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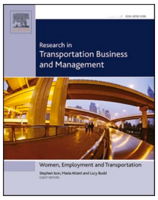

Technological trajectories and scenarios in seaport digitalization

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ABSTRACT

Digitalization has become a widely used term both in professional language and in scientific literature. It may be seen as a manifestation of technological progression which has been traditionally given a strong emphasis in theories of economic growth. The roots of digitalization are thus old, but the terminology has experienced rapid growth during the last decades. This paper focuses on the future prospects of digitalization in Finnish ports operating international trade and transports. In the case of transport, logistics, and ports the public sector has, mainly through ministries and offices focusing on economic development and employment, initiated numerous development programs with foresight ambitions. Commonly, these programs have a mid-range target setting referring to a 5–10-years time span into the future. The primary data is collected from two workshops (group interviews). As a result, the research identifies the main drivers and technologies that are significant for port digitalization. These are discussed in the context of three alternative scenarios: Digital supremacy; business as usual; and digital failure. These three scenarios are classified with SWOT (Strengths; Weaknesses; Opportunities; Threats) and PESTEL (Political; Economic; Social; Technological; Environmental; Legal) frameworks. It is assumed that the actualized future development will follow the mid-sections of the scenarios depending on global trends in politics and trade that impact the supply and demand that underlie the need for transport.

1. Introduction

Digitalization is considered as one of the key drivers of modern transport business. Practically all advanced economies have created their own national guidelines or future scenario documents identifying potential gains and threats caused by technological progression. In the transport sector, these changes are, in general, estimated to be rapid and extensive. Ports in particular are expected to have an increasingly significant position as nodes of multimodal transport and supply chains benefiting from new technological advancements (see Acciaro et al., 2018; Mangan, Lalwani, & Fynes, 2008; Olivier & Slack, 2006). For example, administrative port organizations could find economic opportunities from synergies and economies of scale if more operational data would be available for the development needs of the whole port community. An open data analysis (Inkinen, Helminen, & Saarikoski, 2019) indicated that the main challenges for the short-term (<5 years) port digitalization concern, to a large extent, the enabling of more efficient information distribution between port community organizations, operators, and public-private-partnerships (for efficiency gains; see Aydogdu & Aksoy, 2015; Vairetti, González-Ramírez, Maldonado, Álvarez, & Voβ, 2019).

Port digitalization is a complex phenomenon that has not been extensively studied in maritime research when compared to specific maritime topics such as vessel navigation, route optimization, or autonomous shipping. As an example, only 53 articles were found in an extensive Scopus database with a keyword combination ‘port digitalization’ (19.12.2020). Among these articles, ports are commonly studies as nodes in multimodal transport chains, and as interfaces in the mode changes aided by digital technologies. Therefore in this article ‘port digitalization’ is a generic term and it refers to the adoption, collection, storage, analysis, and use of digital information in ports and port communities. It is manifested through digital platforms and it has impacts on operational management causing changes in organizational work cultures and practices in ports (e.g. Heilig, Lalla-Ruiz, & Voß, 2017). These technologies may include high-end robotics and automation (Zolich et al., 2019), IoT integrations (Herrero Cárcel, 2016), autonomous and remote controlled operations of vessel docking (Wang, Wang, & Tan, 2015) as well as software platforms and communication tools enabling easier and more efficient ways of conducting onshore port affairs (Gölzer & Fritzsche, 2017). There are trajectories where information

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technologies (ITs) are expected to strive towards convergence rather than divergence. These two development pathways are most commonly separated in future studies of technological change (e.g. in terms of IoT, see Ferretti & Schiavone, 2016).

The emergence of new data sources and the resulting data combination potential brings forth a core dimension of digitalization: the benefit (change or impact) in one digitalization process has an effect on other digitalization processes that are operating within the same technology sphere. In other words, ports may be considered as one unit on the meta-level but they are composed of a multitude of simultaneous data processes. Integration of these processes not only enables new alternatives for measurement, monitoring and management, but also has impacts on other unexpected systems within the same framework. The accumulation of these small or great changes modifies the whole system within different time spans. These introductory notions lead to the two research questions of this paper:

1) What future scenarios and technological trajectories are identifiable for port digitalization?
2) What properties and implications do these scenarios have in SWOT (Strengths, Weaknesses, Opportunities, and Threats) and PESTEL (Political, Economic, Social, Technological, Environmental and Legal) frameworks?

2. Background: Main trends of digitalization in ports

2.1. Policy guidance and digitalization in ports

The empirical data of this paper are from Finland. Therefore it is necessary to start the story from a broad continental (European) context in terms of digitalization policies. European Commission (EC) (2019) has produced a roadmap action plan for transportation including ports. The EC report highlights the following as the technological goals (or drivers) for the change in waterborne transport:

- Safety
- Efficiency gains through digitalization and interaction between technological business models
- Environmental soundness
- Human factors (behavior and activity)

The EC report identifies particular automation systems that are very likely the first ones to break on to the markets. These include a) operational real-time monitoring systems that are based on sensor fusion technologies; b) automated docking procedures (automooring); and c) autonomous vessels used in short sea shipping (SSS). It is commonly acknowledged that development programs for the maritime sector are focusing on maritime industries. They seldom consider ports as a significant development target. This can be seen e.g. in the Finnish national research and development program that focuses mainly on vessel technologies and the sea environment. The maritime sector driven development program however does encourage ports to strive towards a 'smart port' concept (e.g. Ang, Goh, Saldivar, & Li, 2017) and sustainable corporate management (e.g. Ashrafi, Walker, Magnan, Adams, & Acciaro, 2020).

An interesting observation is that the current roadmaps and strategy reports do not put too much emphasis on 'port digitalization' per se: digital technologies are often recognized and implied but they are not substantiated or defined in detail. However, this is a common feature with policy documents in general. The EC (2019) report is one of the few transport policy documents that actually define specific technology domains. This may also be interpreted as an indication of traditionalism within the maritime sector and industry. Several processes, documentation transfers, and agreements are still conducted with papers, traditional forms, and filing. It is interesting that the most complex forms of digitalization (such as fully autonomous vessels) have penetrated the goal setting agendas where simpler forms of digitalization that focus more on daily operations (e.g. electronic signing) have not gained too much interest. However, through these forms of digitalization, extensive savings and efficiency gains are obtainable (e.g. with big data applications, see Hämäläinen & Inkinen, 2017, 2019).

One of the most significant megatrends in contemporary societal development concerns the environment and increased environmental awareness. The transport sector is one of those industries that is often mentioned and considered when environmental issues are under investigation. This entails convergence between environmental, transport and technology policies. The general goal of carbon neutrality and environmental regulation in transport therefore poses a number of trajectories for which digitalization could provide solutions or supportive knowledge (e.g. Vandermeulen, 1996). Environmental soundness is one increasingly important enabler of competitive advantages – also in ports. For example, management and coordination of waste processing in different ports serving the same area (e.g. the Baltic Sea) could benefit from collaborative agreements that are supported by digital solutions (e.g. Svaetichin & Inkinen, 2017).

Considering ports, Lee, Yeo, and Thai (2014) conducted a study where enhanced data and usability of data analytics enables potentials for environmentally solid port operations. Environmental goal setting in ports (and in sea-borne transport) is regulated by numerous international agreements and highlights the significance of the IMO (International Maritime Organization) in regulative guidance of maritime transports. Particularly, as Finnish ports are located on the shores of the Baltic Sea, the newly implemented Sulphur Emission Control Area (SECA) regulations are putting pressure on the industry to achieve lower emission rates (e.g. routing optimization, see Fagerholt, Gausel, Rakke, & Psaraftis, 2015; e.g. environmental innovation, see Makkonen & Inkinen, 2018).

Authoritative collaboration within the industry is commonly acknowledged as a backbone for data transfer standardization. The need to create collective standardized solutions motivates long-term digitalization planning (also Bensaou, 1997; Chae, Yen, & Sheu, 2005). One of these actions is the IMO-driven e-navigation action plan that was initialized in November 2014 and updated in May 2018. The action plan attempts mainly to improve maritime safety by developing big picture awareness on board. Digitalized navigation systems and standards are designed to ease ship operations both at sea and in ports. It is essential that port information systems are compatible with e-navigation standards even though the action plan focuses on the development of ship systems and not on ports as such. The governance and management of ports is elemental for digitalization adoption and there are good research examples of governance research in European ports e.g. from Rotterdam (Chandra & Hillegersberg, 2018). This line of thought could be extended to broader forms of port co-operation and specialization (e.g. an extensive special issues focusing on the topic by Notteboom, Knatz, & Parola, 2018), the topic that is also widely discussed among the Finnish ports.

2.2. Digitalization maturity layers for ports

The demand for maritime transports and ports is dependent on the development of the world economy, trade agreements and disagreements (i.e. trade wars), the corporate development of highly specialized technologies (particularly in digital services), and the role of international regulation and respect towards that regulation. The main characteristics of digitalization are rooted in the distinction between incremental and radical (product) innovations. Digitalization is considered to be one of the 'pervasive megatrends' that has a significant impact on all technology domains.

Goal setting documents seldom identify specific technology domains or categories and they tend to remain on broad and generic meta-level (using only concepts such as 'digitalization' or 'automation'). This may hinder practical implementation and creates room for divergent technology pathways (e.g. Carlan, Sys, Vanelslander, & Roumboutsos, 2017). This has created a need for digitalization maturity layers. For example, the port of Rotterdam and the British Port Association have divided port digitalization into four maturity layers:

1) Single ports are striving to develop and digitalize their own processes;
2) Port communities and companies operating in the vicinity of the port integrate their operations and data sharing that is a fundamental part of digitalization;
3) Logistic chains integrate: other logistic companies and operators working outside of ports are integrating their systems with ports. Digitalization has expanded beyond the vicinity of ports;
4) Global port data exchange processes as parts of global logistic chains: ports are networked with each other creating highly detailed on-demand transport chains.

The studied Finnish ports (22 in total) are mainly on the second layer of this maturity scheme. Smaller ports have more difficulties and resource limitations in implementing digitalization and approximately 30% (6 or 7) are still on the first layer depending on interpretation. An interesting observation is that data exchange and transfer is not often considered as a competitive advantage in Finnish ports. In general and based on the workshop discussions, Finnish ports are considered to be more conservative towards digitalization when compared to European leading hubs (e.g. foundations of institutional arrangements observable in an extensive international case collection, eds. Brooks, Cullinane, & Pallis, 2017) such as the Netherlands (de Langen & van der Lugt, 2017), the UK (Monios, 2017), Italy (Parola, Ferrari, Tei, Satta, & Musso, 2017), and Turkey (Esmer & Durub, 2017). We consider that the presented case results from Finland will give additional knowledge particularly on digitalization management in peripheral settings. The results have also relevance for ports located in countries having a similar dependence on sea transports. As a reference, approximately 85% of Finnish international trade is seaborne – causing that a common statement in Finnish professional logistics is a phrase 'Finland is an island'.

Final consideration here is that port digitalization is integrally linked to the spatial structures and locations (cities and their regions, e.g. Wang, Olivier, Notteboom, & Slack, 2007). Thus, transports in ports have to continue to port hinterlands and, particularly, in the case of ports located inside cities (or very close proximity to cities), they have to take the impact on other transport modes into close consideration (e.g. Hein, 2014; OECD, 2014). Congestion of the in-out routes to ports is one of the universal problems. Sea transports and cruise industries differ considerably as it is common that cruise ports locate very close to urban centers whereas cargo ports have gradually moved to (relatively) remote locations. Port digitalization therefore embraces port-city interfacing and traffic management close to ports. Potential development areas are found in information dissemination (e.g. cruise ship arrival/downloading times) expected time lengths of high-volume traffic and estimations for rush-hours in ports. These are significant in city-port relations and governance (Daamen & Vribes, 2013).

2.3. Workshop data collection method

The empirical part is based on earlier literature and on primary data collected from port development managers and other experts working with digitalization. Two workshops were organized in order to obtain qualitative data. In practice, the workshop discussion contents were developed on the basis of the European Commission (2017) Digital Transformation Scoreboard (DTS) classes where digitalization is classified according to seven distinct technology domains: 1) Big data analysis; 2) Automation and robotics; 3) Cyber security; 4) IoT and sensor networks; 5) Cloud services; 6) Mobile services; and 7) Social media.

The approach is similar to a group interview method where a large number of participants (in this case 42 in the first workshop and 48 in the second) were divided into three specific topic groups:

1) The role and significance of digitalization through specific technology domains;
2) The need for new information sources and data integration; and
3) Views on open data and data sharing internally within port communities and externally with other segments in transport chains (outside of port areas).

The discussion in the workgroups then followed a similar path in all groups, including discussion topics for the current conditions of the particular technologies and forms of digitalization, the short-term challenges and development trends and finally longer-term scenarios for the future digitalization in ports. It is recognized that port-level data sources are limited and highly contextual (results and perspectives depend on national specifics and conditions), but the use of a port-focused approach is the most suitable one. Another alternative would have been to use purely external experts (e.g. academia, consultancies, or customers).

The results and discussion parts include two main steps: 1) identification of the main drivers of change and corresponding technology categories i.e. trajectories of development that is followed by identification of three alterative scenarios for port digitalization. They are named 'digital supremacy' referring to the most aggressive growth of digitalization; 'business as usual' referring to slow but steady increase of digitalization in ports; and 'digital failure' referring to decreasing and problematic adoption of digitalization. 2) After presenting the key characteristics of each scenario the discussion part includes three analytical classifications that are cross-referenced with the scenarios. The classifications are as follows:

- Combination of main drivers and trajectories with scenarios
- Strengths, Weaknesses, Opportunities and Threats (SWOT) framework.
- Political, Economic, Social, Technological, Environmental, and Legal classification (PESTEL, e.g. Kiiski, 2017) framework.

These general classification frameworks provide useful information that requires new preparations in the ports. Port communities have explicitly raised the issue of information transfer and the need for finding a common view and ground for the needs of digitalization. Overall, the applied frameworks integrate technology domains (Drivers and trajectories) into the societal (PESTEL) and development potential (SWOT) contexts according to each diverging alternative scenario.

3. Results: Identifying drivers and scenarios

3.1. General drivers and key technologies for port digitalization

To scrutinize, and to answer the first research question, the most important drivers and trajectories for port digitalization in Finnish ports yielded by the workshops are as follows:

General drivers:

1) Authoritative collaboration within the industry as a backbone for data transfer standardization
2) Logistical hubs and overall supply chain management
3) Ports in society and legitimization
4) Carbon neutrality and environmental regulation

Technological trajectories, specifically:

5) 3D printing and laser scaling
6) Artificial intelligence (AI), (big) data analytics and blockchain
7) IoT, sensor technologies and 5G
8) Robotics and automation, autonomous shipping and drones

9) Cyber security (generic for all)

According to ports, the key technologies of digitalization include big data analysis, automation, IoT, cyber security, cloud and mobile services, and applications of social media. Their significance is considered to increase substantially in the late 2020s. As may also be seen, the referenced DTS classification is overlapping with the identified technology drivers from the workshops. This highlights the fact that the main development categories have matured to 'common knowledge'. An important distinction is that the 'drivers and trajectories' are more detailed and include more options than the DTS.

A general remark based on the research is that all seven points are considered feasible technology venues that will gain significance both in the mid-term (5-year) and long-term (10-year) time spans. Cyber security in particular was considered highly important on the short term and thus the growth potential for the longer term is limited. Respondents also considered that mobile services have reached their apex – there are numerous port-dependent solutions enabling extensive data access to other devices and resources required for efficient port operations. In practice, all port employees are equipped with modern state-of-the-art handheld devices capable of supporting future applications at least 3–5 years ahead. Presented technology domains are already a part of port operations and management in the largest Finnish export-import ports (in detail Inkinen et al., 2019).

3.2. Implications for the selected technology domains

3.2.1. 3D printing and laser scaling

3D printing is one of the fast growing technology domains indicated in the workshops. The operational efficiency gains produced by the 3D printing emerge trough hub-driven production. This also shortens distances of final product (3D printed items) transports, particularly if produced to the ports own needs (e.g. 3D Pilot Project in Rotterdam, 2016). In addition, 3D technology has a potential for altering the production and maintenance of transport equipment (e.g. Chen, 2017). For example, the benefits of complex component design may provide substantial efficiency gains in loading processes conducted by robotics. This is one of the key determinants of autonomous ships (their self-capability to repair and solve problems on-demand basis with only remote control). These renovation capabilities are dependent on developments in robotics and autonomous units, thus innovations in production machinery and control.

Increasing volume of 3D printing may have the following impacts on ports:

- 3D printing requires smaller investments than traditional manufacturing. This enables more efficient use of distributed production and in turn provides potentials for ports to host new industries and production facilities within port areas.
- 3D printing is more cost efficient enabling tailor-made production in niche products. Printing potentials emerges in the intermediate products and spare parts useable for pre-manufactured end products. The potential for close proximity production decreases capital fixation, due to shorter logistics chains, particularly in the case of high-cost products.
- There are already examples where ports have started to produce and offer 3D printing facilities to external customers. Economic gains may be found in the production of ship and machinery spare parts needed on location (e.g. the port of Rotterdam: Additive Manufacturing FieldLab project).

3D modeling is tightly connected to laser scaling (Lidar) and digital replication (digital twins). An important example is found on production of 3D digital models that in ports are commonly collected from underwater terrain. The models are produced with location data aiding data-based decision making. In the case country Finland VRT Finland (a private company) has produced GISGRO platform particularly designed for ports. The system enables 3D recording with specific characteristics data of port infrastructure including underwater structures. The combination of IoT with laser scaling data enhances situational awareness at the port vicinity that is needed for the real-time proactive tools (e.g. Hofmann & Branding, 2019). They are needed for emergency preparedness and avoidance protocols (e.g. ship/equipment collisions at the ports).

3.2.2. AI and (big) data analytics

Big data analytics are founded on the ever increasing amount of available raw data that has not been systematically collected or analyzed. The increasing possibility to use different data sources has particularly impacted analytical management (e.g. analytical CRM for large corporations). In port operations the majority of unconventional data is obtained from machinery and increasingly applied IoT networks. Data management for high volume data masses requires automated filtering and classification (e.g. Ding, 2020).

Machine learning and resulting capability for decision making is one of the main prerequisites for autonomous ship development including other self-maintaining technologies. This is connected both to secure information transfer and blockchain as well as AI applications that are founded on the principle that produced decisions are done (at least to some extent) by the AI algorithms. Thus, human (programmer) intervention should be minimum or none. The automated reporting increases the transparency of the process and real-time monitoring becomes (more) feasible (Bavassano, Ferrari, & Tei, 2020). These connections are good examples of emerging and continuously developing technology integration (and convergence) taking place in high-end industrial processes.

The IoT connectivity to other transport systems is important. The system requirements for hinterland transport (e.g. railways and trucks) are increasing as the port side systems should equal the outside developments (i.e. sensors and data transmitters). The challenge is widened as the number of potential cloud-service users expands to subcontractors and other short term visitors to port areas. They all may apply specific and newly developed application interfaces causing an increase in potential cyber security risks (e.g. viruses/malware) with unsupervised connecting devices – this also increases the workload of data management units responsible for organizational cyber security.

Data analytics and better use of continuously created data enables processes of anticipatory (proactive) infrastructure and machinery maintenance, thus creating a potential for data-based (supply-chain) management in ports. This requires data strategy and detailed technology action planning in ports. The key topics include data processing and interoperability challenges (e.g. IoT) together with business (potential) evaluation. There are international examples of these developments, e.g. in the work done by Wärtsilä Corp. in 'Portify project', and in the Port of Rotterdam initiated 'PortXchange' platform designed for port call optimization. Both of these are verifiable examples of digitalization where acquiring, modifying, and classifying of data is an enabler of more efficient daily port operation.

3.2.3. Automation: Robotics, autonomous shipping in ports, and drones applying 5G

Robotics and automation applies AI. Situation awareness is crucial, for example, in the autonomous operations and the system requires machine learning algorithms in vessel wide system designs as well as in external monitoring. AI is also required in the route planning and vessel steering that requires a support from IoT systems (e.g. Aslam, Michaelides, & Herodotou, 2020). Regulation is crucial here and IMO's Maritime Safety Committee has defined (2018) four different phases (or degrees) for autonomous vessels, i.e. Maritime Autonomous Surface Ships (MASS):

1. Vessels having automated processes to support decision making. The crew operates and controls vessel-wide systems. A part of the system array may be automated and occasionally without supervision but the crew needs to be ready to assume control when needed.
2. Remotely controlled vessel with a crew. The ship is controlled remotely but the crew is present in order to take control if needed. Limits the amount of required crew on ships.
3. Remotely controlled vessel without a crew. The ship is fully controlled externally.
4. Fully autonomous vessel with AI that makes all the decisions and operations independently.

Autonomous vessel developers share a common understanding that level 4 (fully autonomous) vessel production is not the most desirable goal in the near future. More likely, the autonomous ships of the upcoming years (until 2030) will have small crews for the need of exceptional circumstances and maintenance. This is directly linked to 5G networks, as they are considered to be the significant long-term technology that enables very short response times required for autonomous shipping. Ports are also needed in this development and they have initiated their own 5G projects. However, in terms of IoT the transmitted data volumes are small and the communications are often better performed over other than mobile networks (such as Sigfox, LoRa or NB-IoT; see Gartner, 2019). This is verified also in practice as there are number of existing IoT projects in large European ports (e.g. Hamburg; Rotterdam; Valencia).

The emergence of autonomous (or remotely controlled) vessels brings forth several development phases for port infrastructures:

- Remote control centers (if located within port vicinities)
- Communication and data interchange systems with vessels
- Automated mooring systems capable of adoption/change
- Staff education for the needs of digitalization and new process management

Port infrastructure does not exist in isolation and therefore interconnections to other transport modes are pivotal. For ports, there are experimental living labs focusing on stevedoring and cargo up- and downloading. Robotics has potential here and, particularly considering the case location, Finnish companies providing e.g. RFID technologies have a central development position in these technologies applied in ports (e.g. Shi, Tao, & Voß, 2011). Near future investments in cranes and lifts are moving towards solutions enabling remote control and supervision. Robotics will have an important role in maintenance and repairs of port equipment and infrastructure.

Sea-land interface is an important topic in advanced technology integration in ports. This is particularly topical in the case of automation as the following steps can be separated for vessel arrival: Preparation for arrival ➔ Passing locks and bridges ➔ Docking/Automooring ➔ Loading/Unloading ➔ Preparation for Departure. These steps require the acknowledgement and treatment of the following three points of digitalization. First, there is a need for increased sensor-based decision support tools; second, implications for human assisted autonomy in the processes; and third, the handling of the challenges in the adoption of the autonomous phase. In general, the future span for the fully autonomous phase is expected to require +15 years. The most likely scenario is a combination of human assisted and fully autonomous systems.

Finally, a newly emerged port technologies are drones (small unmanned and remotely controlled aerial devices) that have become increasingly affordable. Their usability potential lies in monitoring and surveillance of port geography. Anticipatory risk monitoring is perhaps the most potential subject area for the strategic management. Drones are also efficient tools in damage reporting after an accident, hazard or mishap. Drones enable efficiency gains for vessel inspections in ports as there is no need for turning maneuvering. Underwater drone development on the other hand provides efficiencies e.g. in hull integrity and propulsion inspections.

3.3. *Integrating frameworks with scenarios*

As presented in Section 3.2, port digitalization may be defined as a complex set of technologies that are either converging or diverging. For analytical purposes, a set of future drivers was pre-considered from the viewpoint of port operations. Table 1 presents the synthesis of the main digitalization drivers and technologies. The scenarios are embedded into the PESTEL framework (Table 2) that is supported by a SWOT analysis (Table 3).

Tables 2 and 3 collect the main interpretations, and a clear result is the consensus that an 'active development mindset' is a highly significant factor in the pursuit of completion advantage. This would also enable brand new and unanticipated potentials for industrial information integration in ports. The case ports in Finland are small in comparison to global mega-ports handling the majority of the global transport. However, the use of smaller ports in a smaller national economy context enables more manageable research design. This can be seen e.g. in the availability of the key stakeholder representatives for the workshops and interviews as well as considerations of port specialization that is more important for smaller ports. Information exchange is needed both ways: from the ports from national contexts to the scientific community and from the scientific community towards local actors. For example, dissemination of the European port experiences may provide useful insights for port management and policy across specialization fields and transport profiles (e.g. case of Turkey, see Keceli, 2011).

4. Discussion of the scenarios

4.1. *Scenario 1: Digital supremacy*

The answer to the second research question of the paper is obtained in Tables 1–3 as they provide the following collective interpretations: The first scenario 'Digital supremacy' proposes a future prospect where economic collaboration and technological progression have been developed in a globally sound, predictable, and solid environment enabling ambitious global investments in digitalization. The scenario also assumes that the slow rate of agreed standardization has progressed and there are a reasonable number of key technologies that are interoperable regardless of tailor-made add-ons and other customer-specific solutions for port operations management (also Agrifoglio, Cannavale, Laurenza, & Metallo, 2017). Ports themselves have developed data-hub properties enabling big data analysis and a potential for data markets in intermodal logistics.

Data services and metadata facilitation has become a viable part of port business operations. This is supported by a large-scale adoption of 5G networks and a determined striving towards new 6G (and beyond) solutions. Real-time data storages and applications are continuously used and developed, supporting autonomous trafficking and cargo-handling. Blockchain technologies have also been utilized and adopted in the secure supply chain management and trustworthy networks are operating as quality control measures. This requires coherent societal development in global trade relations and increasing trust in international relations and regulation. Cyber security related obstacles in particular have been, to a large extent, removed due to efficient and encompassing IPR agreements and transparency, particularly in automated data collection and treatment in global private companies. Additionally, public-private relations are strongly enhanced in global IT development creating more sustainable and trustworthy global development contexts for technological progression.

The suitable global business environment for data collection and IT development has aided the global supply chains needed for the management of increasing amounts of transport in tons and value. Data transfer and processing are inseparable among major technology producers and software providers. As a result, the level of standardization

Table 1
Combined results of scenarios in relation to individual technology drivers.

Main drivers	Digital supremacy	Business as usual	Digital failure
Authoritative collaboration (Governing driver)	Standardization has been succesfull globally. Several breakthroughs in technological interoperabilty.	Collaboration and standardization has progressed but only slightly. Several national interests and conflicting situations exist.	Standardization has decreased and national/ organization specific system developments dominate.
Logistical hubs and market development (economic driver)	Convergence of general e-commerce plaforms and logistic platforms. large IT companies dominate logistics management. Maturization of the market e-services.	Large IT and e-commerce companies have become a part of the logistics market as competitors to traditional logistics companies. Market has consolidated but not there are plenty of development areas in IT integration.	Logistics market is not growing. Significant amount of partial optimization and lack of collaboration. IT integration not progressing due to divergence.
Port impact in society (Societal driver)	Digitalization aids planning processes efficiently and participatory methods are used in order to integrate ports into their surroundings. Ports have become more significant locations within cities.	Ports are competing with other forms of land-use. The role of ports is considered as a silo in society (transport industry). Traditional planning causes residential are-port area conflicts.	Other forms of land use are prioritized before port areas. Extensive problems with congestion. IT solutions are unable to ease traffic management and flow control in port vicinities.
Carbon neutrality (Environmental driver)	New energy and engine solutions provide significant reductions in port emissions. IoT and sensor technologies widely applied in monitoring and real-time reducing emissions.	Small steps in order to reduce carbon and other emissions from ports. Diverging interests in environmental management and partial solutions for emission control.	Environmental conflicts are increasing and even current levels are not hold. Lack of collaboration and partial optimization of costs lead to use of non-efficient solutions and technologies.
Technological trajectories			
3D printing	3D Printing impacts core transport business. Transportation of raw materials increases. Selected ports invest in production facilities for 3D production.	3D printing and production offers business potentials for some ports. The impact on transport business is limited. Investment levels are small but provide niche potentials.	3D printing and production remain marginal in ports. Their potential is not considered significant and they wither away from port agendas.
AI & big data	All parts of supply chain are IT embedded. AI is the new ‘normal’ in ports. Port management and key-decisions rely extensively on data analysis and AI decision making.	AI helps and gives efficiency gains in daily operations. All key-decisions and management remain human driven. Data analytics are used as a supportive addition in decision making.	Resistance to change (including employees, governing bodies, employers) causes that the use of data analytics are limited. AI is not used as a supportive tool. Adoption of non-interoperative support tools that are port specific.
Block-chain	BC technology is widely used in all transactions related to supply chain and port operations. BC covers practically all domains of transport documentation.	BC is driven only by the largest companies. Transaction chains are done within company blocks. Number of closed systems.	BC is virtually non applied due to diasgreements and lack of collaboration between companies. The lack of general concensus is causing BC to remain marginal.
IoT and sensor technologies	The use of sensor techologies and IoT is widely accepted. Efficient use and optimization of flow data enables decreases in accidents, congestion and maintence.	These technologies are used but only by the largest and the most resourced ports. Sensor networks produce raw data for data-analysis and AI.	Problems in data security and confidentiality limit the use of technology integration. Reliability problems are causing that majority of port organizations remain using old methods in their operations.
Robotics and automation	Extensive adoption of robotics and automation in all ports. Increasing use of drone technologies and applications.	Robotics are used only in largest ports. Scaling benefits towards smaller ports are emerging slowly.	Employees and interest groups are not ready for massive changes. Robotics are considered expensive and investments remain low.
Laser scaling	Remote sensing data is widely applied in port planning and decision making. Real-time 3D monitoring is used in maintenance and decision making.	Some applications of laser scaling are used in the largest ports. Limited impact and disagreements of benefits.	3D models and remote observation are considered insignificant and too expensive. The development plans depend on speficially ordered mappings on the need basis that does not provide constant platform for renewal of practices.
Cyber-security	New secure solutions have increased trust towards AI decision making. BC technologies are widely applied enabling these developments. Cyber-crime numbers are dwindling.	The constant competition between criminal activities and cyber-security tools continous. Acceptance levels and privacy debates continue to exist as they have done thus far.	Adopted new technologies pose great security risks causing limitations in their use. Severe trust issues towards technology use in private data management.

has exceeded a threshold level required for efficient fluent system interoperability and machine-to-machine interaction. Additionally, the remaining gaps in the supply chain interoperability are, when needed, debugged with AI solutions capable of auto-correction and format modification without supervision. Data-wise, an alternative and simpler way is to correct the missing values (gaps and links) with data-based analytics such as weighted averages or other descriptive characteristics (numerical, alphabetical or symbolical) depending on the collected data form.

The scenario supposes that almost all transports are optimized by the just-in-time principle. This also reduces environmental stress and optimizes efficiency. Cargo handling and flow-through times in ports have decreased significantly due to the extensive adoption of IoT and sensor technologies enabling nearly total machine reliability and optimization (e.g. Fancello et al., 2011). Automation has also reduced risk indicators (e.g. numbers of accidents and reported events) significantly. Wireless data transactions are fully reliable with back-up systems, and first networks going beyond 5G are already in the testing phase. Ports themselves have been able to establish themselves as ‘data-hubs’. Data management is controlled most likely by the port authorities. This is feasible as they are collectives managing holistic port operations and branding and responding directly to port owners. Data services have

Table 2
Summary results of the PESTEL framework.

PESTEL categories	Digital supremecy	Business as usual	Digital failure
Political	• Regulation is effective on all domains • Comprehensive legal terms in trade • Common goal to enhance the balance between regulation and efficiency	• Stagnation in e-governance/ regulation • Regulative restriction slow progression • Slow responses to technological change cause lacking behind decision making	• Severe scepticism regarding the information society • Silo-effect in governance and system isolation
Economic	• Global trade systems in high technologies • No trade wars • Verified economic gains through automation and cloud services	• Balanced but not increasing economic gains of technology integration • Restrictions in global trade but not significant problems resulting decline	• Too many fragmented system platforms cause overall costs to increase • Lack of coordination efforts increase total costs in port operations
Social	• Civil acceptance of technologies in transport and mobility are high • Large scale use of travel and transport applications • High trust in cyber-security	• Public acceptance skeptical regarding technologies • Cyber security issues significant but manageable	• Declining development in ICTs due to cyber-sercurity and privacy problems • Bilateral and exclusive arrangements in supply chains
Technological	• Rapid advancements in technology integration • Automation and IoT have become commonplace in all operations	• A mixture of common platforms and individual systems • Partial fragmentation and interoperability	• Diverging system development • Significant amount of competing (isolated) and non communicating platforms and formats
Environmental	• Clean technology breakthroughs • Global environmental risks are reducing • New solutions in engine technologies an fuels have decreased emissions	• Slow and incremantal changes in clean tech • Emissions levels remain the same: relative decline but not absolute • Environmental regulation manageable but not optimal	• Use of fossil fuels continue to increase and environmental agreements are not respected • Digitalization benefits are experienced negative and marginal
Legal	• Intellectual property rights and cyber-legislation have matured • Maritime law has developed to recognize autonomous traffic • International legislation recognizes internlinks between maritime, environmental, and digital legislations	• Silo legislation still dominates • IPR and cyber-legislation have progressed some small steps • There are inconsistencies among national legislations relevant for autonomous traffic	• No progression in legislation - rather the opposite • Severe conflicts in the development of environmental, trade, and digital legislations • Nations are part-optimizing international trade according to their own agendas

Table 3
Summary results of the SWOT according to scenarios.

	Strengths	Weaknesses	Opportunities	Threats
Digital supremecy	• Autonomous system benefits and efficincy gains are extensive • Human errors decline • Opens potentials for efficient real-time adjustments in shipping and port operations	• Automated decision making debatable (values, etc) • Continues current global development line if environmental efficiency is not increased simultaneously	• Pathway towards fully interactive technology integration for the future • Releases resources from traditional fields to clean-tech and emerging industries • Enables fully adjustable JIT principle	• Machine dependency • Moral and ethical judgement • Polarization of countries and regions in their capability to manage and develop complicating technology networks
Business as usual	• Incremental changes are relatively easy to foresee • Accurate estimations produce easier solutions to be implemented • Current technologies are easier to adopt than radical ones	• Changes are small and so are effects • Environmental concerns remain as changes in practices are small • No great benefits of the ICT potentials are are realized	• Potentials for niche business • Long-term standardizations make market entry easier in investement intensive businesses • State-of-the-art developments in certain technology domains withstanding time	• Small changes do not solve large scale problems • Environmental deteriation continues • Slow technological progression causes second class software and cyber-security problems
Digital failure	• Decreasing reliance of ICT causes positive effects for human employment in traditional fields • Total decline in world economy causes small scale business renewal • Possibly positive environmental effects due to decreasing transport	• Regression towards nation state dominated global condition • Material consumption decreases and may cause decrease in material quality of life • Severe impacts on markets possibly cause civil unrest	• Decline causes potentials to some specific fields, e.g. close-proximity farming • Redistribution of wealth • Slower lifestyle if desired	• Civil unrest • Decline in wealth and welfare • Increasing unemployment in transport sector in IT fields and development

become a commodity in ports and they are sold outside port vicinities, e.g. to surrounding cities, warehousing companies, land-based transportation businesses and other partners (see Heilig & Voß, 2017).

Similar progress is anticipated with AI and (big) data analytics that are common tools in everyday processes of all ports. Finland should be one of the international forerunners in the development of small port intelligent systems. Robotics and automation are extensively developed and they are gaining accelerating growth volumes in total traffic. Similarly, 3D modeling based on laser scaling is also widely adopted and used routinely in port underwater dredging. Static and dynamic systems are interoperable, enabling the digitalization of port vicinities and aiding system-level planning processes. These include cargo content, volume data and mode of transport data (dimensions, consumption and refueling needs) enabling advancements in planning, marketing and environmental impact assessment (also Trozzi & Vaccaro, 2000). All these affect port efficiency and reduce the need for expansion areas even when traffic volumes continue to grow substantially.

A significant element in the 'digital supremacy' scenario is that cyber security has significantly increased via blockchain technologies. An extensive adoption of these trustworthy technologies – those that are self-leaning in respect to malware threats are essential. These developments are fundamentally connected to overall societal development, environmental management, and global trade conditions. The transportation system has conceptually evolved towards physical global network that has self-sustaining properties (also Ducruet & Zaidi, 2012). This means that transport process may include elements of production and enhancement during the process of getting the product from initial manufacturer to the markets. Traditional subcontracting and global production multi-actor chains have significantly different logistical needs in comparison to simple in-house production transports (from producer to retailers and then to consumers).

4.2. Scenario 2: Business as usual

The second identified category 'business as usual' refers to a situation where sea-borne transport volumes remain on a relatively mild growth path (demand does not significantly increase) and the ports are able to enhance their current handling volumes with the developing digital solutions. The second scenario does not expect great changes to take place in the economic context where ports operate. The growth in GDP is expected to remain low (<1% per year) and the economic structure moves gradually further towards services. The scenario also expects that transport volumes are modestly growing and below the global averages. In addition, digitalization progresses, to a large extent, only in the largest national ports that are producing their specific solutions for situational awareness and scheduling.

Standardization has progressed, enabling system integrations. However, the progression is slowly phased and continuous efforts are needed in order to gain economies of scale from digitalization. Data transaction volumes and capacities have also increased. This creates a potential for ports to function as efficient and reliable nodes in the transport chain. The increasing capabilities of technology also improve safety in ports (in terms of employees as well as cargo). There are, however, a large number of competing systems resulting in lower expectancies for efficiency gains and functionality.

Supply chain management continues to concentrate, involving smaller numbers of operators (organizations) due to digitalization. Global online retailers (e.g. Amazon; Alibaba) in particular have an increasingly significant role in the organization of global transports. Similarly, global logistics companies will have a more pronounced role in the converging markets. It is likely that the transportation market will be agglomerated into a few well-known global alliances, following the development that has taken place in the aviation industry.

Ports will continue to develop their specific profiles. Smaller ports will most likely focus more on their specific cargo segments. So called generic ports having an extensive product portfolio will continue to develop specific services required for individual segments but they will do so divergently. Large ports will continue to develop even further to a collection of smaller locations focusing on specific types of transport. An example of this polarizing path is found in blockchain technologies. They are expected to be applied only by the largest and most developed ports.

This scenario implies that physical (spatial) expansion needs within ports are small and the current capacity is adequate for handling the cargo transport growth experienced in 10 years time. Normal trend development expects that big data analyses have become common place and data-based management practices are also adopted in small ports – not only in the largest ones that currently are the most active developers of digital solutions and implementation. A feasible and mild expectation of port infrastructure management and daily operations is that laser-scaling produces updateable 3D models of ports with integrated location-based data (e.g. in grid cells or other spatial units). The scenario is also based on the assumption that current data transfer capacities are extended (or are preparing to extend) beyond 5G level towards faster phases. This high capacity data processing and transfer infrastructure enables the development of autonomous shipping and cargo handling in some largest ports.

Digitalization has already had an impact on port efficiencies (flow-through time and reliability). However, the capabilities and readiness of ports to handle and manage digitalization progression has diverged. In other words, the forerunners in port digitalization are becoming more advanced more rapidly than the average progression would suggest. This differentiation will cause more pressures for specialization particularly for slowly developing ports. For example, there are great variations in the capabilities of ports to handle autonomous vessels in the near future. This is directly linked to the sensor technologies and IoT readiness that have become standardized options for vessels equipped with similar technologies.

AI and big data analytics bring forth additional support for traffic fluidity and smoothness. An interesting development is identifiable in the establishment and creation of situational awareness systems that are fully based on 3D modeling and laser scaling. Content data is significant as simulation models are widely applied in logistics management and planning. The interviewed ports have high hopes for the data combination potentials particularly in questions of optimization of ship docking durations and the overall in-out time of vessels entering and exiting ports (e.g. Kim, Kim, & Park, 2017). The results are manifested in security and reliability statistics (e.g. number of accidents, injuries, and hazards). Big data assisted decision making systems are becoming more common in strategic management support. This is supported by the proactive maintenance of equipment and infrastructure.

The main challenge in the 'business as usual' scenario is that environmental goals and actions are not met swiftly enough – environmental soundness is strongly associated with digitalization and the diminishing use of fossil fuels. The problem is that the majority of cargo handling machinery still functions on fossil fuels and continues to do so into the foreseeable future. The second main challenge is cyber security that continues to be a significant development field for traditional industries such as ports. It will continue to require more resources in the future too.

4.3. Scenario 3: Digital failure

In the third and final scenario, 'digitalization failure', the contextual background assumes that the global phase of digitalization has been slowed down due to the trade wars, global economic slow-down, increasing insecurity in global relations, and increasing armed conflicts. Thus, again the context lies far beyond ports and transport – it is in global politics and economy. The background assumption is that international trade has diminished due to extensive disagreements. The number of severe international crises and disturbances has impacted global trade flows and international agreements are not respected. They are also under constant debate, decreasing trust in the global trade system. Standardization has not progressed as hoped and the multitude of different formats and system platforms has caused a slow rate of adoption.

There are limitations in know-how among port employees to apply and take advantage of heterogeneous end-user services. These shortcomings have caused a situation where port flow-through times have not decreased and transport times have remained on levels similar to the reference year. Similarly, global 3PL and 4PL actors have introduced their own and technology platform-bound supply chain optimization tools. These systems have limited interoperability and a number of segmented partial solutions for operations optimization have emerged. The total costs are increasing due to overlapping system requirements and the industry has formed alliances using specific system silos. This again leads to increasing organizational dependence on key individuals mastering these complex systems. The increasing complexity and system fragmentation cause re-evaluations of technology use in the core business plans of companies (resulting in alliances).

Supply chain management weakens in time resulting in inefficiency. Varying operating systems and technologies also cause challenges to green port goals in daily operations. Smaller ports are expected to remain with older technologies and keep using less automated solutions. The withholding of investments increases the relative use volumes of older technologies, often powered with non-renewable energy sources. The development is forced due to the use of 5G networks that are mainly applied only by larger port operators that have closed their systems and restricted data dissemination to other port community members. The transport management in ports is done in segments where each member of the chain makes their own system level decisions regardless of the functionality benefits of the whole chain. This leads to manual 'excel' management data storages that are updated, maintained, and managed by single key individuals. Thus, a similar development will take place as did with numerous Quality Control Systems (QCS). They were highly popular as a part of quality management but their impact on daily work has been limited in ports.

Global logistics operators have developed their own customer specific data systems and their interoperability with other competing systems is low. The operator-focused segmentation of technological systems causes partial optimization solutions and the development of the holistic supply chain standard remains obscured. This organizational centricity causes additional congestion in ports. The efforts directing transportation planning into a coordinating action have diminished. A significant reason for this is the unreliability of data. IoT and sensor network alternatives are not widely examined in ports anymore (for implementation) as they have proved unreliable. Legislation related to privacy issues and data distribution are limiting progress. As these technologies are directly linked to the adoption and development of AI and big data, analytics suffer correspondingly. Resistance to change is extensive among port employees. The resistance is reflected in legislators and politicians who in general have adopted a critical view on digitalization.

In this scenario, it is assumed that autonomous shipping remains only on the testing level or is adopted only for a short distance, e.g. crossings of short sea areas, and its functionality is thus limited to substitution (e.g. ferries). Another feasible condition of autonomous shipping is that connections have been agreed on by bilateral agreements between specific ports. This form of transportation is not (or is minimally) reflective of the system level transport management. Security and trustworthiness have decreased, resulting in more controlled and segmented data systems. Global standard development has remained the same or degraded from the level of 2020. The diversity and fragmentation of existing software platforms have increased the risks in cyber security substantially. This has, in turn, led to a silo approach in ports and thus stagnating the development towards fully interactive and accessible platforms. The increased amount of regulation and technological vulnerabilities has caused ineffective scalability and smaller ports are not able to benefit from the positive experiences of the larger ports that are developing their own specific technical solutions. Ports are responding to increasing transport volumes by extending their operation hours towards 24/7 instead of focusing on improving handling efficiency.

5. Conclusions and management implications

5.1. *Concluding remark 1*

The key drivers for the future change in ports include data standardization, logistic supply chain management, societal (municipal) significance of ports in their home cities, environmental efficiency (carbon neutrality) of ports and technological trajectories. The most probable development pathway for port digitalization will include characteristics from all three alternatives. These categories are seen as self-supporting alternatives diverging (in time) from each other. This means path-dependency: Each step of the way supports the selected route and diminishes the possibility of deviance towards other pathways.

5.2. *Concluding remark 2*

All scenarios are connected to developments of the global business environment and large societal conflicts in trade and politics that may cause severe problems for digitalization. The presented three scenarios of dynamics underlying perspectives of progression are therefore framed on the backbone of societal and economic conditions of which ports are an important part through international trade and transport. General trends include the recognition of the importance of technological reliability and cyber threats to the adaption and use of technology.

5.3. *Concluding remark 3*

The results support the primacy of cyber security and trust before other developments are able to root and take hold of the system level management. As such, cloud and mobile services (easy information transfer regardless of location or users) are currently considered major trends too. The scenarios expect that ports are moving from static information applications to dynamic real-time cargo and transport data sourcing. Data driven application modeling enables both visualization and content combination creating 'virtual ports' that can be managed from remote locations. Examples of these developments are fully autonomous port quays that may be governed from remote locations (e.g. collective data management centers possibly located several kilometers from the actual loading areas). Virtual port models can also be used in port expansion planning, marketing, and assessments. Flexible alternative planning also enables more efficient land-use and transport infrastructure designs for future needs.

Finally, we may draw the following implications for port digitalization management and policy. First, digitalization requires continuous planning and proactive attitude from the port managers. This was an evident feeling obtained from the workshops. The second implication is that planned (not yet implemented) standardization protocols and solutions require highly professional procurement know-how particularly when digitalization (in its various technology domains) is developing as fast as it currently is. Particularly, IoT and large-scale networked machineries require constant e-security updating and interoperability. The third implication concerns strategic vision and implementation of digitalization in the long-term (10 years and beyond). In the case of maritime issues, the future of autonomous vessels is highly dependent on the visionary capability. Proactive management continuous to become even more significant as ports are currently using only a fraction of the data they produce in their normal operations. A practical implication concerns machine readability (and interexchange) of data. This basic starting point enables more sophisticated tools of digitalization. It also enables easier and more transparent data management. Finally, data security and reliability will continue to be in the heart of port digitalization for the years to come.

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Tommi Inkinen wrote and designed the paper; Reima Helminen and Janne Saarikoski organized the data collection, workshops and the research approach. All authors contributed to qualitative interpretations and agree with the results presented in the paper.

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Conflicts of interest

The authors declare no conflict of interest.

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