ports, shipping companies and terminals. The aim of the company is to improve the efficiency of port calls and to help their clients reduce emissions with a joint platform enabling optimal planning, execution and monitoring of port call activities (Port

of Rotterdam 2019a). Moreover, the port has been developing the Internet of Things platform in partnership with IBM, Cisco, Esri and Axians; it utilizes a broad network of sensors to provide accurate and up-to-date water and weather data to help the port authority plan and manage shipping operations more effectively (Port of Rotterdam 2019b). The use of the system is expected to decrease waiting times, optimize berthing and accelerate loading times.

Another example is the platform for collaboration and optimization around port operations developed by a start-up called Awake.AI. The platform combines data on sea and weather conditions, vessel port situational information, port infrastructure availability and cargo flow, and it provides relevant data and analytics for various actors (port authorities, ship operators, terminal operators and cargo owners) so they can improve their operations (Awake.ai 2020). In that respect, the company positions their offering as a ‘smart port as a service’ and sees it as a pre-requisite for future wide implementation of autonomous shipping.

To achieve true efficiency improvements, it is crucial that such digital platforms for sharing information and predicting vessel and port operations be implemented in an increasing number of ports. Then, network effects can be achieved, and possibilities for the efficient use of maritime transport infrastructure drastically increase.

4.2. Smart ship

The increase in available data about vessel operations has naturally led to advancements in ship intelligence. As in the case of smart ports, different business actors define what constitutes a smart ship differently. The common feature is the increasing opportunities for improving decision-making for operating and managing vessels based on various combinations of data sets and analysis algorithms. For example, Hyundai Electric offers a smart ship solution service that uses an ICT platform to connect all systems and devices on board to support integrated monitoring, control, and operation of vessels in a safe and efficient manner. As a result, it is possible to achieve a standardized method of navigation despite varying seafarers’ skills, which is predicted to cut annual operating costs by 6% due to the enhanced efficiency and safety (Hyundai Electric 2020).

The elements constituting a smart ship may include the following digital solutions:

- Routing and *voyage optimization* algorithms that aid in safe navigation and allow a decrease in a vessel’s fuel consumption and environmental impact
- Solutions providing *situational awareness* for ships that enable safe navigation and the potential for remote and autonomous navigation
- *Equipment monitoring* and remote maintenance of systems on-board the vessels
- Asset and *fleet management* based on an analysis of information regarding the performance of vessel fleets

While all these digital solutions are relevant for ensuring a vessel’s efficient operation, the latter two types of digital solutions deliver benefits for shipowners and operators and mainly concern the management of vessels. This chapter focuses more on the effects of digitalization on maritime transport infrastructure management and the impacts on end-to-end logistic chains; therefore, we will only discuss the former two digital solutions and explicate their interconnection with smart ports, smart fairways, and the digitalization of logistic and supply chains.

Situational awareness is a key prerequisite for safe navigation in order to avoid collisions and prevent vessels from running aground. Traditionally, the crew has achieved this by monitoring a vessel's position in relation to other nearby vessels and obstacles and referring to the navigation charts. Later, ships were equipped with radars and other types of sensors that detected nearby objects with more precision and efficiency than a human eye, especially in reduced visibility conditions like fog. The latest digital solutions for situational awareness, like the one offered by the Norwegian company Kongsberg, collect real-time data that allow for detection, classification and observation of vessels, other objects and the shoreline in order to offer a complete picture of the surroundings for the vessel crew (Kongsberg 2020).

This digital innovation is critical to enabling more efficient navigation as well as port operations. A vessel that is 'aware' of its surroundings can be remotely controlled or can even operate fully autonomously in more challenging conditions like when approaching ports and berthing. This can improve the safety of port operations and reduce time spent in ports, for example time required for mooring^{xi} (Lambert et al. 2019).

Voyage optimization solutions use information on sea and weather conditions and match it to the planned route, vessel propulsion system, speed limitations in specific fairways and other parameters in order to dynamically optimize the route and the speed to reach the destination at the agreed time. For example, NAPA provides a voyage optimization solution that allows routes and speed profiles to be adjusted in order to save bunker consumption and increase navigation and cargo transportation safety (e.g. by avoiding rough seas), while adhering to the planned time of arrival at a destination point (NAPA 2020). Further, the information about such route and speed optimisation efforts can be used by ship operators to discuss and agree on changes in scheduled arrivals and operations with stakeholders.

On the other hand, voyage optimization software is capable of producing quite accurate ETAs, which can affect the time spent in ports. If proper communication between vessels and port actors is established, it is possible to agree on a later arrival when it is clear that there is no available berth or cargo handling equipment at a port at the agreed time of arrival. Thus, rather than spend unproductive time waiting to enter a port or berth, the ship operator can use that time to reduce sailing speed, thereby reducing bunker consumption. Further, based on such real-time predictions of vessels' ETAs, different stakeholders involved in the maritime logistic chain will be able to adjust their resource dispositions flexibly at an early stage to adapt to the ship's arrival time.

To summarize, as different digital solutions are implemented on ships and shore, vessels are becoming more intelligent. It can be seen as an evolution based on automation and digitalization that will ultimately lead to fully autonomous shipping. According to MUNIN Project^{xii} results, over a 25-year period, it is possible to save \$7 million per ship in fuel use, crew supplies and salaries compared to traditional fully-crewed vessels (MUNIN 2020). If not already fully autonomous, highly automated vessels rely on the electronic on-board systems that take over a large part of the tasks and provide support to the crew (Burmeister et al. 2014).

4.3. Smart fairway

As discussed earlier, navigational aids such as buoys at sea and fairways can be equipped with a number of sensors and measuring instruments, thereby becoming 'smart buoys' (Arctia 2020). Apart from collecting the data about the buoy's state and location, it is possible to gather other important information for maritime traffic, such as water level, wave height and the rate and direction of the water flow (Tapaninen 2020). These data can be shared with the actors that need

it. A clear example is ship operators' use of such data for voyage optimization, as discussed earlier. It is estimated that if a typical vessel can save 30 minutes on the ship's way in and on its way out of port through a smart fairway, there will be six additional days per year for other port calls (Erlund 2019).

Going a step further, 'fairway as a service' would provide seafarers with a combined picture of sea and weather conditions together with a detailed model of the seabed in the respective area of the sea. This information can be transmitted directly to the bridge of a vessel approaching such a smart fairway (Finnish Transport Infrastructure Agency 2016). This is the basis for remote pilotage and self-pilotage of vessels, which is important part in enabling autonomous and remotely controlled vessel operation. Based on such data, it is also possible to plan the loading of the vessel to fit the conditions on the planned route, that is, to enable more cargo loading at high water (Finnish Transport Infrastructure Agency 2016).

Smart buoys can also be equipped with 5G transmitters not only to transmit the relevant data they produce but also to increase vessels' connectivity at sea.

The business model behind smart or intelligent fairways is based on the idea of utilizing the current marine buoy infrastructure and installing measuring instruments owned by various parties on navigational aids (Arctia 2020). Smart buoys are expected to become an information-producing entirety – a crucial part of digital corridors. By connecting to other 'smart' systems, a smart fairway can potentially enable even better situational awareness for decision-making in maritime transportation (Finnish Shipowners' Association 2020).

4.4. Logistic and supply chain–level digitalization

Data on vessel and port operations is an important input for higher-level system-related digital innovations. For instance, platforms for finding optimal routes and vessels for transporting cargo also require knowledge of port infrastructure capacity and availability in real time. While these solutions aim to optimize the end-to-end logistic chain, they ultimately affect the utilization rate of port infrastructure. In this vein, a start-up called Seaber has developed a platform through which a cargo owner or shipping company can optimize their operations by looking for the most optimal way to transport cargo and combine transportations. By using the platform, a shipping company can optimize the use of its vessels, and a cargo owner can find optimal vessels and routes for transport (Rantanen et al. 2019).

On the other side of this optimization problem is the potential to use artificial intelligence to predict cargo flows (Rantanen et al. 2019). This could include, for example, the analysis of RFID-equipped^{xiii} container movements, and it would ensure complete transparency along the entire process chain (Prokop 2012). The development of digital platforms that integrate these data provides more power for the ultimate users of logistic chains, that is, import and export companies that ship their goods; it also increases pressure towards infrastructure operators to provide the best availability and prompt service in ports. Ultimately, ports will become links in a hyperconnected agile global logistics system, which has the potential to overcome current unsustainability symptoms that include products idling in storages, too many unsold products, and unnecessary moves of products, crisscrossing the world (Jahn and Saxe 2017; Montreuil 2011).

In that respect, the increasing transparency and volume of information flow along logistic chains have the potential to change how cargo and vessel traffic flows are organized and managed. Logistic system-level digital platforms and solutions, including blockchain, are being increasingly used by the shipping industry, transforming business and partnership models. As a result, more efficient and secure trade (digital trade) would rely on electronic document transmission and offer greater supply-chain visibility for customers who rely on shipping industry services (UNCTAD 2019).

Autonomous shipping combined with blockchain solutions for digital paperwork can enable such digital trade by eliminating transaction cost for organizing shipments. In that sense, it goes beyond the concept of smart ships because eliminating crew on vessels can change the underlying logic behind sea logistics. Supply chain and inventory management is moving towards omnichannel operations, where cargo receivers do not care of the source of goods as long as their specifications fulfil the requirement. Thus, multiple autonomous vessels can act as ‘floating stocks’ that can be traded and then directed to the customer with no human participation and at zero transaction cost as long as other digital solutions such as smart contracting, financing and automated trade are implemented as well.

5. Coordination of fragmented systems

There is an urgent need for real-time and secure data transfer throughout the whole logistic chain, which is partly lacking cost-efficient and reliable communication means. Varying data quality and scattered locations are also obstacles for the optimal utilization of data. One significant obstacle to developing transparency is the uncertainty regarding the reliability of the information systems, as most information in the transport chain is confidential and should not be exposed to outsiders (Tapaninen 2020). As a result, a lack of data sharing is hindering data-based optimization efforts (Rantanen et al. 2019).

To address the issue of data sharing and interoperability, International Maritime Organization (IMO) has defined the concept of e-Navigation to be ‘a harmonized collection, integration, exchange, presentation and analysis of marine information onboard and ashore by electronic means to enhance berth to berth navigation and related services and protection of the marine environment’ (IMO 2020). The connected e-Maritime concept goes beyond facilitating data interoperability to promoting the use of maritime data and information to enabling value added services in maritime transport and improves the profitability of shipping (Graff 2009).

There is also a lot of ongoing work related to standardized communication between ships and ports. The Sea Traffic Management (STM) Validation Project is a European initiative under the EU’s Motorways of the Sea umbrella, which focuses on implementing new digital information exchange services for shipping and port industries. The STM is a concept for sharing secure, relevant and timely maritime information among authorized service providers and users using a common framework and common standards for information and access management. Interoperability between actors is achieved by specifying not only what format the data should have but also how the data exchange should be done (STM 2019). The expected benefits of such coordinated and synchronized port operations include a 50% reduction of accidents, 10% reduction in voyage costs and 30% reduction in waiting time for berthing (STM 2019).

One of the main barriers to achieving a global scale in digital solutions for maritime transport relates to the need to develop systems that attempt to achieve the same tasks in several international territories but need to be adjusted to different approaches and data formats in each region. This issue is tackled by organizations like the UK's Open Data Institute, which promotes common data standards in order to facilitate safety at sea and new data-driven services in the maritime transport sector (Lambert et al. 2019).

6. Change in the structure of the maritime transport business ecosystem

The increasing volumes of generated data regarding maritime transport create apt opportunities for the appearance and growth of digital platforms such as cargo and vessel matching or 'port as a service' types of platforms. It is discussed that highly fragmented industries characterized by extreme information asymmetries are the first to be impacted by 'platform revolution' (Sarkar 2016). In that respect, sea logistics is a sector with a swelling need for transformation and efficiency improvement (Gustafsson et al. 2015), and digital transformation coupled with transition to a platform economy have the potential to facilitate such a change. However, it is important to note that technical solutions are not a panacea for all the bottlenecks and outdated practices in the sea logistics. In fact, the implementation of digital solutions often proves challenging due to the established structure of the respective business ecosystem and institutionalized lock-ins in the ways of working (Eriksson et al. 2019; Tsvetkova et al. 2019). Thus, maritime transportation is undergoing a system-level transformation, where digitalization has an important role or even acts as a catalyzer. However, there is still a need to redefine the value creation and capturing of logics, business models and their interconnections in the ecosystem, roles, contractual and legal frameworks that also shape industry architecture (Tsvetkova et al. 2017). The question remains: which types of actors will lead this transformation, which incumbents will reinvent their role and business models, and which of them will cease to exist? It is also necessary to carefully consider how technological and operational innovations (digital innovations being a part of those) can lead the maritime transport sector towards sustainability (Schwartz et al. 2020).

One of the main effects of digital platforms in this transformation is the shift towards multi-sided markets and facilitation of network effects (Jia et al. 2019; van Alstynne et al. 2016). Ports, being an interface between sea and land logistics, have historically provided services to multiple sides, including vessel operators, cargo owners, land logistics operators or port operators like stevedoring companies. With the advent of 'smart ports', as discussed in section 4.1, there is a potential for providing more value through data-based services and data-driven business models. The general trend of 'infrastructure as a service' will greatly impact the business models of infrastructure owners, as the information about infrastructure use becomes more valuable than the possession of that infrastructure. In a platform economy, the competitive advantage changes from the control of valuable resources to the ability to orchestrate information flows and organize activities among the ecosystem actors (van Alstynne et al. 2016). Incumbent actors such as port authorities and logistic operators have a choice to either proactively use the enabling technologies to reinvent their own business models or to be potentially forced out of the market by emerging business that will replace them in the fourth industrial revolution (Jahn and Saxe 2017). According to Marwyk and Treppte (2016), there are only a few types of logistic players that will survive the digital transformation, including booking and optimization platforms, carrier and terminal operators, supply chain specialists, and various service providers.

It is uncertain, however, which actors will lead the integration of information flows related to logistic chains (and port operations as only one portion of those). One possibility is that incumbent actors such as port authorities would ‘digitalize’ port calls and port operations through implementing various digital solutions like Port Community Systems and Port Collaborative Decision Making (PortCDM) (Lind et al. 2018) and would replicate the solutions in other ports to achieve standardization, thereby improving efficiency. In this scenario, the biggest container ‘hub’ ports that have invested in digital solutions could lead the change. However, it is uncertain whether it would be feasible to replicate the solutions developed to serve their specific needs and whether those digital solutions would be applicable in smaller ports or ports handling different types of cargo. In a similar vein, terminal operators are engaging in consolidation to achieve efficiency and attract more customers as ports of call (UNCTAD 2019). This can enable interoperability and the integration of data required for digital transformation.

Simultaneously, there are examples of vertical integration pursued by terminal operators, such as the acquisition in 2018 by the DP World of Unifeeder^{xiv} and by shipping companies, when major global container lines acquire regional carriers (UNCTAD 2019). This vertical integration trend shows attempts to gain a control of logistic chains in order to expand the portfolio of services and improve the efficiency of core operations. In light of digitalization, vertical integration appears to be a solution for overcoming fragmentation because it can facilitate data integration and transparency of information flow along logistic chains.

Another major question is which actor(s) will take lead the integration of data regarding cargo flows and logistic infrastructure and coordination of shipments. The role of the freight forwarder has been played by various business actors: shipping lines, land logistic companies, brokers and Fourth Party Logistic providers (4PLs)^{xv}. With the advent of digital platforms, there is a space for ‘digital newcomers’ to take this role. They can base their business completely on managing information flows along logistic chains and would not own any transport infrastructure. It is likely, though, that specific industry knowledge will be required to succeed, which will create certain entry barriers for such newcomers from the ICT industry.

Finally, the position of logistic service customers is likely to change as more transparency in logistics is achieved, and as various platforms allow for direct transactions between cargo shippers and actors in the logistic chain. Port operations, for example, have been a ‘black box’ for cargo shippers, and cargo flow through ports has been organized by freight forwarders, brokers and agents. With the new digital solutions, the transparency of cargo movements will drastically increase, and the choices of shipment routes and ports of call will be informed by real-time data analysis. Such a shift towards ‘control tower mentality’ in overseeing logistics and supply chains is reflected in new digital solutions like, for example, IBM Sterling^{xvi}.

7. New challenges

It is frequently stated nowadays that ‘data is the new oil’. While digital transformation enables new business models and revenue streams, it also redistributes power and threatens incumbent firms. It is already clear that the ownership and control of data will bring new power struggles. As discussed in the previous section, the actors that can aggregate a larger share of data will also be able to capture significant value. On the other hand, business actors that have been benefitting from information asymmetry, such as brokers and agents, are likely to lose their intermediary positions due to the prevalence of digital platforms that perform the same function while creating more value for the users through network effects. At the same time, the uncontrolled rising

market power of certain platforms in the maritime sector and its implications for competition, data security and consumer protection has become a concern (UNCTAD 2019).

Other actors might resist the transparency in logistic chains, at least initially, because such transparency contradicts the established ways of working. For example, as vessels become more intelligent and autonomous, it will be easier to identify real reasons for accidents (such as equipment failure or human error), which will make the assignment of liability more straightforward and difficult to evade.

Another challenge is to ensure data protection and security, which is a common concern for all digitalized industries. When digital solutions are implemented, there is a need for secure systems that guarantee the protection of the companies' internal infrastructure and operating systems from cyberattacks (Fruth and Teuteberg 2017). Apart from confidential business data and sensitive internal systems, personal data can also be a target for misuse in maritime logistics. For instance, when using AIS technology, personal data of the watchkeeping officer or captain are also transmitted. Data regarding the crew are available for everyone who has a corresponding receiver and can therefore create a threat to the ship and its crew members when sailing in areas affected by piracy (Fruth and Teuteberg 2017).

Cybersecurity is significant in maritime transportation because the costs of cyberattacks can be vast and the consequences fatal. For instance, digital navigation systems could be manipulated so that they sheer off or run aground, which would endanger the lives of the crew, people at sea and on land. The financial effects on shipowners and ship operators would also be immense. In 2017, container shipping company A.P. Moller - Maersk estimated that a cyber attack it had endured could cost \$300 million in lost revenue (Lambert et al. 2019).

Finally, the development of overlapping, incompatible and not interacting digital solutions for maritime transportation poses yet another challenge (Rantanen et al. 2019). The possibility of such 'digital fragmentation' is quite real because there must be considerations for national regulations and standards, dispersed efforts to solve problems relevant for specific types of maritime infrastructure, and general fragmentation in the logistics sector. A specific problem is the gap between the speed of change in digital industry and the maritime transport sector, where investment cycles are measured in decades.

8. Regulation

Due to the increasing digitalization across sectors, there is an imperative to develop common guidelines and legislation that address how personal data can be collected and managed in an ethical and safe manner. In the European context, regulations like GDPR^{xvii} apply equally to the maritime transport sector and set requirements for accountability in handling of personal data.

The risk of cybersecurity attacks is another issue that requires regulatory intervention. Through digital solutions discussed in this chapter, ships and ports are increasingly connected to each other through cyberspace, which exposes maritime operators to cybersecurity risks. The maritime industry has been slow to realize the implications of this new environment and thus lags behind other industries in terms of cyber risk mitigation and regulation (Hopcraft and Martin 2018). However, certain initiatives, such as the work of ENISA^{xviii}, provide guidance on how to secure smart infrastructures from cyber threats; they aim to highlight good security practices and propose recommendations to operators, manufacturers and decision-makers. In particular, ENISA developed a report that provides a useful foundation upon which entities involved in the port ecosystem can build their cybersecurity strategy (Drougkas et al. 2019). Regarding cybersecurity

on vessels, IMO provided a deadline of 2021 for shipowners and managers to provide evidence that they have incorporated cyber risk management into their ship safety processes (Lambert et al. 2019).

Apart from the concerns about safety and security in digitalization, there is a need for data sharing and interoperability in order to avoid the ‘digital fragmentation’ discussed in section 7 and to extract the full benefits of digitalization in the maritime sector. European Data Strategy will likely become a strong enabler of the free flow of privately held non-personal data across sectors through the adoption of common rules for data access and reuse, among other measures (European Commission 2020a). While such a common strategy for the digital economy can help blur the boundaries for data flow between different transport modes and industries along logistic chains, there must still be more sector-specific regulation to account for the specificity of liability and the nature of data in maritime transport. As discussed in section 5, certain initiatives attempt to address the standardization of data exchange and data interoperability in the maritime sector. The role of EU e-Navigation and e-Maritime frameworks is to bring together all port call-related reporting to enable data to be shared and reused more efficiently as well as to enable value adding services based on the data’s availability (European Commission 2020b; Graff 2009).

Then, increased data availability and resulting transparency of factors like cargo flow and port infrastructure availability do not automatically guarantee cooperation from all actors in order to improve the efficiency of maritime transport. To provide an example, while information about available slots in port can become available in real time and as predictions for such availability become more reliable and more commonly shared, port authorities and operators are not obligated to grant these slots to vessel operators. Thus, certain regulatory intervention might be required in order to facilitate different actors’ participation in the emerging platforms, thereby solving the ‘chicken and egg’ problem common for platforms (Caillaud and Jullien 2003).

Finally, the trend towards vertical integration in maritime transportation as well as the emergence of platforms discussed in section 6 has the potential to require regulatory intervention as well. This can include, for example, domestic regulation to avoid anticompetitive behaviour that is necessary to oversee ports as public utilities (UNCTAD 2019). There is also a need for national competition authorities, regulators and port authorities to monitor markets and evaluate alternative options when granting container terminal concessions to private operators, while accounting for vertical and horizontal market integration (UNCTAD 2019).

It is worth highlighting digitalization in maritime transport and its role in improving sustainability. Particularly, the availability of data regarding infrastructure use, cargo and vessel flows through ports can be used to help enforce and monitor compliance with existing and future environmental regulations. For example, Regulation (EU) 2015/757 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport (2015) requires ship operators to monitor and report their carbon emissions and transport work on all voyages to, from and between EU ports, but the procedure for collecting such information is not transparent. The collection of data on vessel voyages and port calls enabled by various digital solutions can serve to collect precise and traceable information for calculating the carbon footprint for every step of maritime transport.

9. Conclusions

The impact of digital innovations on the management of maritime transport infrastructure is particularly significant. As connectivity between different elements of maritime infrastructure

and other logistic infrastructure increases, and as various digital solutions allow for understanding how it is used in relation to the cargo flow, there will be a solid basis for improving the efficiency of infrastructure use as well as for planning further investments. Importantly, it will be possible to elucidate the actual role of maritime transport infrastructure as an element in global logistics and supply chains and change its relationship with other elements as the sector is being transformed.

Digitalization can act as the major catalyzer in transforming maritime transportation towards becoming more integrated, efficient and transparent. It brings opportunities for new and renewed business models and threatens the position of some incumbents in the logistic business ecosystem. Such changes, however, cannot rest purely on digital solutions, but they require changes in established institutions that are strong in the maritime sector: new contractual models, governance structures, and industry mindsets will need to accompany the technological innovations.

We present some indications of the impact of a number of digital innovations discussed in this chapter on costs and efficiency (Table 2).

Table 2 Expected impact on the maritime transport efficiency of selected digital innovations

Digital innovation	Potential impact	Source
BIM, IoT, smart monitoring and asset management	Reduction of 27–38% in Capex	(McKinsey & Company 2017)
Sea Traffic Management services including route optimization and port call synchronization	Safety: 50% reduction of accidents Efficiency: 10% reduction in voyage costs and 30% reduction in waiting time for berthing Environment: 7% lower fuel consumption and 7% lower greenhouse gas emissions	(STM 2019)
Smart fairway	Saving 30 min on the ship's way in and on its way out of port through a smart fairway can spare 6 days per year to be used for other port calls	(Erlund 2019)
Slow steaming enabled by voyage optimization	Reducing the nominal speed from 27 to 22 knots (by 19%) for a studied vessel will reduce the engine power by 42% of nominal output, resulting in an hourly main engine fuel oil savings of approximately 58%.	(Gustafsson et al. 2015)
	Increasing the voyage by 12 hours and reducing speed from 23 to 20 knots would decrease fuel costs by 12,7% (1500 €)	(Gustafsson et al. 2016)
Combination of voyage optimization and other operational measures	10-20% reduction in fuel consumption	(Aro et al. 2020)
	Prevention of safety-critical engine breakages during voyage with an estimated value of 2000 €/day	
Combination of cargo and vessel matching and voyage optimization	22.35% reduction in fuel consumption	(Schwartz et al. 2020)
Smart Ship	Hyundai Heavy Industries' ISSS (Integrated Smart Ship Solution) standardizes navigation despite varying seafarers' skills; it also enhances efficiency	(Mfame 2017)

	and safety, which is predicted to cut annual operating cost by 6%	
Autonomous ship	Over a 25-year period, a savings of \$7 million per ship in fuel use, crew supplies and salaries compared to traditional fully crewed vessels is possible according to MUNIN Project results (Maritime Unmanned Navigation through Intelligence in Networks)	(MUNIN 2020)

In certain cases, the combinations of several solutions can generate more benefits or are a prerequisite for these benefits due to the complementary nature of those solutions. On a system level, the impact of all the digital solutions, once implemented, is challenging to assess, but network effects are expected. This elevates the need for understanding the current structure of the respective business ecosystem and for evaluating how various digital solutions can help transform a mature industry with an old tradition such as shipping. Such an understanding is necessary for answering the following questions: which of the solutions can deliver the greatest benefits and to which actors, and what is the optimal roadmap for implementing the multitude of digital solutions? By answering these questions, the actors in maritime transport will be able to find their role in the changing environment and make smart choices in terms of infrastructure management.

References

- Adner, R. (2016), 'Ecosystem as structure: an actionable construct for strategy', *Journal of Management*, **43** (1), 39–58.
- Andrade, F.A.A., R. Storvold and T.A. Johansen (2017), 'Autonomous UAV surveillance of a ship's path with MPC for maritime situational awareness', in *2017 International Conference on Unmanned Aircraft Systems (ICUAS)*, pp. 633–9.
- Arctia (2020), *Smart Buoy - More than a Navigational Aid*, accessed 3 March 2020 at <https://www.arctia.fi/en/services/polyethylene-buoys-navigational-aids/smart-buoys.html>.
- Aro, A., Rytter, N. G. M., and T. Itälina (2020), 'Maritime industry processes in the Baltic Sea Region – Synthesis of eco-inefficiencies and the potential of digital technologies for solving them', ECOPRODIGI Research Report, Turku, Finland, accessed at <https://ecoprodiigi.eu/wp-content/uploads/2020/02/ECOPRODIGI-Research-Report-1-2020-final.pdf>.
- Awake.ai (2020), *A Unique Platform Where Supply Chains Meet. Introducing Awake Platform*, accessed 5 July 2020 at <https://www.awake.ai/platform>.
- Baird, A. (2010), 'Redefining maritime transport infrastructure', *Proceedings of the Institution of Civil Engineers - Civil Engineering*, **163** (5), 29–33.
- Burmeister, H.-C., W. Bruhn, Ø.J. Rødseth and T. Porathe (2014), 'Autonomous unmanned merchant vessel and its contribution towards the e-navigation implementation: the MUNIN perspective.'
- Caillaud, B. and B. Jullien (2003), 'Chicken & egg: competition among intermediation service providers', *The RAND Journal of Economics*, **34** (2), 309–28.
- Drougkas, A., A. Sarri, P. Kyranoudi and A. Zisi (2019), *Port Cybersecurity*, Heraklion: ENISA.
- EMSA (2020), *European Maritime Single Window Prototype*, vol. 2020, accessed at <http://www.emsa.europa.eu/related-projects/emsw.html>.
- Eriksson, K., K. Wikström, M. Hellström and R.E. Levitt (2019), 'Projects in the business ecosystem: the case of short sea shipping and logistics', *Project Management Journal*, **50** (2), 195–209.
- Erlund, T. (2019), 'Fairway as a service – the smart way to aid navigation', accessed 13 December 2019 at <https://breakingwaves.fi/2018/09/12/fairway-as-a-service-the-smart-way-to-aid-navigation/>.
- European Commission (2020a), *European Data Strategy. Making the EU a Role Model for a Society Empowered by Data*, accessed 21 July 2020 at https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-data-strategy_en.
- European Commission (2020b), *European Maritime Single Window Environment*, accessed 18 June 2020 at https://ec.europa.eu/transport/modes/maritime/digital-services/e-maritime_en.

- Regulation (EU) 2015/757 of the European Parliament and of the Council of 29 April 2015 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport, and amending Directive 2009/16/EC* (2015).
- Finnish Shipowners' Association (2020), *Digitalization and Automation*, Finnish Shipowners' Association, accessed 5 February 2020 at <https://shipowners.fi/en/digitalization-and-automation/>.
- Finnish Transport Infrastructure Agency (2016), *Testing of Intelligent Fairways, Scheduled to Begin next Year, Will Pave Way for Autonomous Ships*, accessed 10 April 2020 at <https://vayla.fi/web/en/-/testing-of-intelligent-fairways-scheduled-to-begin-next-year-will-pave-way-for-autonomous-ships>.
- Frost & Sullivan (2020), 'TF Future Watch: Smart Ports benchmarking study', Team Finland Market Opportunities.
- Fruth, M. and F. Teuteberg (2017), 'Digitization in maritime logistics—what is there and what is missing?', *Cogent Business & Management*, **4** (1), 1411066.
- Gibson, G., R. Milnes, M. Morris and N. Hill (2011), 'Shipping infrastructure', accessed at https://iea-etsap.org/E-TechDS/PDF/T17_Shipping_Infrastructure_v4_final_gs.pdf.
- Graff, J. (2009), 'e-Maritime: an enabling framework for knowledge transfer and innovative information services development across the waterborne transport sector', *International Journal on Marine Navigation and Safety of Sea Transportation*, **3** (2), 213–7.
- Gustafsson, M., T. Nokelainen, A. Tsvetkova and K. Wikström (2016), 'Revolutionizing short sea shipping. Positioning report', Turku, Finland.
- Gustafsson, M., A. Tsvetkova, M. Ivanova-Gongne, A. Keltaniemi, T. Nokelainen and V. Sifontes Herrera (2015), 'Positioning report. Analysis of the current shipping industry structure and a vision for a renewed shipping industry ecosystem', Turku, Finland.
- Hopcraft, R. and K.M. Martin (2018), 'Effective maritime cybersecurity regulation – the case for a cyber code', *Journal of the Indian Ocean Region*, **14** (3), 354–66.
- Huundai Electric (2020), *Smart Ship Solution*, accessed 21 May 2020 at <http://www.hyundai-electric.com/elec/en/integriect/integriect1.jsp>.
- IMO (2020), *E-Navigation*, accessed 4 January 2020 at <http://www.imo.org/en/OurWork/Safety/Navigation/Pages/eNavigation.aspx>.
- Inkinen, T., R. Helminen and J. Saarikoski (2019), 'Port digitalization with open data: challenges, opportunities, and integrations', *Journal of Open Innovation: Technology, Market, and Complexity*, **5** (2), 30.
- Jahn, C. and S. Saxe (2017), *Digitalization of seaports – visions for the future*, Fraunhofer CML, Fraunhofer Verlag.
- Jia, X., M.A. Cusumano and J. Chen (2019), *An Analysis of Multi-Sided Platform Research over the Past Three Decades: Framework and Discussion*, accessed at <http://questromworld-test.bu.edu/platformstrategy/files/2019/07/Platform-Review-Article-and-supplemental-material-2019-07-15-BU-Conference.pdf>.

- Kongsberg (2020), *Situational Awareness. Enhancing Safety through Intelligent Data Fusion*, accessed 12 June 2020 at <https://www.kongsberg.com/maritime/about-us/news-and-media/our-stories/intelligent-awareness/>.
- Lambert, N., J. Turner and A. Hamflett (2019), *Technology and the Blue Economy: From Autonomous Shipping to Big Data*, London, UK: Kogan Page, Limited.
- Lee, S.-Y., J.L. Tongzon and Y. Kim (2016), ‘Port e-Transformation, customer satisfaction and competitiveness’, *Maritime Policy & Management*, **43** (5), 630–43.
- Lind, M., H. Becha, R.T. Watson, N. Kouwenhoven, P. Zuesongdham and U. Baldauf (2020), ‘Digital twins for the maritime sector’, *Smart Maritime Network*, July, accessed at <https://smartmaritimenetwork.com/wp-content/uploads/2020/07/Digital-twins-for-the-maritime-sector.pdf>.
- Lind, M., M. Bergmann, S. Haraldson, R.T. Watson, J. Park, J. Gimenez and T. Andersen (2018), *Port Collaborative Decision Making (PortCDM): An Enabler for Port Call Optimization by International Harmonization*, accessed at <http://fathom.world/wp-content/uploads/2018/02/Collaborative-Port-Call-Optimization.pdf>.
- Marwyk, K. van and S. Treppte (2016), ‘2016 logistics study on digital business models: results’, Roland Berger, accessed 20 September 2020 at https://www.rolandberger.com/publications/publication_pdf/roland_berger_logistics_final_web_251016.pdf.
- McKinsey & Company (2017), *Reinventing Construction: A Route to Higher Productivity*, accessed at https://www.mckinsey.com/~/_media/McKinsey/Industries/Capital%20Projects%20and%20Infrastructure/Our%20Insights/Reinventing%20construction%20through%20a%20productivity%20revolution/MGI-Reinventing-Construction-Executive-summary.ashx.
- Mfame (2017), *A Smart Ship Solution Cuts Costs, Boosts Safety*, accessed at <https://mfame.guru/smart-ship-solution-cuts-costs-boosts-safety/>.
- Montreuil, B. (2011), ‘Toward a Physical Internet: meeting the global logistics sustainability grand challenge’, *Logistics Research*, **3** (2), 71-87.
- MUNIN (2020), *MUNIN Results*, accessed 28 May 2020 at <http://www.unmanned-ship.org/munin/about/munin-results-2/>.
- NAPA (2020), *Overview of NAPA Voyage Optimization*, accessed 21 July 2020 at <https://www.napa.fi/software-and-services/ship-operations/napa-fleet-intelligence/voyage-optimization/#overview>.
- Port of Helsinki (2019), *Helsinki’s West Harbour Fairway Made More Intelligent and Safer*, 24 October, accessed at <https://www.portofhelsinki.fi/en/port-helsinki/whats-new/news/helsinkis-west-harbour-fairway-made-more-intelligent-and-safer>.
- Port of Rotterdam (2019a), *Port of Rotterdam Authority Launches New Company PortXchange to Make Digital Shipping App Pronto Available to Ports Worldwide*, accessed 21 January 2020 at <https://www.portofrotterdam.com/en/news-and-press-releases/port-of-rotterdam-authority-launches-portxchange>.

- Port of Rotterdam (2019b), *Port of Rotterdam Puts Internet of Things Platform into Operation*, accessed 13 January 2020 at <https://www.portofrotterdam.com/en/news-and-press-releases/port-of-rotterdam-puts-internet-of-things-platform-into-operation>.
- Prokop, D. (2012), ‘Smart containers and the public goods approach to supply chain security’, *International Journal of Shipping and Transport Logistics*, **4** (2), 124–36.
- Rantanen, A., N. Berg and E. Kanto (2019), ‘Digitalization as a tool to reduce GHG emissions in maritime transport’, Helsinki, Finland: Finnish Transport and Communications Agency, accessed at https://www.traficom.fi/sites/default/files/media/publication/Traficom_maritime_digitalization_CO2_20190927_ABSTRACTS.pdf.
- Sarkar, C. (2016), ‘“The Platform Revolution” – an interview with Geoffrey Parker and Marshall Van Alstyne’ *The Marketing Journal*, accessed at <https://www.marketingjournal.org/the-platform-revolution-an-interview-with-geoffrey-parker-and-marshall-van-alstyne/>.
- Schwartz, H., M. Gustafsson and J. Spohr (2020), ‘Emission abatement in shipping – is it possible to reduce carbon dioxide emissions profitably?’, *Journal of Cleaner Production*, **254**, 120069.
- STM (2019), *Sea Traffic Management Validation Project. Final Report*, accessed at <https://s3-eu-west-1.amazonaws.com/stm-stmvalidation/uploads/20190709125520/STM-Validation-Final-report.pdf>.
- Tallink Silja Line (2020), *Tallinn Port, D-Terminal*, accessed 15 January 2020 at <https://www.tallinksilja.com/tallinn-d-terminal>.
- Tapaninen, U. (2020), *Maritime Transport: Shipping Logistics and Operations*, Kogan Page Publishers.
- Transport Intelligence (2019), *Global Freight Forwarding 2019*, Transport Intelligence.
- Tsvetkova, A., K. Eriksson, R.E. Levitt and K. Wikström (2019), ‘Workflow interdependence analysis of projects in business ecosystems’, *The Engineering Project Organization Journal*, **8**, accessed at <https://doi.org/https://doi.org/10.25219/epoj.2018.00110>.
- Tsvetkova, A., T. Nokelainen, M. Gustafsson and K. Eriksson (2017), ‘A framework for ecosystemic strategizing and change’, in J. Vesalainen, K. Valkokari, and M. Hellström (eds), *Practices for Network Management: In Search of Collaborative Advantage*, Cham: Springer International Publishing, pp. 275–301.
- UNCTAD (2019), ‘Review of Maritime Transport 2019’, accessed at https://unctad.org/en/PublicationsLibrary/rmt2019_en.pdf.
- van Alstyne, M.W., G.G. Parker and S.P. Choudary (2016), ‘Pipelines, platforms, and the new rules of strategy’, *Harvard Business Review*, **94** (4), 54–62.

ⁱ ‘Voyages in ballast’ or ‘ballast sailing’ refers to vessels sailing without cargo or only partly loaded

ⁱⁱ ‘Business ecosystem’ has been defined as ‘the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize’ (Adner 2016)

-
- ⁱⁱⁱ The navigable part of harbours that is often marked by floating buoys or other navigational aids
- ^{iv} Inspired by the depiction of digital and autonomous maritime transport systems developed by DIMECC's ONE SEA initiative, see <https://www.dimecc.com/dimecc-services/one-sea-ecosystem/>
- ^v Lidar is a surveying method that measures distance to a target by illuminating it with laser light and measuring the reflected light with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3-D representations of the target
- ^{vi} Very High Frequency (VHF) and High Frequency (HF)
- ^{vii} See e.g. SeaHow buoy technology <https://www.arctia.fi/en/services/polyethylene-buoys-navigational-aids/smart-buoys.html>
- ^{viii} Slow steaming is a process of deliberately reducing the speed of cargo ships to cut down fuel consumption and carbon emissions
- ^{ix} See <https://www.bimco.org/contracts-and-clauses/bimco-clauses>
- ^x RoRo ports serve roll-on/roll-off (roro) ships that are designed to carry wheeled cargo such as cars, trucks, trailers, etc., which are driven on and off the ship on their own wheels. RoPax vessels can carry both vehicles and passengers and can be a cruise ferry
- ^{xi} Mooring refers to holding a ship fast by attaching it to the shore or to an anchor using a cable or rope
- ^{xii} Maritime Unmanned Navigation through Intelligence in Networks
- ^{xiii} RFID stands for Radio-frequency identification
- ^{xiv} A Danish logistics company that operates a container feeder (smaller 'distribution' container vessels) and shortsea network in Europe
- ^{xv} 4PLs is a supply chain integrator that organizes and manages logistics for manufacturers
- ^{xvi} See <https://www.ibm.com/se-en/supply-chain/sterling>
- ^{xvii} General Data Protection Regulation that regulates processing by an individual, a company or an organization of personal data relating to individuals in the EU
- ^{xviii} European Union Agency for Cybersecurity www.enisa.europa.eu